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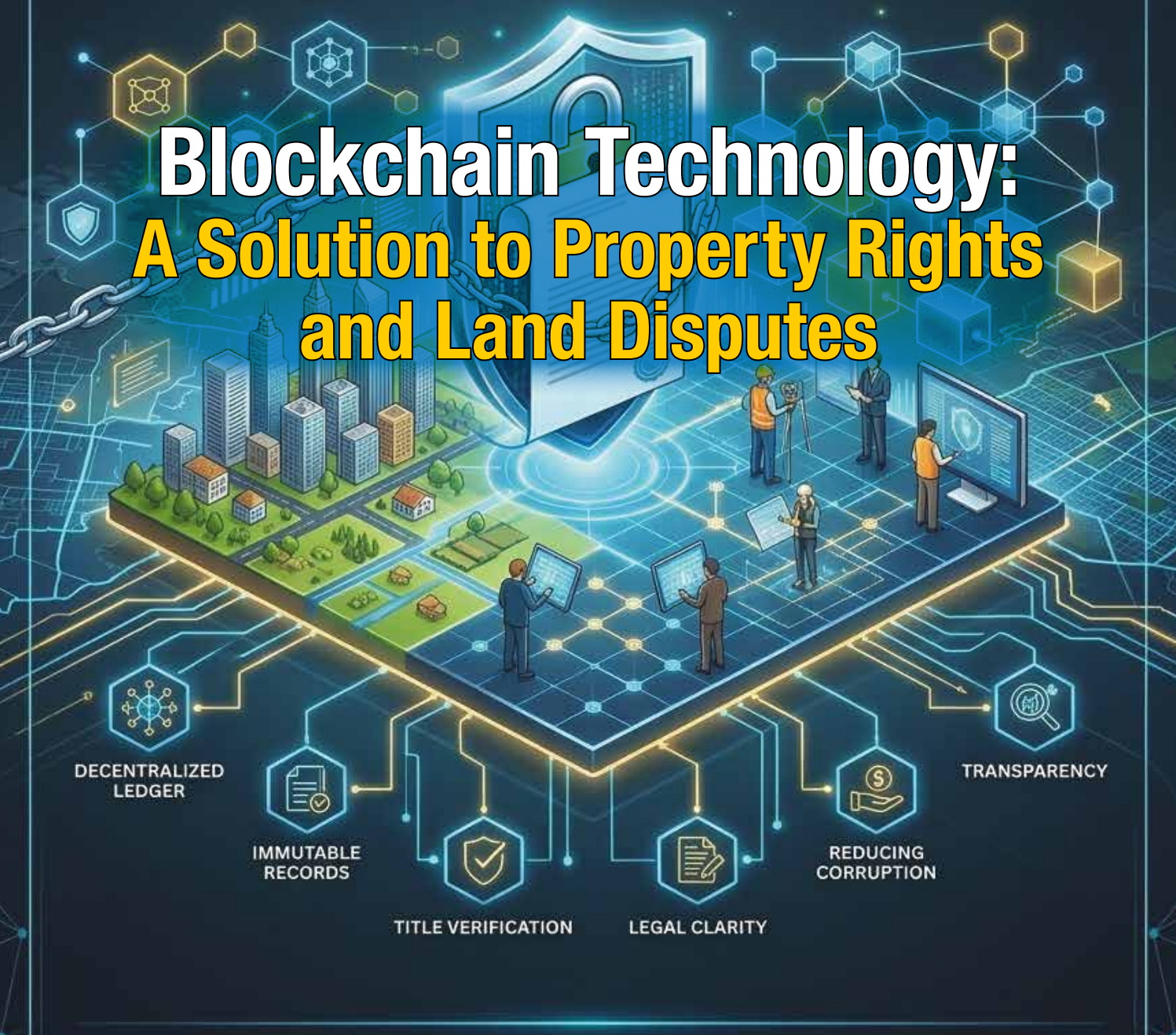
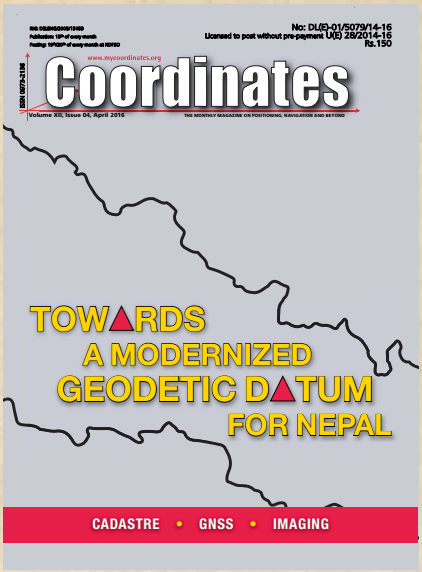
Blockchain Technology: A Solution to Property Rights and Land Disputes



Maps - Connecting the past, present and future

In Coordinates

10 years before...



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Towards a modernized geodetic datum for Nepal

Chris Pearson, School of Surveying, University of Otago, New Zealand
Niraj Manandhar, Survey Department, Nepal

Because of the effect of the 25th April, 2015 Gorkha earthquake, significant earth deformation has occurred in a large area of Nepal centered on the Kathmandu Valley. As a result, the geodetic control in this region is significantly distorted with published geodetic control coordinates being displaced from their true position on the ground upto by 2m. Correcting these distortions will require a new geodetic datum. In this paper, we consider the possibility of Nepal adopting a semi-dynamic datum, which would be based on ITRF2014 and include a national deformation model capable of correcting for the recent earthquakes and normal tectonic motion.

An analysis of the Turkish Cadastre in view of the Cadastre 2014 Vision

Dr Mehmet CETE, Associate Professor,Izmir Katip Celebi University, Faculty of Engineering and Architecture, Department of Geomatics Engineering, Izmir, Turkey

Cadastre 2014 has guided re-engineering processes of land registration and cadastre systems in many countries. It has been also a benchmark during improvements of the systems. Thanks to this vision document, many countries have been sure that their re-engineering processes were on the right way. Turkey is one of those countries.

Local GNSS Monitoring

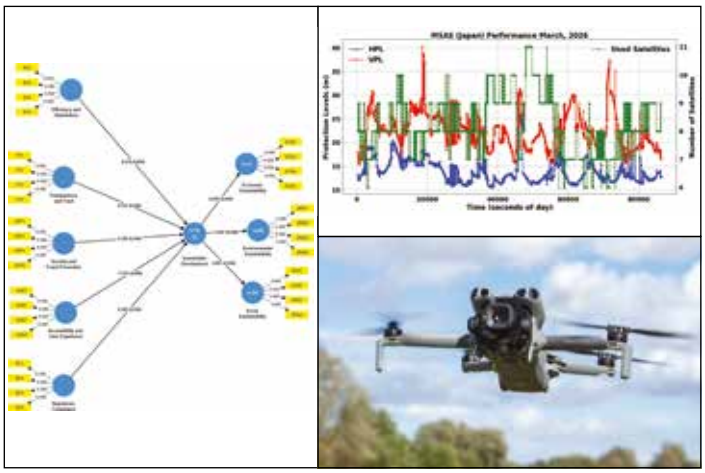
A Guilloton and B Montagne, Thales Avionics, Valence, France

The present article described a promising jamming detection solution developed during the HONTZA project. Using this solution, we were able to detect 5 interferences in GPMB duing the test periods. When compared to results obtained by other studies which detected up to one hundred events in a month, these results suggest that a fine tuning of detection thresholds is necessary to raise relevant alarms. The solutions we propose provides the right alert at the right time and avoids false alarm.

Review of Normalized Difference Vegetation Index (NDVI) as an Indicator of Drought

Dr Rishiraj Dutta, Technical Specialist (Department of Climate Change & Climate Risk Management), Asian Disaster Preparedness Center, Samsen Nai, Phayathai, Bangkok, Thailand

Direct crop monitoring methods with remote sensing indices such as NDVI or other vegetation indices have been adding values in minimising the risk to the agricultural sector from natural hazards such as droughts and floods. Time series NDVI data have been used during the cropping seasons and deriving the crop growth profiles from the NDVI statistics at the required scale.



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AbdelKarim Fawwaz AlBataineh, Ashok Kumar Jain 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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Cover image generated using AI

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

A courtroom in the United States,

Is now confronting a long-standing question.

Did social media merely host behaviour or actively shape it?

As Mark Zuckerberg defends Meta,

The issue extends beyond one company.

It is about the architecture of attention.

Past goals to maximise user engagement now face legal scrutiny.

Design choices that may amplify vulnerability among young users.

Time spent, once a success metric, is now evidence.

Meta argues that personal circumstances, not platforms, drive harm.

But algorithms are not neutral,

They optimise and reinforce behaviour.

The courts may redefine where liability begins.

If engagement is engineered, responsibility cannot be denied.

Bal Krishna, Editor
bal@mycoordinates.org

GNSS (SBAS) Constellation Specific Monthly Analysis Summary: March 2026

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

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

Introduction

This article continues the monthly performance analysis of the GNSS constellation. Readers are encouraged to refer to previous issues for foundational discussions and earlier results.

Satellite Based Augmentation Systems (SBAS) enable high-integrity GNSS navigation for all phases of flight, including precision-like approaches with vertical guidance. In the Asia–Pacific region, several SBAS implementations are progressing at different maturity levels. This article presents a consolidated analysis of four systems—GAGAN (India), MSAS (Japan), KASS (Republic of Korea), and SouthPAN (Australia/New Zealand). The study combines (i) observed Horizontal and Vertical Protection Level behavior from a representative day in March 2026, (ii) officially declared SBAS service capabilities and supported aviation procedures, and (iii) spaceweather conditions on the analysed day. The results provide a coherent view of current SBAS readiness across the Asia–Pacific region, excluding the mature WAAS and EGNOS systems.

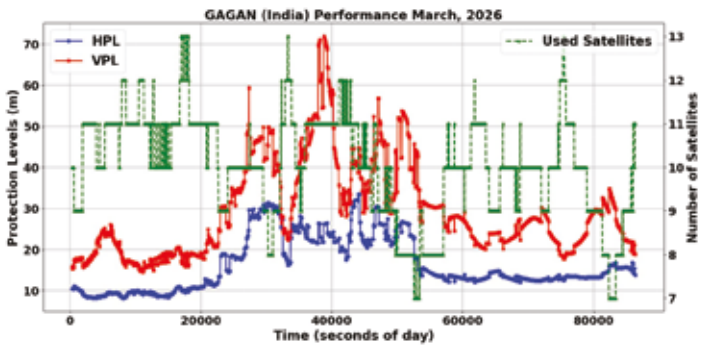

Figure 1: GAGAN performance in terms of achieved protection levels throughout the day of year 082, 2026.

1. Observed performance analysis

GAGAN exhibits HPL values typically between 9 m and 30 m, while VPL shows significant variability, occasionally exceeding 50–70 m. These characteristics constrain operations primarily to NPA and APV-I and are consistent with equatorial ionospheric challenges.

MSAS shows relatively stable but conservative protection levels, with HPL generally between 11–18 m and VPL around 17–30 m. Limited satellite usage restricts vertical performance and explains the absence of widespread APV-I or LPV operations.

KASS demonstrates HPL performance largely within 10–15 m and VPL typically between 18–30 m, with occasional short excursions. This behaviour aligns with APV-I and emerging LPV capability when assessed over longer time windows.

SouthPAN shows the strongest nominal performance, with consistently low HPL (6–10 m) and VPL (12–18 m). High satellite usage provides robust geometry, enabling LPV and LPV-200 operations.

For all above SBAS, the peak inflation of the protection level

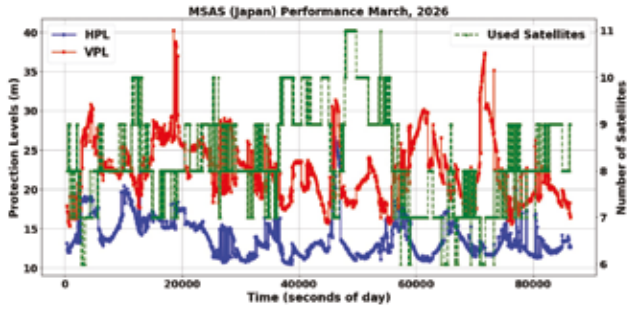

Figure 2: MSAS performance in terms of achieved protection levels throughout the day of year 082, 2026.

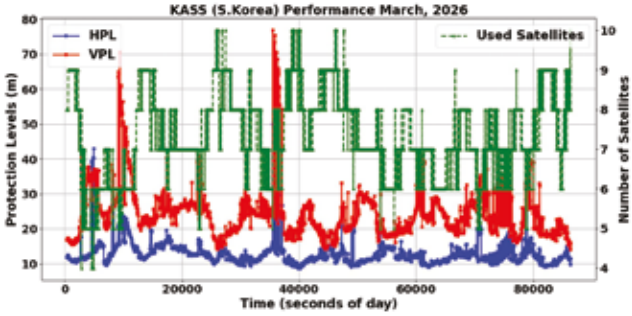

Figure 3: KASS performance in terms of achieved protection levels throughout the day of year 082, 2026.

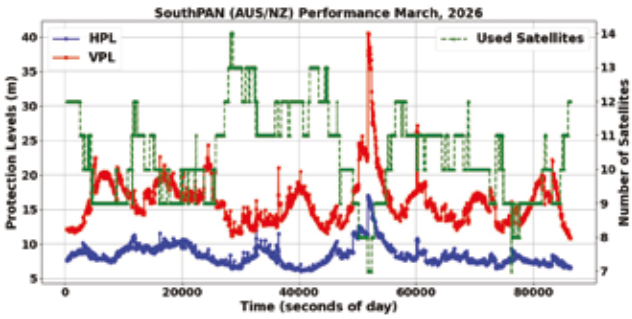

Figure 4: SouthPAN performance in terms of achieved protection levels throughout the day of year 082, 2026.

coincides with the geometry of the satellite (as indicated by the reduced number of used satellites). There are indeed other variables like the ionospheric and orbit & clock errors, which are not part this assessment.

2. Officially declared performance and supported procedures

GAGAN is officially certified for RNP 0.1 and APV-I with declared APV availability over most of the Indian landmass. MSAS supports en-route and limited terminal operations but does not declare APV-I or LPV nationwide. KASS officially supports RNP APCH including LPV with published horizontal and vertical alert limits of 40 m and 50 m respectively. SouthPAN is designed to support APV-I, LPV, and LPV200 and has published target VPL values below 35 m over its primary service region.

3. Space weather conditions on DOY 082, 2026

Day of Year 082 (23 March 2026) occurred under moderately unsettled geomagnetic conditions, with Kp values above 6 and geomagnetic storm G2. Therefore, the observed protection level variations are attributable to not only geometry, ionospheric modelling, and system design but also to a potential space weather impact.

4. Conclusions

The combined analysis shows strong consistency between declared system capabilities and observed performance. SouthPAN and KASS demonstrate readiness for advanced approach operations, while GAGAN and MSAS continue to fulfil essential regional safety roles for en-route and non-precision navigation. SouthPAN represents the benchmark for next-generation LPV-capable SBAS. KASS is rapidly maturing with credible LPV readiness, while GAGAN and MSAS remain operationally relevant for en-route, terminal, and APV-I or NPA services.

Notes on GNSS performances

The regular performance monitoring of the GNSS constellation (for last two years, please refer to previous monthly issues) showed a stable and consistent SISRE performance. The bar plot shows the standard performance.

NAVIC System degradation

As reported by multiple technical news outlets and GNSS monitoring articles, the NavIC constellation experienced a significant degradation of standalone PNT capability from 13 March 2026 onward. In particular, this date marks the loss of continuous broadcast from PRN 06, which reduced the number of usable NavIC space vehicles below the minimum required for reliable standalone positioning.

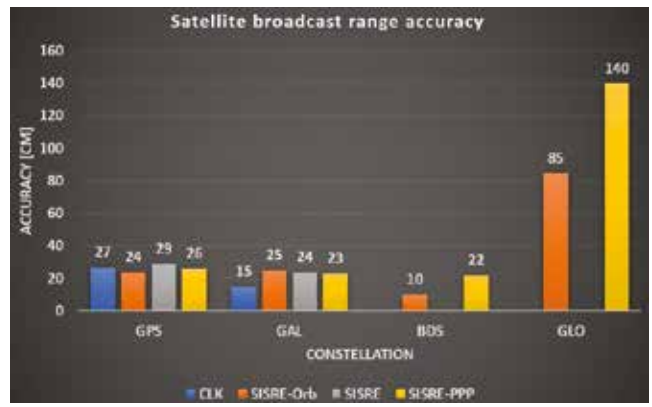

Figure 5: The Signal in Space Range Error (SISRE) for different GNSS constellation.

An analysis published in February 2026 (GNSS constellation-specific monthly analysis for January 2026, https://mycoordinates.org/gnss-constellation-specific-monthly-analysis-summary-january-2026/) examined the achievable positioning performance using NavIC-only, dual-frequency solutions. At that time, the constellation still provided at least four simultaneously visible satellites over the Indian service region, enabling meaningful PNT solutions. This condition remained valid until 12 March 2026.

NavIC-Only positioning performance prior to 13 March 2026

The dual-frequency NavIC-only positioning results showed that, for most of the day, reasonable horizontal and vertical performance could still be achieved, despite the reduced constellation size. The time series exhibited two pronounced error excursions per day, which were traced to near-singularity events in the geometry matrix. These events occurred when the effective satellite geometry became poorly conditioned, leading to temporary amplification of position errors.

Excluding these near-singular epochs, the remaining periods demonstrated comparatively stable solutions, confirming that NavIC, while degraded, was still capable of delivering limited standalone PNT performance up to that point.

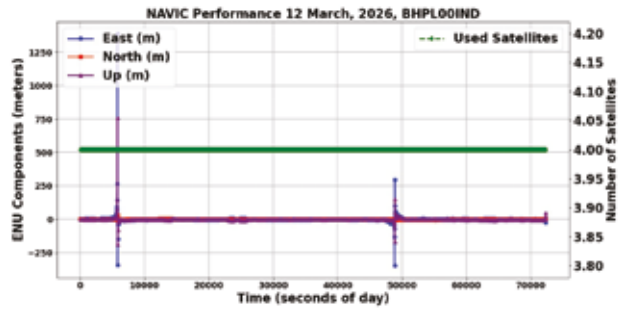

Figure 6: The dual frequency positioning of NAVIC standalone solution at BHPL00IND

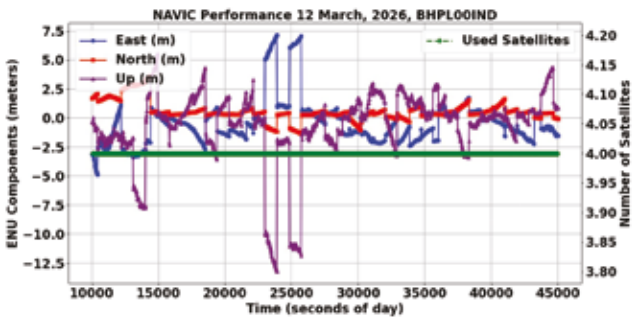

Figure 7. The performance in between two near singularity events. This is an enlarged plot of Figure 6 from 10000 seconds to 45000 seconds.

Loss of PRN 06 Broadcast after 13 March 2026

From 13 March 2026 onward, PRN 06 ceased regular signal-in-space broadcast, and no longer contributed to navigation solutions. This event effectively reduced the operational NavIC constellation below the threshold required for standalone positioning, rendering NavIC-only PNT operation impractical for most users.

Based on publicly available system status information and prior NavIC anomaly history, the most probable cause of PRN 06 unavailability is a payload-level anomaly, most notably related to on-board atomic clock performance or clock steering functionality. Similar clock degradations have affected multiple first-generation NavIC satellites in recent years, leading ISRO to periodically restrict or suspend navigation message transmission from affected spacecraft as a precautionary measure.

In such cases, the satellite may remain physically operational and trackable, but its navigation signal is marked as unusable or withdrawn entirely from service to preserve system integrity for remaining users. No evidence suggests an orbital failure; rather, the outage is consistent with clock-related or navigation payload integrity issues previously acknowledged within the NavIC programme.

Operational implications

The loss of PRN 06 eliminated the possibility of sustaining foursatellite NavIC geometry over the primary service region. As a result:

- Standalone NavIC PNT services effectively became unavailable from 13 March 2026
- NavIC performance degraded from a limited but usable state to **insufficient** constellation geometry
- NavIC's role reverted primarily to:
  - A supplementary ranging source in multi-GNSS receivers
  - A supporting element for system monitoring and augmentation, rather than a standalone navigation system

Data sources and Tools:

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

SBAS Mentor, ESA

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

serenad-public.cnes.fr (SBAS data)

The effect of smart contracts (blockchain technology) on Jordan's land registry and survey department for sustainable development

AbdelKarim Fawwaz AlBataineh
Faculty of Administrative and Financial Sciences, Department of Finance & Banking, University of Petra, Amman, Jordan

Abstract

This study explores the implementation of blockchain technology, specifically smart contracts, within the Land Registry and Survey Department to enhance sustainable development in Jordan. Utilizing a quantitative, cross-sectional survey design, the research targeted 12,450 employees of the Jordanian Department of Lands and Survey, with a stratified random sample of 448 respondents. The data, gathered through online surveys and analyzed via Partial Least Squares Structural Equation Modeling (PLS-SEM), reveals significant positive relationships between blockchain implementation facets—such as Security and Fraud Prevention, Efficiency and Automation, Regulatory Compliance, Transparency and Trust, and Accessibility and User Experience—and sustainable development outcomes. Despite these promising results, the study acknowledges critical challenges such as the need for technical expertise, regulatory frameworks, and initial investment hurdles. Addressing these challenges is crucial for balanced implementation and sustained engagement with the technology. The model accounts for 77.6% of the variance in sustainable development, highlighting blockchain's potential to simultaneously tackle multiple land administration challenges. This research provides empirical evidence of blockchain's impact on sustainable development, offering a comprehensive framework for its application in land registries, particularly in developing nations. The findings hold significant implications for policymakers, land registry administrators, and technology implementers, underscoring the importance of integrating technological innovation within existing regulatory and institutional contexts to achieve sustainable economic, environmental, and social growth.

Keywords Blockchain technology· Jordanian department of lands and survey· PLS-SEM· Sustainable Development

1 Introduction

Land registration and management systems fundamentally underpin property rights and economic development globally, with developing countries facing particularly complex challenges. Jordan's land registration system epitomizes these systemic issues, characterized by persistent inaccuracies, fraud, and economic inefficiencies that substantially impede sustainable development efforts [6, 72, 94, 95]. The economic implications of ineffective land registration are profound.

A 2018 World Bank report revealed that approximately 30% of land in Jordan remains unregistered or speculatively owned, potentially representing billions of dollars in unrealized economic value. These registration inefficiencies obstruct land development and limit credit options, as most banks require registered land deeds for mortgages (Stano & Ninacs, 2020). The International Monetary Fund (IMF) study in 2020 suggested that improving land administration could increase annual economic growth by up to 2%, with the potential to unlock $12 billion in dead capital. Transparency and corruption further complicate the land registration ecosystem. A 2019 Transparency International survey exposed that 15% of Jordanian respondents admitted to paying bribes related to land services, indicating significant institutional challenges [9]. The World Bank's Doing Business Report (2020) highlighted administrative inefficiencies, noting that land registration in Jordan averages 26 days, compared to 20 days in high-income OECD countries. Environmental sustainability is equally compromised by ineffective land management. The United Nations Development Program's 2021 report documented a 20% decrease in arable land over two decades, exacerbating food security challenges in a region already confronting water scarcity and desertification (UNDP, 2021). Social inequities persist, with the Jordan Strategy Forum (2019) reporting that merely 17% of registered land was owned by women, despite legal amendments intended to strengthen women's property rights. Existing research on land registration technologies reveals significant gaps. While previous studies have explored various aspects of land registry systems, they predominantly focused on theoretical feasibility [1, 15, 16, 25, 57, 66, 91]. Lazuashvili et al. [47] discussed efficiency improvements, Antonopoulos et al. [14] examined technical decentralization challenges, and Benbunan-Fich and Castellanos [18] explored smart contracts in real estate transactions, primarily in developed countries. Blockchain technology and smart contracts emerge as potential transformative solutions, offering unprecedented capabilities through transparency, immutability, and decentralization [11, 13, 17, 31, 32, 50, 68, 90]. However, adoption faces significant challenges, including technical expertise requirements, legal complexities, and substantial initial investment needs. This research makes critical contributions to the existing literature. First, it provides empirical evidence quantifying blockchain technology's impact on sustainable development within land registry systems. Second, the study develops a comprehensive analytical framework for assessing technological interventions across economic, environmental, and social sustainability dimensions. Third, it offers practical insights for policymakers and land registry administrators in developing countries considering blockchain implementation. The study bridges significant literature gaps by addressing limitations in previous research. While Lemmen et al. [52] and Kshetri and Voas [45] highlighted environmental benefits of digital land registries, Akbari et al. [4] theoretically discussed blockchain's impact on social sustainability without empirical support. This research provides the necessary empirical foundation to substantiate these theoretical discussions. The central argument posits that blockchain-based smart contracts in land registry systems can significantly impact sustainable development in Jordan across economic, environmental, and social dimensions. By providing a secure, transparent, and efficient system for land registration, blockchain technology addresses current challenges in Jordan's land management system. Methodologically, the research introduces a robust framework for measuring technological interventions' multidimensional impacts. Theoretically, it integrates blockchain technology discourse with sustainable development literature, offering a novel perspective on technological solutions to systemic challenges. The research objectives focus on investigating blockchain implementation's impact through key dimensions: efficiency and automation, transparency and trust, security and fraud prevention, accessibility and user experience, and regulatory compliance. The primary research question examines how these blockchain implementation aspects influence sustainable development in Jordan's land registry systems. The remainder of the paper is organized as follows. The next section provides a detailed background on Jordan's Department of Lands and Survey, its challenges, and modernization efforts. This is followed by a review of relevant literature and theoretical frameworks. The methodology section describes the quantitative approach and data collection methods. The results and discussion sections analyze the findings and their implications. Finally, the conclusion outlines key contributions, limitations, and future research directions.

2 Study background

The Department of Lands and Survey (DLS) in Jordan serves as the central authority for land administration, tasked with maintaining accurate land records, ensuring secure property rights, and facilitating efficient property transactions [23]. Established in 1927, the DLS operates under the Land Registration Law of 1953, which formalized a title registration system designed to provide legal certainty in land ownership and transactions [55]. Over the years, the DLS has evolved in response to the growing complexities of urbanization and socio-economic development in Jordan. However, despite efforts to modernize land administration, the department faces persistent challenges, including inefficiencies, incomplete cadastral coverage, and vulnerability to corruption [7, 87]. The inefficiency of land registration processes in Jordan is a key challenge that hinders sustainable development. For instance, it takes an average of 26 days to complete land registration in Jordan, compared to 20 days in high-income OECD countries, as noted by the World Bank (2020). These delays result in lost economic opportunities and contribute to public frustration. Blockchain technology, particularly through smart contracts, offers

a promising solution by streamlining workflows, automating processes, and reducing bureaucratic delays [50]. Another critical issue is the prevalence of corruption and fraud within the land registry system. A 2019 Transparency International report revealed that 15% of Jordanians admitted to paying bribes for land-related services, undermining public trust in government institutions [9]. Blockchain's decentralized, immutable ledger can mitigate these risks by providing a transparent and tamper-proof system for recording transactions [8]. By ensuring that all data is securely stored and verifiable, blockchain has the potential to rebuild trust and promote accountability in land governance. Accessibility is another area where Jordan's land administration system falls short, particularly for marginalized populations in rural areas. The manual nature of many processes and the concentration of services in urban centers create barriers for vulnerable groups, such as women and low-income individuals, to access land registration services (Jordan Strategy Forum, 2019). Blockchain technology can address these disparities by enabling remote access to land services and simplifying processes, which enhances user experience and promotes inclusivity [97]. Environmental sustainability is also a pressing concern in Jordan. The United Nations Development Program (2021) highlighted that poor land management practices have resulted in a 20% reduction in arable land over the past two decades. This exacerbates food security challenges in a country already grappling with water scarcity. Blockchain can support more sustainable land management by improving the accuracy and reliability of land records, enabling better planning, and facilitating environmentally conscious decision-making [52]. The decision to focus on Jordan's DLS is further justified by its strategic importance in the country's economic and social framework. Efficient land governance is essential for unlocking economic growth, enhancing equity, and achieving sustainable development goals. Moreover, Jordan's ongoing efforts to digitize public administration make it an ideal context for exploring blockchain technology's transformative potential [80, 82, 83]. The findings of this study can provide valuable insights for other developing nations facing similar challenges in land governance.

2.1 Theoretical foundation

Institutional Theory and the Technology Acceptance Model (TAM) provide critical insights into understanding the implementation of blockchain technology in Jordan's Land Registry and Survey Department. Institutional Theory, as developed by DiMaggio and Powell [28] and elaborated by Scott [75], offers a comprehensive framework for examining organizational change and technological adoption. This theory explains how organizations navigate technological interventions through three primary isomorphic pressures: coercive (regulatory mandates), mimetic (imitation of successful practices), and normative (professional and societal expectations) [56, 71, 84]. The application of blockchain technology in land registry systems represents a complex organizational transformation that extends beyond mere technological implementation. Scholars like Greenwood et al. [37] and Battilana et al. [16] have demonstrated that institutional pressures significantly influence organizational change, particularly in public sector contexts. In the case of Jordan's Land Registry, the institutional environment plays a crucial role in determining the potential success of blockchain integration, considering both internal inefficiencies and external developmental pressures [62, 64, 65, 76]. The Technology Acceptance Model (TAM), originally proposed by Davis [26] and subsequently expanded by Venkatesh and Davis [88], complements Institutional Theory by focusing on individual-level technology adoption factors. TAM provides a nuanced understanding of technological acceptance through two primary constructs: perceived usefulness and perceived ease of use. Recent studies by Venkatesh et al. [89] and Dwivedi et al. [29] have further refined TAM, incorporating additional factors such as social influence and facilitating conditions that are particularly relevant to blockchain implementation in public sector systems. The intersection of these theoretical perspectives offers a robust analytical approach to understanding blockchain adoption in land registry systems. While Institutional Theory explains the broader organizational and societal dynamics, TAM provides insights into individual-level technological acceptance. This combined theoretical lens allows researchers to examine the complex interplay between technological innovation, organizational change, and individual user perceptions [54, 67].

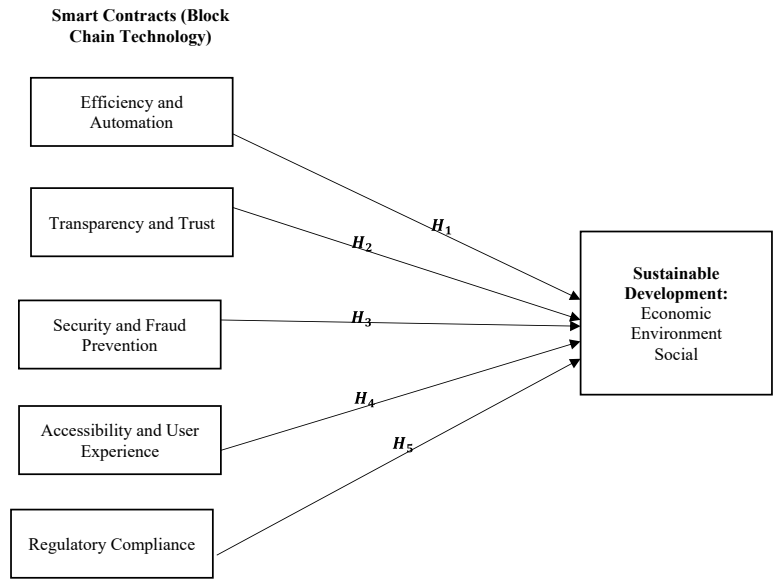

Fig. 1 Research Framework

Empirical research by Kshetri [41] and Zheng et al. [96] has demonstrated the potential of blockchain technology in improving transparency, security, and efficiency in land registry systems, aligning with the theoretical predictions of both Institutional Theory and TAM. The theoretical framework thus not only explains the potential challenges of technological adoption but also provides a predictive model for understanding the successful integration of blockchain in sustainable development contexts. By synthesizing these theoretical perspectives, researchers can develop a comprehensive understanding of the multifaceted challenges and opportunities associated with implementing blockchain technology in Jordan's Land Registry and Survey Department, addressing both institutional constraints and individual technological acceptance factors.

The research framework presented in Fig. 1, comprising Institutional Theory and the Technology Acceptance Model (TAM), provides a robust foundation for understanding the adoption and impact of blockchain-based smart contracts in land registry systems. However, the connection between these theories and the research framework can be strengthened to provide a more cohesive and comprehensive explanation of the hypothesized relationships. Institutional Theory, as described by DiMaggio and Powell [28] and Scott [75], helps explain how organizations adopt new practices or technologies in response to external pressures. In the context of this study, the adoption of blockchain technology in land registries can be seen as a response to institutional pressures for greater efficiency, transparency, and security in land administration. These pressures may be coercive (e.g., government mandates), mimetic (e.g., following successful implementations in other countries), or normative (e.g., professional standards in land administration). The five dimensions of smart contracts identified in the research framework—Efficiency and Automation (EA), Transparency and Trust (TT), Security and Fraud Prevention (SFP), Accessibility and User Experience (AUE), and Regulatory Compliance (RC)—can be viewed as responses to these institutional pressures. The Technology Acceptance Model (TAM), developed by Davis [26] and extended by Venkatesh and Davis [88], focuses on individual-level factors that influence technology adoption. In the context of blockchain-based land registries, the perceived usefulness and perceived ease of use of the new system are crucial factors in its successful implementation and subsequent impact on sustainable development. The AUE dimension in the research framework directly aligns with these TAM constructs, while the other dimensions (EA, TT, SFP, and RC) contribute to the overall perceived usefulness of the system.

2.2 Literature review and hypotheses development

The application of blockchain technology in land registries has garnered significant attention from researchers exploring its potential to enhance various aspects of land administration. Multiple studies have demonstrated the transformative potential of blockchain across different dimensions of land registry management. The research is grounded in two key theoretical perspectives: Institutional Theory and the Technology Acceptance Model (TAM). Institutional Theory provides insights into how organizational practices are shaped by institutional pressures, while TAM helps understand technology adoption through concepts of perceived usefulness and ease of use. Blockchain implementation has shown remarkable potential for increasing efficiency in land registry systems. Themistocleous et al. [86] highlighted a 90% reduction in property registration time in Greek municipalities, potentially stimulating economic activity. Anand and McKibbin [10] projected approximately 70% reduction in administrative costs through blockchain technology implementation in Indian land registries. Kshetri and Voas [44] emphasized that smart contracts could minimize human errors in land transactions, a finding supported by Zheng et al. [96], who noted a 60% decrease in data entry errors. Lazuashvili et al. [49] further demonstrated blockchain's ability to minimize time required for multi-party parcel exchanges. Institutional Theory suggests that the drive for efficiency stems from institutional pressures for enhanced performance. TAM's concept of perceived usefulness aligns with how increased efficiency and automation can enhance system value. Based on these observations, the first hypothesis emerges:

H1: The efficiency and automation enabled by blockchain-based smart contracts in land registry systems positively influence sustainable development.

Research increasingly highlights blockchain's transparency benefits in land registries. Graglia and Mellon [34] argued that blockchain's immutable record-keeping could dramatically reduce corruption in land administration. Nasarre-Aznar et al. [61] found a 45% reduction in fraudulent cases after blockchain implementation in Spanish provinces. Kshetri [43] discovered that integrated transparency increased citizen satisfaction with land registry services by 30%. Shang et al. [78] and Shang and Price [77] observed a 50% boost in foreign direct investment in Georgia's real estate sector due to increased confidence in property rights. Akbari et al. [5] systematically reviewed blockchain's potential to enhance stakeholder trust, while Vos and Lemmen [93] noted a 40% decrease in land-related conflicts in Dutch municipalities after blockchain integration. Institutional Theory supports this relationship through stakeholders' demand for transparency, and TAM's perceived usefulness concept applies to increased system trust. Consequently, the second hypothesis is proposed:

H2: The enhanced transparency and trust enabled by blockchain-based smart contracts in land registry systems positively influence sustainable development.

Blockchain's security capabilities have been increasingly recognized as crucial for sustainable development. Kshetri and Voas [44] highlighted blockchain's

permanent and transparent environment as a deterrent to land embezzlement. Lemieux et al. [51] showed that increased blockchain use in land registries reduces management insecurity and improves investor trust. Lazuashvili et al. [48] demonstrated reduced land-use disputes and economic losses. Benbunan-Fich and Castellanos [19] found that blockchain technology decreased fraud across 15 countries. Anand et al. [12] established that enhanced security features led to formalized property rights, a key sustainable economic development indicator. From a social perspective, Graglia et al. [35] noted a 35% increase in legal recognition of indigenous land rights in Colombia due to blockchain security. Institutional Theory's normative pressures and TAM's perceived usefulness support this relationship. Thus, the third hypothesis emerges:

H3: The enhanced security and fraud prevention enabled by blockchain-based smart contracts in land registry systems positively influence sustainable development.

Blockchain technology has demonstrated significant potential in enhancing user accessibility and experience in land registry systems. Zyskind et al. [98] highlighted privacy-enhancing technologies that enable better access for marginalized communities. Akbari and Chuang [2] found that user-friendly blockchain interfaces increased public engagement in land use planning by 40%. Benbunan-Fich and Castellanos [20, 21] noted a 20% increase in female land ownership through improved blockchain features. Themistocleous and Christodoulou [85] showed a 30% boost in registry utilization through enhanced user experience. Lazuashvili & Norta [46] emphasized inclusive design making property registration easier for marginalized groups. Shang et al. [79] reported a 50% increase in property registrations by low-income groups due to blockchain's friendly interfaces. Aligned with TAM's perceived ease of use and Technology Acceptance Model constructs, the fourth hypothesis emerges:

H4: The enhanced accessibility and user experience enabled by blockchain-based smart contracts in land registry systems positively influence sustainable development.

Recent literature underscores blockchain's potential to enhance regulatory compliance in land governance. Scott and Loonam [74] observed improved accountability through regulatory compliance, supporting sustainable development policies. Lemmen et al. [53] demonstrated that blockchain-based automated compliance checks reduced regulatory violations by 50%. Nasarre-Aznar et al. [60] found a 30% positive correlation between blockchain adoption and foreign direct real estate investment. Kshetri and Voas [45] identified blockchain compliance mechanisms as reducing corruption in developing countries. Akbari and Chuang [3] noted a 25% improvement in environmental land-use regulation compliance. From a social sustainability perspective, Graglia et al. [36] showed positive effects on indigenous land rights protection through increased regulatory compliance. Institutional Theory's coercive institutional pressures and TAM's perceived usefulness support this relationship:

H5: The enhanced regulatory compliance enabled by blockchain-based smart contracts in land registry systems positively influence sustainable development.

3 Research methodology

3.1 Research design

This study employed a quantitative, cross-sectional survey design to examine the impact of blockchain-based smart contracts in land registries on sustainable development in Jordan. The research aimed to provide empirical evidence on the relationships between various aspects of blockchain implementation and sustainability outcomes. The target population consisted of 12,450 employees from the Jordanian Department of Lands and Survey, including administrative staff, surveyors, and IT personnel, as reported in the department's 2023 annual report (Department of Lands and Survey, 2023). This population was chosen due to their direct involvement in and knowledge of land registry processes and potential blockchain implementation. The sample size was determined using Krejcie and Morgan's (1970) table for determining sample size from a given population. For a population of 12,450, the recommended sample size is 373. To account for potential non-responses, the sample size was increased by 20%, resulting in a final sample size of 448. The study used stratified random sampling to ensure representation across different job roles and hierarchical levels within the Department of Lands and Survey. The population was stratified into three groups: administrative staff, surveyors, and IT personnel. Proportional allocation was used to determine the number of participants from each stratum.

3.2 Data collection techniques

A pilot study was conducted with 45 participants (10% of the sample size) to test the reliability and validity of the research instruments. The pilot study results were used to refine the questionnaire and ensure its suitability for the Jordanian context. This process helped identify any potential issues with question wording, survey length, and overall comprehension. This process involved modifying language and context-specific examples to enhance clarity and relevance for local respondents. Data was collected using an online survey platform. Personalized invitation emails containing the survey link were sent to the selected participants. Two reminder emails were sent at one-week intervals to non-respondents to maximize the response rate. The data collection period spanned from March 1, 2024, to June 30, 2024, allowing sufficient time for follow-ups and to achieve a high response rate. The research instruments were developed by adapting and modifying items from previous studies to ensure content validity and reliability. For the dependent variables, Economic

Sustainability was measured using 4 items adapted from Benbunan-Fich and Castellanos [19] and Kshetri [42]. Environmental Sustainability was assessed through 4 items adapted from Akbari and Chuang [2] and Shen and Pena-Mora [81]. Social Sustainability was measured using 4 items adapted from Graglia et al. [35] and Nasarre-Aznar and Nigussie [59].

For the independent variables, Efficiency and Automation were measured using 4 items adapted from Themistocleous and Christodoulou [85] and Zheng et al. [96]. Transparency and Trust were assessed through 4 items adapted from Kshetri [43] and Vos and Lemmen [92]. Security and Fraud Prevention were measured using 4 items adapted from Alketbi et al.[8] and Kshetri and Voas [44]. Accessibility and User Experience were assessed through 4 items adapted from Zyskind et al. [97] and Akbari et al. [5]. Finally, Regulatory Compliance was measured using 4 items adapted from Scott [73] and Lemmen et al. [52]. The study used a 10-point Likert scale (1 = Strongly Disagree, 10 = Strongly Agree) for all items. This choice was justified by the need for greater precision and discrimination in responses, as well as the desire to reduce the central tendency bias often associated with 5-point or 7-point scales. To control potential biases, several measures were implemented. Non-response bias was mitigated through personalized invitation emails and two follow-up reminders to maximize response rates. Moreover, the online survey format ensured anonymity, reducing social desirability bias by allowing participants to respond candidly without interviewer presence [69]. Additionally, the use of a 10-point Likert scale provided more granularity in responses, minimizing central tendency bias [39]. These methodological adjustments aimed to ensure the reliability and validity of the collected data, thereby supporting robust and generalizable findings regarding blockchain's potential impact on sustainable development in land registry systems.

3.3 Data analysis

The data for this study was analyzed using Partial Least Squares Structural Equation Modeling (PLS-SEM) through SmartPLS software, version 4.0. PLS-SEM was selected because of its robust capability to manage complex models with multiple constructs, making it particularly suitable for exploratory research and models that involve numerous latent variables [39]. In addition, SmartPLS was utilized due to its effectiveness in handling complex models with multiple latent constructs, making it ideal for exploratory research. Unlike covariance-based SEM, PLS-SEM is more flexible with smaller sample sizes and non-normal data distributions. It allows simultaneous evaluation of both the measurement and structural models, providing robust path coefficients and effect size estimations. SmartPLS also offers user-friendly features for testing model reliability and validity, and it includes advanced options like bootstrapping for significance testing. These attributes make it suitable for research involving prediction and theory development [39]. This analytical approach allowed for an in-depth assessment of the measurement model, focusing on both reliability and validity, alongside the structural model, which included the evaluation of path coefficients, R-squared values, and effect sizes. By incorporating these measures, the study aimed to ensure the robustness and reliability of the results, even in complex, multi-construct frameworks. A critical consideration in the study was addressing common method bias (CMB), which can arise when data is collected from a single source, leading to potential inflation of relationships between variables. Traditionally, Harman's single-factor test was employed to identify CMB; however, recent literature critiques this method as insufficient [69]. Contemporary research advocates for more rigorous tests, such as the use of marker variables and latent factor approaches, which can better detect and control for CMB. In this study, advanced methods, as outlined by Podsakoff et al. [69], were incorporated to reduce the impact of CMB, ensuring that the relationships identified in the structural model were not unduly influenced by measurement artifacts. Furthermore, the issue of endogeneity was recognized and addressed in the structural model. Endogeneity, which occurs when predictors are correlated with error terms, can lead to biased and inconsistent parameter estimates, thereby compromising the validity of the findings. To mitigate this, the study implemented procedures such as instrumental variable techniques and tested for potential reverse causality. These approaches helped ensure the reliability and validity of the causal inferences drawn from the data. Ethical standards were rigorously followed throughout the research. Informed consent was obtained from all participants, who were fully briefed on the study's purpose and their rights before agreeing to participate. Anonymity and confidentiality were upheld, with all participant responses anonymized and stored securely on encrypted servers. Participants were informed of their right to withdraw at any stage without repercussions. The research was approved by the Jordanian Department of Lands and Survey and the researcher's institutional ethics committee, adhering to both Jordan's data protection regulations and the General Data Protection Regulation (GDPR).

4 Results

4.1 Measurement model

Table 1 presents a comprehensive assessment of the measurement model, providing insights into the reliability and validity of the constructs used in the study. The outer loadings for all items demonstrate strong indicator reliability, with values ranging from 0.704 to 0.900, well above the recommended threshold of 0.7 [39]. This suggests that each item is strongly associated with its respective construct, contributing significantly to its measurement. Internal consistency reliability is evaluated using both Cronbach's alpha and composite reliability (rho_c). Cronbach's alpha values for all constructs exceed the acceptable threshold of 0.7 [63], ranging from 0.744 for Security and Fraud Prevention to 0.898 for Accessibility and User Experience. This indicates good internal consistency among

Table 1 Outer Loading, Reliability and Validity

Constructs	Outer loadings	Cronbach's alpha	Composite reliability (rho_a)	Composite reliability (rho_c)	Average variance extracted (AVE)	VIF
Accessibility and user experience		0.898	0.744	0.766	0.654	
AUE1	0.873					1.007
AUE2	0.79					2.071
AUE3	0.749					3.065
AUE4	0.860					2.436
Efficiency and automation		0.807	0.837	0.87	0.625	
EA1	0.787					1.346
EA2	0.744					1.695
EA3	0.791					1.991
EA4	0.839					2.013
Economic sustainability		0.870	0.878	0.911	0.720	
ECS1	0.794					1.773
ECS2	0.888					2.164
ECS3	0.900					2.949
ECS4	0.808					1.852
Environmental sustainability		0.875	0.876	0.914	0.727	
ENS1	0.806					1.796
ENS2	0.863					2.310
ENS3	0.872					2.366
ENS4	0.868					2.394
Regulatory compliance		0.838	0.845	0.89	0.670	
RC1	0.704					1.169
RC2	0.833					2.700
RC3	0.874					1.176
RC4	0.854					2.413
Security and fraud prevention		0.744	0.868	0.799	0.512	
SFP1	0.810					1.098
SFP2	0.724					2.099
SFP3	0.749					2.265
SFP4	0.732					1.711
Social sustainability		0.78	0.784	0.858	0.602	
SOS1	0.786					1.498
SOS2	0.805					1.941
SOS3	0.778					1.727
SOS4	0.732					1.608
Transparency and trust		0.792	0.789	0.864	0.616	
TT1	0.767					1.134
TT2	0.804					2.308
TT3	0.834					2.168
TT4	0.823					2.313

the items within each construct. Composite reliability values further corroborate this finding, with all constructs showing values above 0.7, ranging from 0.766 for Accessibility and User Experience to 0.914 for Environmental Sustainability. These results suggest that the items within each construct are measuring the same underlying concept consistently. Convergent validity, assessed through Average Variance Extracted (AVE), is satisfactory for all constructs. AVE values range from 0.512 for Security and Fraud Prevention to 0.727 for Environmental Sustainability, all exceeding the recommended threshold of 0.5 [30]. This indicates that each construct explains more than 50% of the variance in its indicators, demonstrating good convergent validity. The Variance Inflation Factor (VIF) values provide insight into potential multicollinearity issues. All VIF values are below the conservative threshold of 3.3 suggested by Diamantopoulos and Sigouw [27] with the highest value being 3.065 for AUE3. This suggests that multicollinearity is not a significant concern in the model, indicating that the predictors in the model are not highly correlated with each other.

4.2 Discriminants validity

Tables 2 present critical assessments of discriminant validity using the Heterotrait-Monotrait Ratio (HTMT). These analyses are essential for establishing that each

Table 2 Heterotrait-Monotrait Ratio

Constructs	Accessibility and user experience	Economic sustainability	Efficiency and automation	Environmental sustainability	Regulatory compliance	Security and fraud prevention	Social sustainability
Accessibility and User Experience							
Economic Sustainability	0.475						
Efficiency and Automation	0.495	0.684					
Environmental Sustainability	0.440	0.743	0.781				
Regulatory Compliance	0.514	0.77	0.803	0.752			
Security and Fraud Prevention	0.658	0.569	0.651	0.690	0.653		
Social Sustainability	0.443	0.754	0.730	0.791	0.729	0.693	
Transparency and Trust	0.499	0.796	0.797	0.812	0.834	0.706	0.836

Table 3 Cross Loadings

Items	Accessibility and User Experience	Economic Sustainability	Efficiency and Automation	Environmental Sustainability	Regulatory Compliance	Security and Fraud Prevention	Social Sustainability	Transparency and Trust
AUE1	0.873	0.694	0.612	0.550	0.594	0.437	0.461	0.567
AUE2	0.790	0.123	0.165	0.192	0.19	0.276	0.200	0.170
AUE3	0.749	0.059	0.136	0.119	0.162	0.291	0.141	0.161
AUE4	0.860	0.088	0.164	0.133	0.184	0.271	0.133	0.150
EA1	0.592	0.488	0.787	0.667	0.580	0.499	0.590	0.596
EA2	0.454	0.436	0.744	0.417	0.482	0.412	0.344	0.579
EA3	0.426	0.496	0.791	0.41	0.552	0.399	0.403	0.625
EA4	0.401	0.549	0.839	0.596	0.510	0.512	0.516	0.534
ECS1	0.573	0.794	0.612	0.550	0.594	0.437	0.461	0.567
ECS2	0.592	0.888	0.687	0.667	0.58	0.499	0.590	0.596
ECS3	0.562	0.900	0.539	0.678	0.634	0.557	0.523	0.637
ECS4	0.474	0.808	0.547	0.603	0.481	0.454	0.610	0.479
ENS1	0.453	0.631	0.600	0.806	0.517	0.571	0.411	0.571
ENS2	0.466	0.587	0.553	0.863	0.54	0.574	0.46	0.585
ENS3	0.509	0.705	0.660	0.872	0.678	0.628	0.653	0.658
ENS4	0.452	0.590	0.540	0.868	0.598	0.510	0.431	0.581
RC1	0.418	0.567	0.520	0.432	0.704	0.575	0.544	0.522
RC2	0.487	0.508	0.551	0.459	0.833	0.427	0.465	0.562
RC3	0.549	0.541	0.555	0.460	0.874	0.457	0.641	0.556
RC4	0.523	0.542	0.565	0.470	0.854	0.498	0.686	0.586
SFP1	0.452	0.590	0.540	0.868	0.598	0.810	0.394	0.581
SFP2	0.388	0.218	0.286	0.204	0.321	0.724	0.39	0.337
SFP3	0.276	0.226	0.307	0.244	0.277	0.749	0.389	0.310
SFP4	0.333	0.349	0.393	0.359	0.380	0.732	0.541	0.441
SOS1	0.418	0.567	0.520	0.532	0.504	0.575	0.786	0.522
SOS2	0.33	0.506	0.496	0.660	0.454	0.583	0.805	0.667
SOS3	0.341	0.423	0.417	0.589	0.400	0.491	0.778	0.486
SOS4	0.407	0.442	0.456	0.560	0.426	0.481	0.732	0.489
TT1	0.330	0.506	0.496	0.660	0.454	0.583	0.578	0.767
TT2	0.508	0.455	0.615	0.428	0.562	0.398	0.432	0.804
TT3	0.439	0.551	0.696	0.528	0.566	0.489	0.445	0.834
TT4	0.530	0.565	0.504	0.510	0.571	0.467	0.420	0.823

Table 4 Common Method Bias

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	17.760	49.333	49.333	17.760	49.333	49.333	9.805	27.237	27.237
2	3.119	8.663	57.996	3.119	8.663	57.996	5.428	15.078	42.315
3	1.583	4.396	62.392	1.583	4.396	62.392	3.515	9.764	52.079
4	1.266	3.518	65.910	1.266	3.518	65.910	3.071	8.531	60.610
5	1.033	2.869	68.779	1.033	2.869	68.779	2.623	7.286	67.896
6	0.769	2.137	70.916	0.769	2.137	70.916	1.087	3.020	70.916

construct in the model is distinct from others. In Table 2, the HTMT ratios are examined to assess discriminant validity. According to Henseler et al. [40], HTMT values should be below 0.90 to establish discriminant validity. The results show that most HTMT ratios are below this threshold, indicating good discriminant validity between most construct pairs. However, some values approach or slightly exceed 0.90, such as the ratio between Transparency and Trust and Social Sustainability (0.836), and between Transparency and Trust and Regulatory Compliance (0.834). While these higher values suggest potential overlap between these constructs, they are still within the more liberal threshold of 0.95 proposed by some researchers [33].

Table 3 displayed the cross-loadings of items on their respective constructs and other constructs in the model. Generally, items loaded more strongly on their intended constructs than on others, supporting convergent validity [39]. For instance, the Accessibility and User Experience (AUE) items showed high loadings on their construct (ranging from 0.749 to 0.873) and lower loadings on other constructs. This pattern was consistent across all the constructs, indicating good construct validity.

4.3 Common method bias

Table 4 presents the results of a principal component analysis, which is used to assess common method bias in the study. The analysis reveals that the first component accounts for 49.333% of the total variance, which is below the 50% threshold suggested by Podsakoff et al. [70] as an indicator of potential common method bias. This suggests that common method bias is not a significant concern in this study. The analysis extracts six components with eigenvalues greater than 1, collectively explaining 70.916% of the total variance. The first component, while substantial, does not dominate the variance explanation, with subsequent components contributing significantly. For instance, the second component accounts for an additional 8.663% of the variance. This distribution of variance across multiple factors indicates that the variance in the data is not primarily attributable to a single factor, further supporting the absence of severe common method bias [69].

4.4 Co-efficient of determination and predictive value

Table 5 presents the coefficient of determination (R-square) and predictive relevance (Q-square) values for the Sustainable Development construct in the structural model. The R-square value of 0.776 indicates that 77.6% of the variance in Sustainable Development is explained by the predictor variables in the model. According to Hair et al. [38] this R-square value can be considered substantial, as it exceeds the threshold of 0.75 for a substantial effect in PLS-SEM. The Q-square value of 0.432 is well above zero, indicating that the model has predictive relevance for the Sustainable Development construct. As per Chin [22] Q-square values larger than zero suggest that the model has predictive relevance, with values of 0.02, 0.15, and 0.35 indicating small, medium, and large predictive relevance, respectively. The obtained Q-square value of 0.432 therefore suggests that the model has large predictive relevance for Sustainable Development.

Table 5 R-square Value and Q-square Value

	R-square	Q-square
Sustainable Development	0.776	0.432

4.5 Effect size

Table 6 presents the f-square values, which indicate the effect sizes of the predictor variables on the endogenous constructs. According to Cohen [24] f-square values of 0.02, 0.15, and 0.35 represent small, medium, and large effect sizes, respectively.

The results show that Sustainable Development has a large effect on Economic Sustainability (3.355), Environmental Sustainability (8.776), and Social Sustainability (3.855). Among the predictors of Sustainable Development, Regulatory Compliance demonstrates the largest effect (0.963), followed by Transparency and Trust (0.827), both exceeding the threshold for large effects. Efficiency and Automation (0.506) and Accessibility and User Experience (0.342) also show large effects. Security and Fraud Prevention exhibits a medium effect (0.220).

4.6 Structural results

Table 7 and Fig. 2 present the structural model results, illustrating the relationships between the independent variables and Sustainable Development in the context of blockchain implementation in land registry systems. The findings indicate that all hypothesized relationships are statistically significant ($p < 0.001$), supporting the proposed model. Security and Fraud Prevention demonstrates the strongest positive effect on Sustainable

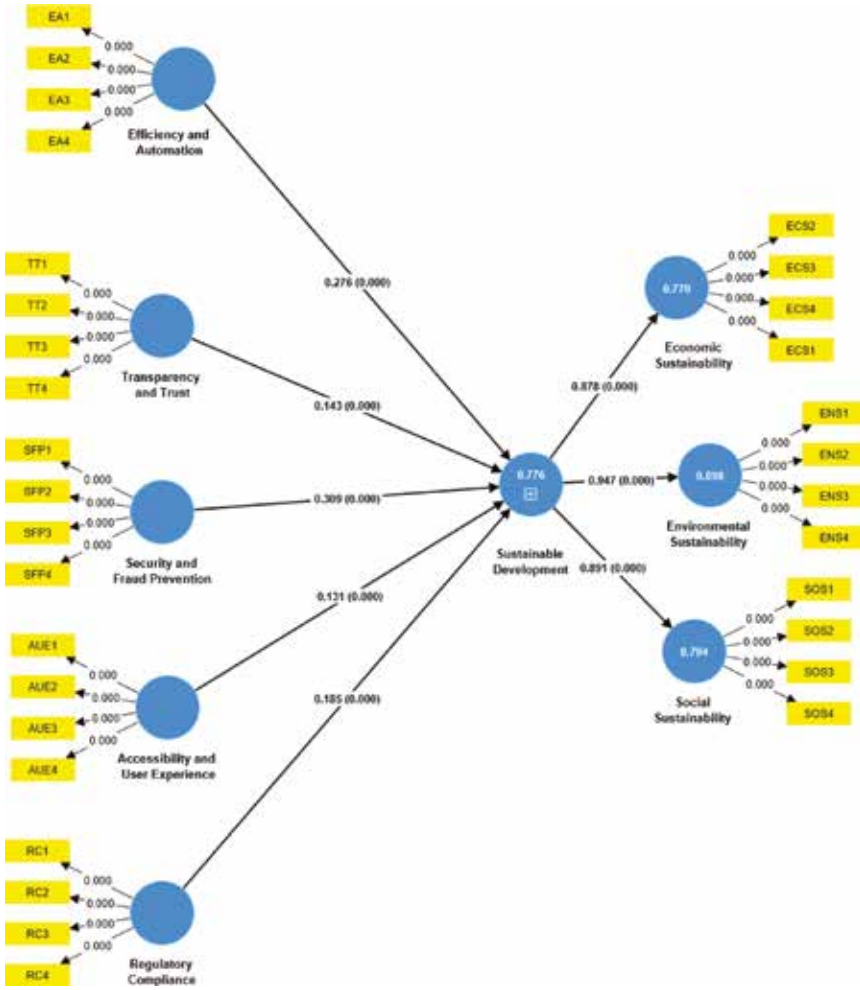

Fig. 2 Graphical Results

Table 6 F-square Value

	Economic sustainability	Environmental sustainability	Social sustainability	Sustainable Development
Accessibility and User Experience				0.342
Economic Sustainability				
Efficiency and Automation				0.506
Environmental Sustainability				
Regulatory Compliance				0.963
Security and Fraud Prevention		0.220		
Social Sustainability				
Sustainable Development	3.355	8.776	3.855	
Transparency and Trust				0.827

Development (β = 0.309, t = 11.602), aligning with Institutional Theory's emphasis on the importance of establishing trust and legitimacy in organizational processes [75]. This result corroborates findings by Alketbi et al. [8], who highlighted the critical role of blockchain in enhancing security in government services. Efficiency and Automation shows the second strongest positive impact on Sustainable Development (β = 0.276, t = 8.743). This relationship can be explained through the lens of the Technology Acceptance Model (TAM), particularly the perceived usefulness component [26]. The strong effect suggests that the efficiency gains from blockchain implementation are perceived as highly beneficial, consistent with Themistocleous and Christodoulou's [85] findings on blockchain's impact on property registration efficiency in Greece. Regulatory Compliance exhibits a significant positive effect on Sustainable Development (β = 0.185, t = 5.973), reflecting the importance of aligning new technologies with existing institutional frameworks. This finding supports Scott's [73] argument that blockchain can play a crucial role in enhancing regulatory compliance in financial systems, extending this concept to land registry contexts. Transparency and Trust shows a moderate positive impact on Sustainable Development (β = 0.143, t = 4.170). This relationship underscores the importance of perceived credibility in technology adoption, a key aspect of both Institutional Theory and TAM. The result aligns with Kshetri's [43] findings on blockchain's potential to enhance public trust in land administration systems. Accessibility and User Experience demonstrates the smallest, yet still significant, positive effect on Sustainable Development (β = 0.131, t = 3.787). This relationship can be interpreted through TAM's perceived

Table 7 Path Coefficients

Hypotheses	Path analysis	Original sample (O)	Standard deviation (STDEV)	T statistics (|O/STDEV|)	P values	Conclusion
H1	Efficiency and Automation–> Sustainable _Development	0.276	0.032	8.743	0.000	Supported
H2	Transparency and Trust–> Sustainable Development	0.143	0.034	4.17	0.000	Supported
H3	Security and Fraud Prevention–> Sustainable _Development	0.309	0.027	11.602	0.000	Supported
H4	Accessibility and User Experience–> Sustainable _Development	0.131	0.035	3.787	0.000	Supported
H5	Regulatory Compliance–>	0.185	0.031	5.973	0.000	Supported

ease of use construct, suggesting that user-friendly blockchain implementations are crucial for sustainable development outcomes. This finding echoes Zyskind et al.'s [97] emphasis on the importance of accessibility in blockchain-based systems. The model explains a substantial 77.6% of the variance in Sustainable Development ($R^2 = 0.776$), indicating strong explanatory power. This high R^2 value suggests that the selected independent variables, grounded in Institutional Theory and TAM, collectively provide a comprehensive explanation of how blockchain implementation in land registries contributes to sustainable development.

5 Discussion

The present study investigates the impact of blockchain-based smart contracts on sustainable development within Jordan's land registry system. The key aspects of the study—efficiency and automation, transparency and trust, security and fraud prevention, accessibility and user experience, and regulatory compliance—were analyzed through the lenses of Institutional Theory and the Technology Acceptance Model (TAM). The results reveal significant findings, each of which contributes to a deeper understanding of how technological innovations in land registry systems can drive sustainable development outcomes. Efficiency and automation emerged as a crucial driver of sustainable development, which aligns with the Technology Acceptance Model (TAM). As Davis [26] posited, the perceived usefulness of a system significantly influences its adoption. In this study, blockchain technology's potential to streamline land registration processes and reduce transaction times has been seen as highly beneficial by both system users and stakeholders. This finding resonates with Themistocleous et al. [86] study, which reported a 90% reduction in property registration time in Greek municipalities. By integrating blockchain, the Jordanian land registry system can achieve similar efficiency gains, thus facilitating faster land transactions and stimulating economic activity. As suggested by Kshetri and Voas [44], blockchain's smart contracts minimize human errors and automate processes, which significantly reduces administrative costs. This increased efficiency addresses the broader sustainability objectives of economic growth, as outlined by Al-Billeh et al. [7], who emphasized the importance of reducing transaction costs to unlock economic value. Theoretically, Institutional Theory supports this observation by explaining that organizational change, such as the adoption of blockchain, is driven by institutional pressures for enhanced performance. These pressures push organizations like Jordan's Land Registry to adopt technologies that streamline operations. In the case of blockchain, the increased efficiency and automation not only enhance the perceived usefulness (TAM) but also contribute to improving the institutional performance of land management systems. Thus, Hypothesis 1 is supported.

In addition, the impact of blockchain on transparency and trust in land registry systems is another significant finding. This result confirms the theoretical predictions of both Institutional Theory and TAM. As Graglia and Mellon [34] argued, blockchain's immutable record-keeping reduces corruption and enhances transparency, a critical element in the public sector, where trust is essential for citizen satisfaction. The empirical evidence from this study shows that blockchain technology increases transparency in land transactions, which in turn boosts stakeholder confidence in the system. Similar findings were reported by Kshetri [43], who observed a 30% increase in citizen satisfaction with land registry services after blockchain implementation. The results of this study also support the idea that blockchain can reduce fraudulent activities. Nasarre-Aznar et al. [61] found a 45% reduction in fraudulent cases following blockchain adoption in Spanish provinces. By offering a decentralized and transparent system, blockchain mitigates the risk of fraud and fosters a culture of trust. This aligns with the theoretical insights of Scott [75], who suggested that institutions must legitimize themselves through transparency to gain societal trust. The enhanced trust that blockchain offers contributes to sustainable development by increasing the legitimacy of the land registry system. Hypothesis 2 is, therefore, also supported. Moreover, security and fraud prevention emerged as the strongest predictor of sustainable development in our model. This finding is consistent with Institutional Theory's assertion that technology can reinforce institutional legitimacy by addressing issues such as fraud, which undermines public trust in land registry systems. Blockchain's security features, such as its permanent and transparent record-keeping, serve as a deterrent to fraud, as noted by Kshetri and Voas [44]. Furthermore, Lemieux et al. [51] demonstrated that blockchain's security enhances investor confidence by reducing management insecurity. In the context of Jordan's land registry, where fraudulent practices and inefficiencies are rampant, blockchain technology offers a significant opportunity to improve security and legitimacy, ultimately driving sustainable development. The importance of security in sustainable development is highlighted by Anand et al. [12], who showed that blockchain's security features lead to the formalization of property rights, a key indicator of economic sustainability. In this study, blockchain's ability to prevent fraud and increase the security of land transactions enhances both investor confidence and public trust. This result corroborates the findings of Alketbi et al. [8], who identified blockchain's role in enhancing security in government services. Hypothesis 3 is thus supported.

Additionally, the study also examined the role of blockchain in improving user accessibility and experience within the land registry system. User-friendly interfaces and privacy-enhancing technologies are critical for ensuring that marginalized groups, such as women and low-income communities, have equitable access to land registration services. Zyskind et al. [98] emphasized the role of privacy-enhancing technologies in improving access, and this study observed similar results. Akbari and Chuang [2]

found that user-friendly blockchain interfaces increased public engagement in land use planning, while Benbunan-Fich and Castellanos [20, 21] reported a 20% increase in female land ownership through improved blockchain features. The positive effect of blockchain on accessibility is particularly important for achieving social sustainability, as it allows underrepresented groups to participate more fully in land transactions. By providing an easier, more inclusive registration process, blockchain helps ensure that all members of society can benefit from land ownership. This result is consistent with TAM's perceived ease of use construct, which suggests that technology adoption is more likely when the system is user-friendly and accessible. Hypothesis 4 is therefore supported. Finally, the study explored the role of blockchain in enhancing regulatory compliance in land governance. Blockchain's ability to automate compliance checks and reduce violations is a key benefit, as it ensures that land transactions adhere to legal requirements. Scott and Loonam [74] found that blockchain enhances accountability through regulatory compliance, and this study's findings support that assertion. Lemmen et al. [53] demonstrated that blockchain-based automated compliance checks reduced regulatory violations by 50%, while Kshetri and Voas [45] highlighted blockchain's potential to reduce corruption, particularly in developing countries. In Jordan, where regulatory compliance is a persistent challenge, blockchain can play a crucial role in improving adherence to land-use regulations and promoting sustainable land governance. This aligns with Institutional Theory's coercive pressures for compliance and TAM's emphasis on perceived usefulness. By improving compliance, blockchain not only enhances the legitimacy of land registry systems but also contributes to broader sustainability goals, particularly environmental and social sustainability. Hypothesis 5 is therefore supported.

5.1 Implication of the study

The findings of this study on the impact of blockchain technology in land registry systems have significant implications across various domains, including managerial, practical, theoretical, and social aspects. Thus, from the point of view of managerial implications, the findings emphasize the need for a broad understanding of the role and implications of blockchain in land registry environments. For the managers and decision-makers to implement the blockchain, it is necessary to look beyond the technological perspectives of the concepts while addressing the organizational, legal, and user requirements for the land administration departments. Efficiency, security and sustainability have been confirmed to have an excellent positive correlation in the literature, hence the efficiency of blockchain should be a major consideration by managers when deciding where to apply the technology. Moreover, the large-scale effects for regulation underlines the future cooperation between managers and policymakers to adapt the blockchain applications in accordance with legal structures and institutions. From the practical perspective, the study is useful for land registry departments and other government institutions that thought about digital solutions based on blockchain technology. The results indicate the potential implementations for blockchain to concentrate on the reinforcement of security and fraud testing, optimization and integration, and embracing the ideas of transparency and trust. These insights can be helpful for practitioners to develop blockchain solutions and align them with the factors affecting Registry's operations in parallel. Nevertheless, the study also has implications for user experience and accessibility; what practitioners must do is to ensure that users can interfaced with blockchain systems effectively; further, they should develop training programs that would make the use of the technology possible. By improving security, transparency, and efficiency, blockchain addresses longstanding challenges in land administration, contributing to economic growth, social equity, and environmental sustainability. These advancements not only benefit landowners and governmental bodies but also support vulnerable populations by securing property rights and reducing corruption. By bridging the gap between theory and practice, this study offers actionable insights that can guide policymakers and practitioners in leveraging blockchain for sustainable development, ultimately benefiting society at large.

Theoretically, this study contributes to the literature by demonstrating the complementarity of Institutional Theory and TAM in explaining the adoption and impact of blockchain technology in public sector organizations. By showing how institutional pressures and individual-level perceptions jointly influence sustainable development outcomes, we provide a more nuanced understanding of the factors driving technological innovation in land registry systems. This integrated theoretical approach offers a valuable framework for future research on technology adoption in public sector contexts. For practitioners and policymakers, our results highlight the need for a holistic approach to blockchain implementation in land registry systems. The strong influence of security and fraud prevention on sustainable development outcomes underscores the importance of prioritizing these aspects in blockchain implementations. Similarly, the significant impact of regulatory compliance suggests that policymakers should focus on creating supportive regulatory frameworks that enable the effective use of blockchain technology while ensuring alignment with existing institutional norms. The positive effects of transparency, trust, and user experience on sustainable development outcomes emphasize the importance of stakeholder engagement and user-centered design in blockchain projects. This finding supports Benbunan-Fich and Castellanos' [19] call for collaborative efforts in applying blockchain to real estate procedures and extends it by linking these efforts to sustainable development goals. Land registry administrators should prioritize user-friendly interfaces and transparent processes to maximize the potential benefits of blockchain technology. In addressing our initial research questions,

this study provides evidence that blockchain technology, when implemented with consideration for institutional factors and user needs, can significantly contribute to sustainable development in land registry systems. By enhancing security, efficiency, transparency, and accessibility while ensuring regulatory compliance, blockchain has the potential to address longstanding challenges in land administration and drive progress towards sustainability goals.

From a social angle, the findings of the study have a wide application. This paper has examined how blockchain solution have the potential of bringing about positive impacts to property rights and land disputes and overall effects on the economy by increasing transparency in the land registry systems, decreasing cases of fraud and also increasing efficiency. Blockchain technology can play an essential role in enhancing the land governance, resulting into tenure security especially for the vulnerable groups as well as expansion of equitable access to the land resources. Moreover, by using blockchain technologies that improve the level of trust and increase transparency in the case of land management, it is possible to limit corruption, which is very important in strengthening the population's confidence in government bodies. The study also has policy implications. The research evidence indicates that the policymakers should facilitate adoption of blockchain on the land registry systems though setting favourable regulatory operations to the technology while at the same time ensuring that there are adequate measures put in place to mitigate on the possible risks. That there is a direct correlation between compliance to regulations and sustainable development, means that there is need for better and developing regulatory guidelines that will suit the ever-changing technological landscape.

5.2 Limitations and future research

This study offers valuable insights into the impact of blockchain technology on land registry systems and sustainable development. However, it is crucial to acknowledge its limitations and identify areas for future research. A primary limitation of this study is its geographical focus on Jordan. While the findings provide a deep understanding of blockchain's impact in this context, they may not be representative of countries with different legal systems, cultures, and technological landscapes. The unique characteristics of Jordan's land registry system and institutional environment likely influenced the results, which in some cases differed from theoretical predictions. To address this limitation, future research should expand to diverse geographical and institutional contexts. Comparative studies across multiple countries could provide a more comprehensive understanding of blockchain's impact on land registry systems globally. The cross-sectional nature of the data collection represents another limitation. By measuring opinions and attitudes at a single point in time, the study cannot conclusively assess the long-term consequences of blockchain implementation. To overcome this, future research should adopt longitudinal approaches. Such studies could track the evolution of blockchain's impact on sustainable development over time, accounting for technological advancements and increasing user awareness. While the study's reliance on surveyed responses from employees of the Jordanian Department of Lands and Survey provided valuable insider perspectives, it may have introduced inherent biases, such as social desirability bias. Future studies could benefit from incorporating more objective indicators of blockchain adoption results, such as measurable efficiency improvements, error reduction rates, and enhanced land governance indicators. To gain a more comprehensive view of blockchain's impact, future research should extend beyond land registry employees to include other stakeholders in the ecosystem. This could involve property owners, real estate agents, policymakers, and technology experts. Their diverse perspectives would provide a more holistic understanding of blockchain's effects on land administration. The predominantly quantitative focus of this study, while providing robust statistical data, may have overlooked important qualitative aspects of blockchain implementation. Future research could employ mixed-method approaches, combining quantitative analysis with qualitative data collection through interviews or case studies. This would offer a more nuanced understanding of the challenges and benefits associated with blockchain technology in land registry systems. As blockchain technology continues to evolve rapidly, future research should explore emerging dynamics and potential synergies with other technologies. Studies could investigate the integration of blockchain with artificial intelligence or Internet of Things (IoT) in land administration environments. Additionally, researchers should delve into more complex levels of blockchain implementation, addressing specific technical challenges related to scalability and integration with existing land registry systems. To assess the long-term impacts of blockchain on land registry systems, future studies should consider conducting longitudinal research. This approach would allow researchers to track changes over time, providing insights into how the technology's impact evolves as it becomes more established and refined. Finally, future research directions could include exploring blockchain's potential in addressing specific sustainable development goals related to land administration. This might involve examining its role in reducing land disputes, enhancing transparency in property transactions, or improving access to land rights for marginalized groups.

6 Conclusion

This study aimed to investigate the impact of applying smart contracts (blockchain technology) in the Land Registry and Survey Department on achieving sustainable development in Jordan. Specifically, it explored the interaction between the characteristics of blockchain applications and sustainable development indicators. Empirical research was conducted through questionnaires

distributed among employees of the Jordanian Department of Lands and Survey, with data analyzed using the PLS-SEM technique. The analysis revealed positive correlations between factors contributing to sustainable development and various aspects of blockchain implementation. Security and fraud prevention emerged as the most significant variable, indicating its strong potential for driving sustainable development, closely followed by efficiency and automation. Furthermore, regulatory compliance, transparency and trust, and accessibility and user experience were also found to have substantial positive effects on sustainable development outcomes. Using the sociopolitical model, Beck and Beck explained 77% of the annual rates of members' substance use and abuse. The model accounted for 6% of the variance in sustainable development, demonstrating the significant influence of its independent variables. The study's findings also highlighted the potential of blockchain to decentralize land registries and support sustainable development goals. Security and efficiency emerged as key factors in addressing inherent issues within traditional land administration systems. The emphasis on regulatory compliance underscores the importance of aligning blockchain implementations with the legal and institutional environment. This research supports both Institutional Theory and the Technology Acceptance Model as appropriate frameworks for explaining the adoption and outcomes of blockchain technology in farmland registration settings. The evidence suggests that successful implementation requires consideration of technological opportunities and challenges, institutional and regulatory factors, and customer needs. This study demonstrates the necessity of sustainable development through IT utilization, particularly highlighting blockchain's impact on land registry systems. The findings contribute to an insightful model that can guide policymakers, land registry managers, and technology implementers. Blockchain technology offers significant improvements in the effectiveness, security, transparency, and credibility of land registration processes, ultimately contributing to the achievement of sustainable development goals. Although the study focused on Jordan, its implications are applicable to other countries with similar land administration challenges, especially in the developing world. Given ongoing advancements in blockchain, more efficient, transparent, and sustainable land administration practices through its adoption seem both possible and likely.

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Author contributions

The author is responsible for all data contained in the manuscript.

Data availability

Data Availability Statement: All data generated or analyzed during this study are included in this published article and its supplementary information files.

Declarations

Competing interests The authors declare no competing interests.

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Publisher's Note

Maps-Connecting the Past, Present and Future

This paper is an extract from the author's book Mapping: Past, Present and Future

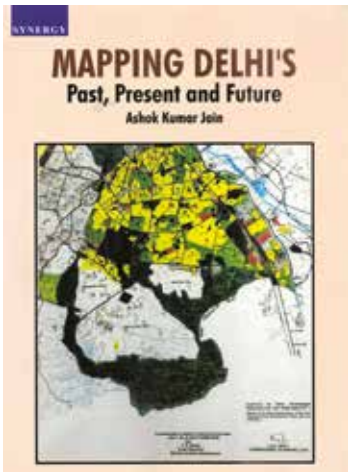
Ashok Kumar Jain
ak. jain6@gmail. com
Worked as Commissioner (Planning), Delhi Development Authority and as a member of the Committee of the Ministry of Housing and Urban Affairs on the DDA (2015). He was a member of UN Habitat (2007-12). He was awarded 2nd Urban Professional Award 2014 at World Urban Forum in Medellin, Colombia and IBC Lifetime Achievement Award (2024), Living Legend (2022) by the Indian Institute of Architects (NC) and the Lifetime Achievement Award by the Smart Habitat Foundation (2022).

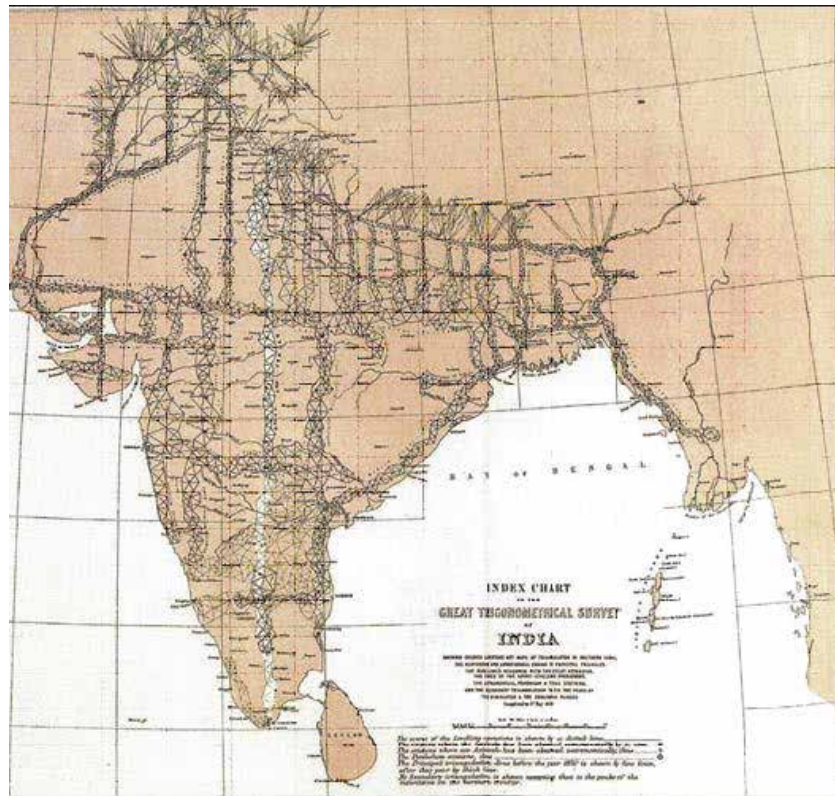
The concept of mapping is shifting from its focus on land, slums, housing, transport, and infrastructure services to environment, ecology, climate change, disasters, health, jobs and heritage. The digital ecosystem and drones have drastically altered the concepts of mapping. The maps are not just the linear depiction of the past and present of but also its future.

Maps, also known as cartography, morphology and pictography, are a tactile form of spatial perception. They connect the past, present and future. They are the language of the surveyors, planners, architects, geographers, etc. Specialized maps include military, transport, railways, shopping, tourist, biodiversity, ecology, hydrology, and various other forms.

The maps can be the basis of discovery of space, co-sharing, co-sensing, presencing, crystallising and generative dialogues in understanding the cross-cultural experiences, and exploring the environment- air, water, landscape and rocks.

A map manifests space and time. Expressed in the form of a drawing, it is multivalent. It can be in the form of a sketch or can be drawn as a plan or a rendering, expressing the geographical features, physical environment, buildings, movement pattern, services and aesthetic





The 1870 Index Chart of the Great Trigonometric Survey of India
***Source*: Wikimedia Commons**

qualities. It can be a vehicle for exploration or an instrument of planning and execution. A map provides an indispensable record of landform, terrain, land and contours, political and administrative boundaries and property ownership.

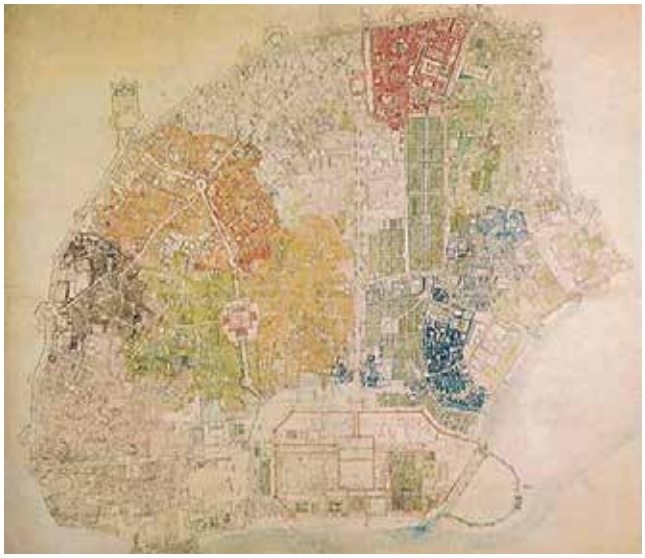


Fig. 2: Map of Shahjahanabad
Source: **Oriental and India Office Collection, Reproduced in Eckart Ehlers and Thomas Krafft (eds) 1993, Shahjahanabad/Old Delhi, Franz Steiner Verlag, Stuttgart**

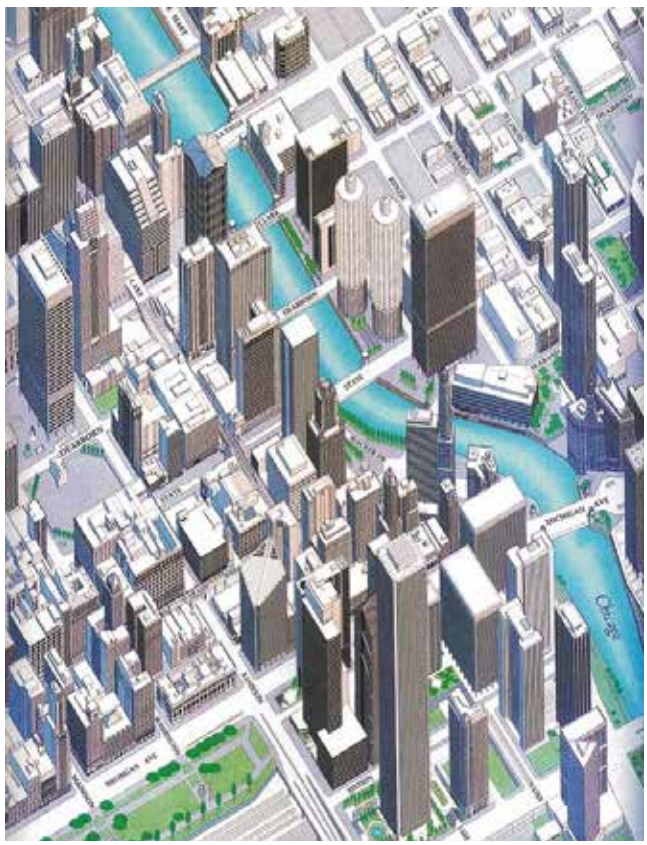


Fig. 3: Map of downtown Chicago drawn in style of Hermann Bollmann
Source: **Clark OE (ed.) Maps that Changed the World, Batsford, London, 2015**

India had been a pioneer and early proponent of surveys and mapping. The Survey of India established in 1767, developed a unique, scientific approach for surveying the entire sub-continent. In appreciation of its efforts, the Himalayas Peak XV in 1865 was named as Mount Everest after the eminent Surveyor General of India George Everest. The Great Trigonometrical Survey of India (1870) established a network of triangulation of the entire subcontinent as the basis for meridional and longitudinal chains of triangles and baselines with the help of Colby apparatus, spirit levels, astronomical pendulum and tidal stations for secondary triangulation of surveys (Fig. 1).

The map of Delhi and its environs drawn by Edward Weller (1857, Oriental and India Office Collection) has been meticulously redrawn by Eckart Ehlers and Thomas Krafft in 1993 (Fig.2). This is one of the most beautiful and detailed maps which has been my guide for unending walks in Shahjahanabad. This map helps to look at the city as the people-their emotions, customs, culture and relationships, much beyond the land use, buildings and legalities. One develops a humane perspective of the city where the ecology, economy, heritage and change co-exist.

The maps of Delhi narrate its rich history and evolution. These include ancient, colonial and Imperial Delhi, Post-Independence Delhi, Rehabilitation Colonies, Master Plans, Zonal Plans, Residential Schemes, Unauthorised Colonies, Resettlement Colonies, Villages, Work Centres, landscape and heritage.

In modern times satellite mapping systems are based on digitization, Geographic Information System (GIS) and Geographic Positioning System (GPS) which also help in tracking the weather, cyclones, floods, rivers, water bodies, geology and biodiversity. Three-dimensional maps have simplified the maps for general users. Hermann Bollmann style of maps are available for many cities all over the world for guidance of the tourists and others (Fig.3).

Geo-referencing and digitization of cadastral maps is being done under the Digital India Land Record Modernisation Programme (DILRMP). As per the Government of India, out of 6,56,793 villages, cadastral maps of 2,31,026 villages have been geo-referenced, and 1,17,38,272 maps have been digitized. In Delhi, land records of 207 villages have been digitized by the GNCTD. The Land and Development Office of the MOHUA have digitized 58,000 properties out of its 65,000 properties (TOI, 12th January 2023)

The Idea of Space and Place

According to Yu-Fu Tuan (Space and People, 1977), space is an abstract term for a complex set of ideas. People of different cultures differ in how they divide up their world, assign values to its parts, and measure them. Man organizes space so that it caters

to his biological and social needs. The map is a combination of space and place which is differentiable into vertical -horizontal, top-bottom, front-back and right-left. The meaning of space often overlaps with that of place. Space is more abstract than place. It is location specific with spatial and visual qualities. These qualities include security, stability, openness, freedom, and coordinative character and a sense of place. Culture is a most significant factor which influences the organization of space and place. Sensory organ-kinesthesia sight, touch, smell greatly enrich our comprehension of the space. By movement a person acquires a sense of direction- forward-backwards, sideways, up and down. The visual space is dependent on flow of activity and other senses, which enrich spatial awareness. Three types of spaces exist- the mythical, pragmatic and abstract. The mythical space is usually based on faith, belief, and tradition, while pragmatic space is defined by economic activities.
The human mind creates abstract spaces which embody their feelings, images and thoughts. The result is sculptural and architectural space composed of places and objects which give it a personality. In India, the cultures and religions have a gigantic influence in mythical mapping of the translucent cosmic world and the pragmatic, astronomical and geographical world. The earliest maps interpreted the Samsara, the cosmos, in the form of sun. moon and the countless rings of seas and continents, with Jambudwipa, Mount Meru at the centre (Fig. 4). To the South of this is the land of Bharatvarsha (India) bounded by the Himalayas and criss-crossed by great rivers. The metaphorical understanding of ancient Indian cosmological tradition is embedded in the concept of coexistence. The depiction of *Bharatvarsha* as *Jambudvipa* in Puranic cosmography manifests the harmonious coexistence i.e. '*Vasudhaiva Kutumbakam*- One Earth, One Family'. The seven-constituent elements of the state represent seven organs (*saptanga*)- (i) king (*swami*), (ii) council of minister (*amatya*), (iii) countryside (*Janapada*), (iv) Fort (*durga*), (v) Treasury (*kosha*), (vi) army (*danda*), and (vii) ally (*mitra*). These join together to bring material well-being (*artha*) and sensual pleasures (*kama*)

The traditional manuscripts are illustrated with the mandala as metaphors of space and place adorned by the sacred gods, goddesses, flora and fauna, seers, pupils, devi-devatas, kings, common people, festivals-games, music-arts, palaces-hutments, etc. (Fig 5). A place achieves a concrete reality through all the senses with an active and reflective mind. It gives a characteristic and symbol making to a place by its setting, topography, skyline, odors and noise.

Some modern architects and planners have experimented with new forms of mapping and drawings, which like antique pictorial maps, display the 3-dimensional spaces on 2 D maps. B.V. Doshi developed this kind of map in his Vidyadhar Nagar Jaipur New Town, which connotes Rajasthani miniature style art (Fig. 6). Morphology and morphogenesis are the terms which are commonly adopted by the surveyors, architects and planners. These terms are rooted in morpho- biology, the study of structure, forms and topography. The geographic approach of mapping divides terrains with territories indicating domains and political controls. However, birds, animals and fish don't know about these lines. The indigenous cultures also challenge such geographic imaginings and view the spaces differently. A classic example is Harry Beck's 1931 map of the London Tube. He ignored the layout of the city, its landmarks, roads, the River Thames and even the cardinal points. Nothing was to scale, stations were spread apart, regardless of the distances between them. The transit lines were colour coded with straight lines that turned only at 45 and 90^0 angles. The stops give a sense of minutes rather than the miles. It was a clear, simple and easy to understand map for everyone. Beck's diagram has become a prototype of metro map around the World, including Delhi, Mumbai, Kolkata and other cities.

The perception of space- whether it is physical, digital, topological, quantum or hyper-requires interactive and cognitive processes by which the onlooker becomes aware of the relative positions of the things around them. The human mind makes sense of space and their relationship with neuroscience, technology and machine learning. These narratives comprise multiple layers of history and visualization. This may lead to a new phase of data poetics that describes the lyrical traces of human memories, such as photographs, maps, documents and sound. The digital age is changing the way we understand and create visual stories in urban space. GPS, Smart Phone Apps, long distance communication and internet have changed the concept of mapping and have vanished the boundaries of geography. Cyber space and new channels of communications have shrunk the world, distances and relationships.

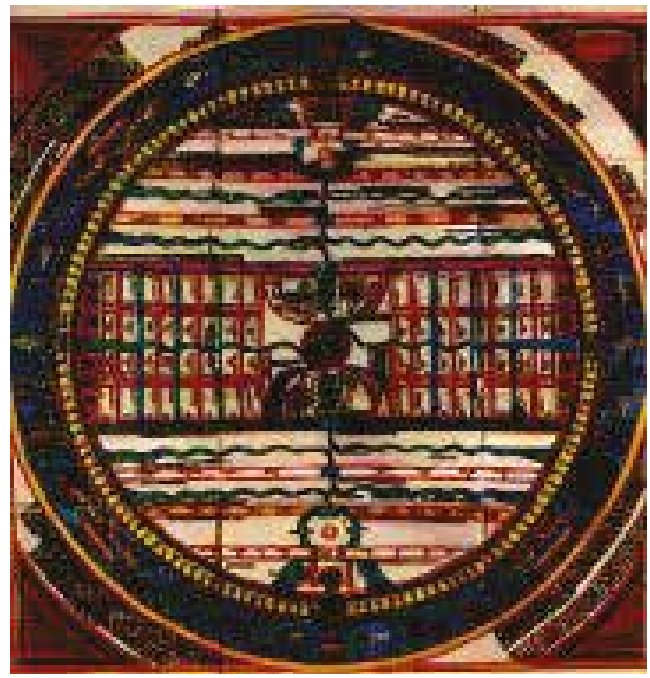


Fig. 4: Jambudweep Cosmological Map, Gujarat 16th Century
Source: **Colette Caillat and Ravi Kumar (1981) The Jain Cosmology, Ravi Kumar Publishers, Basel-Paris, New Delhi**

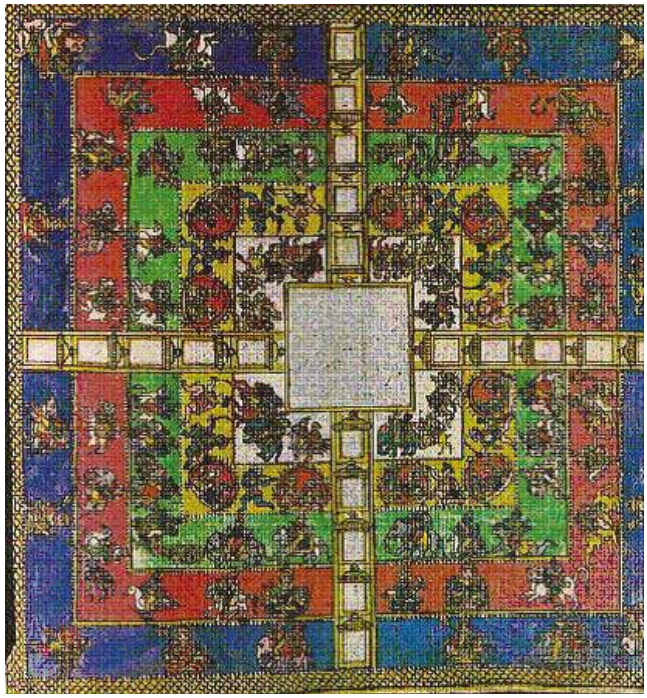


Fig. 5: The Sacred Mandala
Source: **Marg (1983) Vol. XXXVI no. 3, The Iconic and Narrative in Jain Painting**

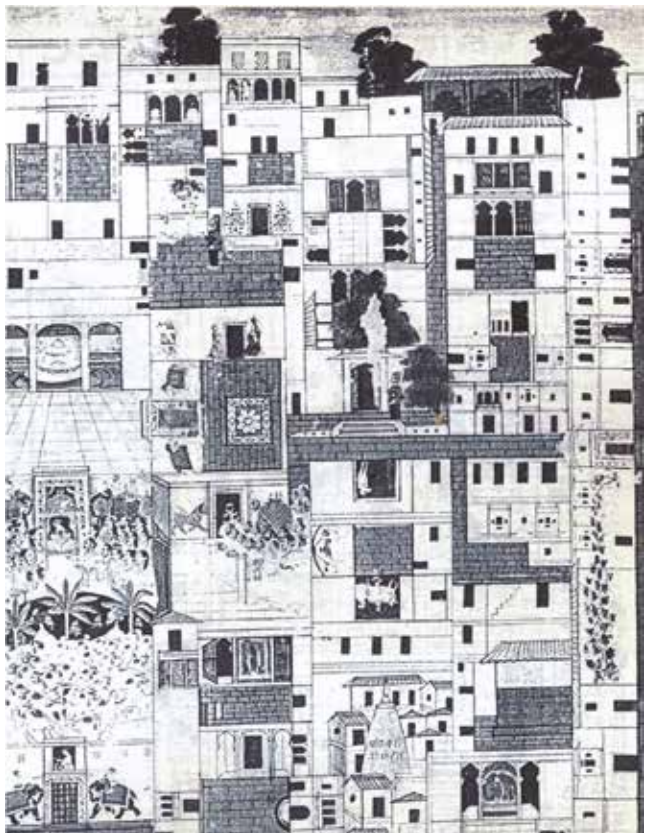


Fig. 6: Architect B.V. Doshi (1986) Vidyadhar Nagar Jaipur New Town, Rajasthani Miniature Style map showing Courtyard Houses
Source: **Curtis, William J. R. Balkrishan Doshi- An Architecture for India, Mapin, Ahmedabad, 1988**

Maps of Delhi

Delhi is an archetypical paradigm which does not adhere to a single tradition. It has been an active laboratory of hybrid cultures. According to Pilar Maria Guerrierie ' *Delhi has played an active role in the complex process of hybridisation in both the pre and post-independence periods, developing its own character as oppose to nearly accepting what was brought from abroad. Both periods have been characterised by a resilience and continuing compromise between indigenous and foreign elements'.*

A prolific legacy of maps, drawings, lithographs and pictures of Delhi are available from different sources. One of the earliest of them is the Gentil Album (after Jean Baptiste Gentil, 1726-1799) of Palais Indiens (1774) at the Bibliotheque Nationale, Paris. (Fig. 7).

Daniel's aquatints of Delhi (1795) have been extensively published. The works of Delhi artists during 1830- 55 who worked for Thomas Theophilus Metcalfe, James Skinner and William Fraser provide interesting glimpses of Delhi. 1836-1846 had been a golden period during which Mazhar Khan painted most detailed views of Delhi, which are with the British Library, London.

In 1846-47 East India Company in collaboration with the Survey of India produced maps of Shahjahanabad. Syed Ahmed Khan's Asar al Sanadid (1852) provides a detailed record of Delhi's monuments. During 1865 to 1875 French artist Louis Rousselet produced the Inde des Rajahs which had beautiful views of Chandni Chowk, Tughlakabad, Kotwali in Chandni Chowk, Qutab Minar, etc. The privileged relationship between the French and the Mughals started during the reign of Jahangir (1606-28) with Augustine-de Bourdeux and Thomas Roe. It was followed by Bernier, Tavernier, Law de Lauriston, Madec, Jacquemont and Rousselet. They were great collectors of paintings, maps and drawings revealing the culture, geography, and morphology of their times.

During 1873, 1877 and 1913, the Survey of India published up to date maps of Delhi (Fig.8). In 1858 Felice Beato photographed Delhi, which recorded its unique charm. 1911 onwards the Wilson Survey of Old Delhi recorded its detailed morphology. During 1916-19 Zafar Hasan sketched the significant historical buildings and monuments of Delhi. During 1912-31 thousand of drawings,

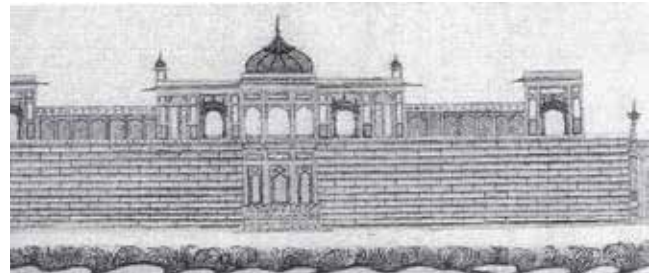


Fig. 7: Red Fort (Royal Palace) Drawn in 1774 by Wazir Shuja-ud Daula
Source: **Bibliotheque Nationale de Francec, La Font Jean Marie and Rehana Lafont, 2010, The French and Delhi, Agra, Aligarh and Sardana, India Research Press, New Delhi**

surveys and designs for Imperial Delhi were prepared by Edwin Lutyens, Herbert Baker, T R Russel, Shoosmith and various other architects, most of which are preserved by the Central PWD, New Delhi. The records of Delhi Improvement Trust (1937-57) were held by its successor Delhi Development Authority, some of which were transferred to the Municipal Corporation of Delhi. Town and Country Planning Organisation is another repository of drawings, such as Wilson Survay and many other survey maps of Delhi for preparation of Delhi Master Plan.

Besides government organisations-National Archives, SOI, ASI, TCPO, CPWD, L&B Department of GNCTD, Land and Development Office (MHOUA), DDA, NDMC and MCD, a rich tranche of maps, drawings and visuals of Delhi are available with the Alkazi Collection, Getty Images, INTACH, Eicher (Maps of Delhi), private surveyors and photographers, individuals and publishers. Notable among these are the Maps of Delhi (Guerrieri, 2017, Niyogi), Maps of India (Lahri, 2012, Niyogi). All these maps are valuable resources which need to be preserved, digitized and published for posterity.

Apart from field surveying, maps are now available through internet, satellite, geographic information system and aerial photography. New technologies are emerging which also map hidden/ underground information (like service lines, minerals,

Fig. 8: Delhi and its Environs based on Survey of India Map (1877)

geology, sub-soil water, temperature, etc.). These have greatly enhanced understanding of the physical realities of the world and help in making the proposals for planning and development.

Diagrams of Historical Geography

Stephen Legg in his book Spaces of Colonialism, (Blackwell, Oxford, 2007) provides a detailed analysis of the historical geography of colonial Delhi. He combined empirical analysis and mapping with the diagrams of the biopolitical Delhi. He refers to Faucault (1978) term 'governmentality', which is an intersection of power, analytics and govermentalisation that seeks to regulate the population, development and urban form.

According to Stephen Legg, New Delhi marked the emergence of the two complimentary but different forms of hierarchy: Spatial and Social. The physical grid also defined the norms of bungalow size, plot size, street amenities, design/elevation and maintenance. While the focus was on the new city, the Old City was not ignored. Viceroy Harding in his address to the Delhi Municipal Committee (DMC) on 23rd December 1912 stated '*you must become a Capital city, not in name, but in fact; you must make your town a model of municipal administration, your institutions, your public buildings, your sanitation must be an example to the rest of India. To attain these results will demand on your part much sustained efforts, and the cultivation of a high sense of public duty. I can promise that the Government of India will be prepared to sustain you in those efforts by every means in its power. We shall not forget when building a New Delhi outside your walls, that there exists an Old Delhi besides us which claims our interest and our assistance.'*

Geoffrey de Montmorency, who was responsible for the capital transfer program, addressed the question of Delhi's expansion in 1912.The Deputy Commissioner Lt. Colonel Montagu William Douglas in 1913 also wrote to the Chief Commissioner about increasing pressure on Delhi. He pleaded that an Improvement Trust must be created in Delhi. He prepared a report for acquisition of land for Imperial Delhi where he also proposed acquisition of land for New Cantonment, Western Extension, South Extension and North Extension. These lands were utilized for various decongestion schemes of Old City even before the creation of the Delhi Improvement Trust (1937) and for refugees' townships and many other schemes undertaken after Independence in 1947.

Mandala- The Morphology of Indian City

The traditional maps were based on the vedic knowledge as contained in the canons of Vastushashtra and Mansara, the treatise on town planning and architecture. As a basic principle, a city manifests a micro-cosm within the broad cosmic cycle, like the planets in the astrological chart. A system of ashtha (8), Navgrah (9 planets), 24 matrika pithas, etc. was devised as a numerical symbolism and for orientation and linkages of the settlement system.

The five elements of nature were also signified by the settlement system. It was perhaps this that the five cities namely, Indraprastha, Bagpat, Panipat, Sonipat and Tilpat signified the 5 elements of nature, viz. air, earth/vegetation, water, fire and space. The form of a city was derived on the principle of Vãstupurush Mandal. It established an interrelationship of physical form of a settlement with the spiritual, cosmic behavioural system. It determines the basic form, its location and orientation of various functions in a settlement. As in music, the basic principles can create an infinite range of compositions, likewise the principles of Mansara can be applied to innumerable forms of a settlement. There is nothing such as an ideal city or an ideal music composition.

The settlements usually had a coherent and balanced set of forces, whether its location, zoning and functional classification. It is thus not a surprise that the mandala form of the Indraprastha,

Fig. 9: The Purana Qila excavations established the existence of settllement from Late Harappan to Medieval period covering about 2500 years of history.
Source: **ASI/INTACH-Delhi a Living Heritage, 2010**

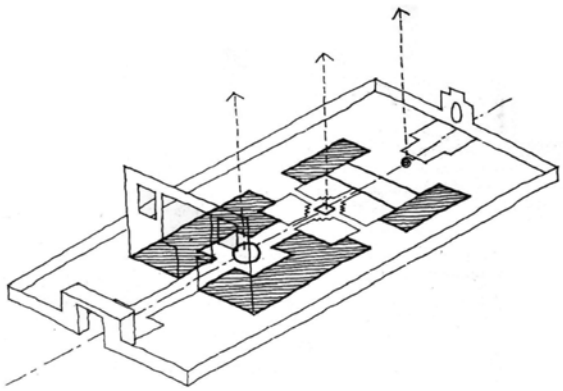


Fig. 10: British Council and Library, New Delhi-the ritualistic pathways, Architect Charles Correa
Source: **Charles Correa and Kenneth Frampton, Charles Correa, Perennial Press, 1996**

and Shahjahanabad coincide with the Vedic principles. The excavations of the Purana Qila have yielded painted grey earthenware which dates to 1000 BC (Fig. 9). The village of Indrapat, which is derived from Indraprastha can be identified in the Survey of India Maps of Delhi, which was cleared along with other villages during the building of New Delhi (1912-20).

It is quite amazing that the Imperial Delhi planned by Edwin Lutyens was located on the western bank of the River Yamuna, like Indraprastha and Shahjahanabad. The Viceroy house (Palace Complex) had been sited on top of the Raisina hill, overlooking the river Yamuna. It is facing the east, so as to get cool breeze and morning glory of rising sun. Two major roads, namely Kingsway (Rajpath) and Queensway (Janpath), provide major linkages to various functions. At the crossing of these two roads, socio-cultural institutions were located, which is the Brahmasthan in the Vãstupurush Mandal. Lutyens' New Delhi is perhaps an unintended revival of the Indo-Roman heritage of city design. The principles of Mandala have again reappeared in some landmark projects, such as the British Council Library Building in New Delhi (Fig. 10).

Urban Mapping for Planning

A map can be defined as representation of earth's pattern as a whole or part on a plane surface with conventional signs, drawn to a scale and projections so that it corresponds to the actual terrestrial position. The survey maps (Survey of India, NRSA, Satellites, Google Earth, Total Station Surveys, Theodolite Plane Table, Drone, etc.) form the basis of planning. The urban maps not only reflect the existing surveys, but also indicate land use, status of ownership, roads and services, status of encroachments and administrative domain. These have a legal status which provides evidence of land ownership, land use, unauthorised construction, etc. This is particularly crucial in view of the court cases against the encroachments, unauthorised construction and non-conforming land use or their regularisation policies.

The urban maps are superimposed with ground surveys, administrative/ revenue maps, land ownership, satellite imageries and other surveys, such as environmental, groundwater, etc. These maps are enlarged or reduced to enable superimposing variety of land information on the same scale (preferably 1:4000, which corresponds to revenue maps 1″ = 330 feet). These provide the base maps and spatial information required for planning of the land , zoning, land use, parks/open spaces, transportation networks, infrastructure services, housing, slum rehabilitation, etc.

The scale of map depends upon the size of the planning area and the coverage and extent of the information to be shown. The scale of maps for different types of planning exercise at various levels can be selected as per the details required for planning. For planning purpose, a map will have the following characteristics:

- **Geometry, positioning and height:** The geometry of a map is achieved through a set of ground control points, called stations and levelling Benchmarks (BMs). These stations may have the utmost accuracy of a geodetic station. BMs are, presently, being provided by the Survey of India (SOI). The position of these stations is given in the form of coordinates expressed in terms of latitude and longitude. In most of the cases, accurate information about the stations and the BM's is restricted.
- **Contents of a map:** The earlier technology of the ground-based methods (plane tabling, etc) has been replaced by the aerial photography(photogrammetry) and satellite imagery. The resolution of the modern-day satellites has reached a level of one metre. This enables the map to be high-resolution with better details.
- **Updating the map:** The satellite imagery is of great help in updating the maps as the satellite visits the same spot at regular intervals.
- **Scale:** The scale of a map can be chosen according to its purpose, which may vary from 1:50,000 (regional/district/urban plans) to 1:100 (architectural drawings).
- **Size of the Map** The size of the map is largely influenced by statutory requirements of the plan. However, availability of infrastructure for mapping also influences the decision of map size. To standardise the size of the maps, Bureau of Indian Standards (BIS) has issued the guidelines.

Future of Mapping

The power of maps is depicted by spatial manifestation that transcends architectural form, materiality and urban order or disorder, overlaying the terra nullius. The mapping is undergoing a radical transition with new forms of technological, geographical, social, economic and ecological associations.

Recently, we have witnessed the wars in Middle East, Iran and Israel, Ukraine and Russia as the drones have emerged the most fatal ammunition, where making the aircrafts redundant. Likewise, drones have revolutionised surveying and mapping, which are rapid, economical and easier to use (Fig. 11). These are replacing conventional mapping and allow dynamic, real-time interactions among the users.

Artificial Intelligence (AI) powered maps and toolbox help to compute and analyse the data in real-time for planning, implementation and coordination. This is leading to a new phase of mapping that celebrates the human memories, photographs, documents and information in creating the future urban space.

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Fig.11: Drones enable GIS/GPS based maps for 3-D and 4-D planning
Source: **https://www.digitalcameraworld.com/buying-guides/the-10-best-camera-drones**

Rocket Lab launches private Japanese 'Strix' satellite

Rocket Lab launched an Earth-observing radar satellite for the Japanese company Synspective on March 20. An Electron rocket topped with one of Synspective's Strix satellites lifted off from Rocket Lab's New Zealand site on Friday at 2:10 p.m. EDT (1810 GMT; 7:10 a.m. on March 21 local New Zealand time), on a mission called "Eight Days a Week." This launch is the eighth that Rocket Lab has conducted for Synspective, which helps explain the mission name. *www.space.com*

China puts satellites into space via Smart Dragon 3 rocket

China placed 10 satellites into orbit with the launch of a Smart Dragon 3 carrier rocket from off the coast of Haiyang in Shandong province on March 22, 2026.

The Smart Dragon 3 is a solid-propellant rocket model with a height of 31 meters and a diameter of 2.65 meters. It can carry a liftoff weight of 140 metric tons. The rocket is capable of sending multiple satellites with a combined weight of 1.5 tons to a typical sun-synchronous orbit at an altitude of 500 kilometers. *www.chinadaily.com.cn*

Aditya-L1 mission invites proposals for second AO observation cycle

The Aditya-L1 Mission marks a major milestone in India's space science programme, enabling continuous and comprehensive observations of the Sun from the Sun–Earth L1 point. Scientific data from the mission are regularly released in public domain for global scientific utilization. At present there are more than 27 TB data in public domain and several important scientific results have been published in International peer reviewed journals. To further maximize the scientific return from this unique mission, the Indian Space Research Organisation (ISRO) has released the second Announcement of Opportunity (AO) inviting proposals from the Indian solar physics community for Aditya-L1 observation time. *www.isro.gov.in*

UAE charts ambitious five-year space roadmap

The UAE will safeguard its achievements and emerge stronger, with all sectors working in lockstep to deliver on a national pledge to the world, according to Vice President and Prime Minister of the UAE. He underscored the country's resilience and institutional strength amid evolving challenges.

Recently, the Cabinet approved the UAE's five-year space sector strategy, as the country accelerates its ambitions in the field. The sector is now valued at more than Dh44 billion and includes over 170 scientific, national and economic entities," Sheikh Mohammed continued.

The UAE has developed and launched 30 satellites, established a national astronaut programme, and carried out a scientific mission to Mars, with a new mission planned to Venus and the asteroid belt. *gulfnews.com*

G20 satellite set for 2027 launch

ISRO Chairman V Narayanan said that the G20 satellite, designed to study climate, air pollution and monitor weather, is expected to be launched in 2027. According to Dr Narayanan, India is the first country to succeed in placing 104 satellites, more than 100 satellites using a single rocket without any collision. The ISRO chief further said a lot of commercial missions were carried out, including 433 satellites of 34 countries, and the heaviest satellite lifted from India was again a commercial satellite. He said ISRO is working towards sending a human to the moon by 2040. *theprint.in*

Ethiopia and Japan strengthen space business collaboration

Ethiopia has taken a significant step toward developing its commercial space sector following the signing of a MoU between the Ethiopian Space Science Society (ESSS) and Japan's space business platform Cross U.

The agreement formalises cooperation between the two institutions to accelerate the growth of Ethiopia's space technology ecosystem and promote space-based business initiatives through international collaboration.

The collaboration outlines key areas of focus, including identifying market-driven use cases for satellite data solutions, supporting the incubation of space startups, and strengthening human capital development through training, internships, and research partnerships. *techreviewafrica.com*

Updated GNSS Interference Resource Guide

The U.S. Federal Aviation Administration (FAA) has updated its GNSS Interference Resource Guide with updated information on GNSS vulnerabilities and general edits throughout. The FAA's Flight Technologies and Procedures Division (AFS-400) developed the guide to provide U.S. operators and pilots with the most current information regarding GPS and GNSS jamming and spoofing. It can be downloaded at *www.faa.gov*

South Korea funds to boost private space sector

The Korea AeroSpace Administration (KASA) has increased the size of its New Space Fund, which supports private sector-led space development, by 25 times in just one year. By drastically expanding the fund from ₩8.1 billion to ₩200 billion and pursuing the creation of a global fund for the first time, KASA is reshaping the domestic aerospace investment ecosystem.

KASA announced recently that it has officially begun the process of selecting a professional fund manager with the goal of establishing the ₩200 billion 4th New Space Fund by September this year, aiming to foster leading companies to spearhead the 'K-aerospace' era. *www.dongascience.com*

EASA and EUROCONTROL publish joint Action Plan

The European Union Aviation Safety Agency (EASA) and EUROCONTROL published a joint Action Plan designed to strengthen the safety and resilience of European aviation operations amid the growing challenge of GNSS interference.

Key Elements of the Joint Action Plan

Through joint monitoring and data-sharing, EASA and EUROCONTROL aim to establish a common, validated operational picture of GNSS interference events across Europe, enabling more accurate detection, reporting and situational awareness.
Both the organisations will deepen their understanding of interference patterns, operational impacts and associated safety risks, with the aim of delivering consistent and harmonised guidance to air navigation service providers (ANSPs), airlines, and national authorities to ensure rapid and aligned responses to interference incidents.

Both the organisations will develop updated operational guidance for flight crews and air traffic controllers to help them manage disruptions effectively and maintain safe operations in degraded navigation environments and join forces and expertise for investigations into ongoing GNSS interference. Both will also promote improved mechanisms for timely information exchange through Member States, ensuring that events with both civil and military dimensions are addressed in a coordinated and transparent manner to minimise disruption and preserve airspace capacity.

The Action Plan envisages close collaboration with A/C manufacturer and avionics industry to support the development of more robust, interferenceresilient avionics solutions over the longer term.
It addresses the concerns expressed in a letter sent on June 6, 2025 by 13 EU Member States to the European Commission that called for immediate and coordinated European action to address the growing number of Radio Frequency Interference (RFI) events affecting GNSSbased systems. The Action Plan also integrates proposals and guidance from international partners including the International Civil Aviation Organization (ICAO), and the International Air Transport Association (IATA). *www.easa.europa.eu*

ESA's Celeste broadcasts first navigation signal

On April, 8 ESA and industrial teams gathered at ESA's Navigation Lab at ESTEC received the very first navigation signal from the Celeste mission. This is a historic first in the world of European PNT. Sent from Celeste IOD-1, the signal is the first dual-frequency navigation message in the L- and S-band, the first sent from a European satellite in low-Earth orbit. A transmission from the Celeste IOD-2 satellite will follow in the coming days.

Navigation signals sent from low Earth orbit benefit from more strength, new dynamics and additional ranging geometry. This makes them valuable to complement existing medium Earth orbit systems and improve overall resilience, robustness, availability, and timeliness, especially in demanding environments like deep urban areas.

This first achievement comes as part of the satellites' commissioning and in-orbit testing phase. Early April, days after their launch on March 28, the satellites completed their launch and early operations phase and were formally declared fit for life in orbit. The satellites are now ongoing checks to verify all vital subsystems, from propulsion to attitude and orbit control, are ready.

These signal transmissions are also contributing to bringing into use the required frequency filings in L- and S-bands for future operational European LEO-PNT missions, together with meeting other regulatory and compatibility commitments in accordance with International Telecommunication Union regulations. *www.esa.int*

Survey to determine highest mountain peak begins

Survey of Bangladesh has taken initiative to determine the country's highest peak. It will conduct survey in the Ruma and Thanchi upazilas of Bandarban district. The survey conducted using modern geodetic methods and advanced GNSS technology. International standards to determine the height of the country's highest peak above mean sea level (MSL) were followed. Through the use of a newly developed Geoid Model, it will be possible to accurately convert ellipsoid heights obtained from GNSS receivers into mean sea level (MSL) elevations of the mountain peaks. *www.dhakatribune.com*

Busan extends Digital Twin partnership with LX

Busan Metropolitan City is extending its partnership with Korea Land and Geospatial Informatix Corporation (LX) by three years to strengthen its digital twin-based urban management capabilities. The city plans to accelerate digital transformation across administrative and citizen services based on pilot project outcomes. Based on the existing agreement, both organizations successfully won the 2024 "Digital Twin Pilot Zone Development" public competition. The administrative and public service platforms currently operate on LX's cloud servers. Busan plans to use Busanjin-gu, the pilot zone, as a hub to expand digital twin technology across the entire city.

The city also strengthened the public nature of its platforms. Busan registered trademark usage rights for its citizen-facing platform "1365 Twin," blocking commercial use and clarifying its status as a public service. Busan plans to improve user manuals and case studies to increase citizen accessibility and expand its digital twin-based safety service model nationwide. *https://en.sedaily.com*

FSI stalls AI-based alerts on deforestation to States

The Forest Survey of India (FSI), which is responsible for the assessment and

monitoring of the country's forest cover, has not issued fortnightly alerts to States on deforestation activities since October 2025 and no data has been updated since then, according to the Anavaran-Deforestation Alert System portal. Since January 2024, the portal has been functioning by combining satellite imagery and machine-learning techniques to help FSI detect changes in forest cover. FSI used to send location-specific alerts to State authorities every 15 days about areas where forest cover may have declined, allowing officials to conduct focused on-ground inspections in those locations. *https://dailypioneer.com*

Marine Spatial Planning framework launched in Puducherry, India

Puducherry has launched the country's first Marine Spatial Planning (MSP) framework as part of a pact under the Indo-Norway Integrated Ocean Initiative, to balance growth alongside sustainable management of ocean resources and coastal environment preservation.

Puducherry and Lakshadweep were chosen as coastlines to pilot the MSP initiative that grew out of a 2019 memorandum of understanding that envisaged India and Norway collaborating on implementing MSP in the oceanic space. The beta version of the MSP for the Union Territory was put together in a collaborative exercise involving the Norwegian Environment Agency, the Ministry of Earth Sciences, the National Centre for Coastal Research (NCCR), the National Centre for Sustainable Coastal Management, the Puducherry Coastal Zone Management Authority and Department of Science, Technology and Environment, Puducherry.

According to Lt. Governor, there was no scientific mapping that showed that roughly 50 per cent of Puducherry's 42 km coastline was vulnerable to moderate to severe sea erosion. She further hoped for continued Norwegian support for the MSP-guided development of a "blue economy" in Puducherry, which had marine resources and a significant fishers community. *www.nccr.gov.in*

Septentrio extends its boxed receiver range with AsteRx EB

Septentrio announces a new enclosed multi-frequency GNSS receiver: AsteRx EB. Its IP67 enclosure protects the receiver from harsh weather conditions, while built-in advanced GNSS+ algorithms ensure reliable operation in environments that are challenging for GNSS, such as areas with foliage or near GNSS interference sources. The RAIM+ integrity monitoring system ensures truthful positioning, which is essential for autonomous navigation. *www.septentrio.com*

Infleqtion delivers quantum precision timing

Infleqtion has announced availability of the first quantum-enabled precision timing solution delivered as part of the company's partnership with Safran Electronics & Defense. The new solution includes Infleqtion's Tiqker™ quantum optical clock, which has been integrated and validated with Safran's White Rabbit and SecureSync® systems. Modern systems depend on technologies such as GPS or GNSS for precise timing, but these are vulnerable to jamming, spoofing, and natural disruption. As threats to traditional timing infrastructure grow, the need for resilient, independent alternatives has become critical. *infleqtion.com*

Net Insight leads development of next-generation PNT technology

Net Insight has been awarded a development project through the European Space Agency's Navigation Innovation and Support Program (NAVISP), a European program designed to foster innovation in the PNT domain and strengthen Europe's technological competitiveness. This project is supported by co-funding from the Swedish National Space Agency, aimed at accelerating the development of robust Positioning, Navigation and Timing (PNT) technology, to address growing societal needs and increasing risks to critical infrastructure.

Through collaboration with the Swedish National Space Agency and ESA's NAVISP program, the project gains access to both national and European funding and support for research and development in PNT technology. At the same time, it enables national initiatives to be aligned with broader European strategies for robust and operationally reliable PNT architectures. NAVISP is designed to stimulate new technologies and applications beyond traditional GNSS- based systems and plays a key role in Europe's efforts to ensure robust and competitive PNT solutions. *www.netinsight.net*

SparkPNT releases RTK GNSS platform

SparkPNT Facet FP is a high-precision GNSS receiver designed to deliver cm-level accuracy with a focus on long-term flexibility, ease of use, and open-source innovation. It combines multi-band, multi-constellation GNSS support with fully open-source firmware — giving users a platform that can adapt as technologies continue to advance. *www.sparkfun.com*

FXP30x and PC30x series antennas

Taoglas is now offering the FXP30x and PC30x series of high-performance embedded combination antennas, a new family of compact antennas designed to support GNSS, cellular and Wi-Fi connectivity for space-constrained electronic devices. Both series enable engineers to integrate multiple wireless technologies within a single antenna, reducing device component count while simplifying device design, speeding up assembly times and accelerating time to market. *www.taoglas.com*

Thales launches the TopStar Smart Receiver

Thales has launched the TopStar Smart Receiver, a three-in-one ultra-compact solution designed to provide land forces with resilient positioning, navigation and timing capabilities, while maintaining radio communications

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www.eurogeography.eu

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https://gistam.scitevents.org

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https://fig2026.org

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https://geotechnicalinnovationconference.com

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

in increasingly contested electronic warfare environments. The TopStar Smart Receiver can be integrated into land vehicles, drones and munitions.

Juniper Spire GNSS receiver

The Juniper Spire is designed to simplify location data collection. Built for rugged environments and long workdays, it offers seamless integration with mobile devices and data collection apps, making it a reliable companion for all GIS and asset mapping applications.

It is designed for work in both remote areas and urban settings, and supports SBAS, Network RTK, and future correction services. *junipersys.com*

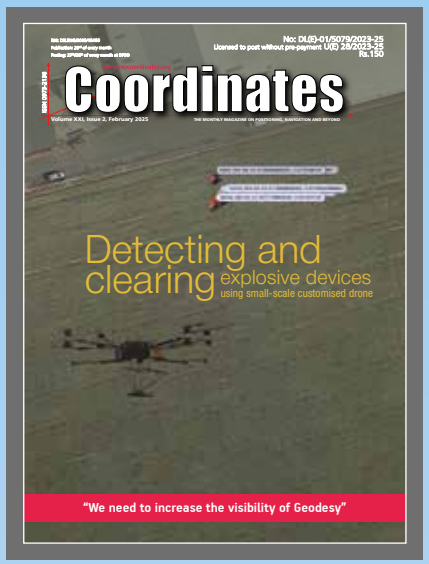
VectorNav introduces high-G capability across tactical IMU

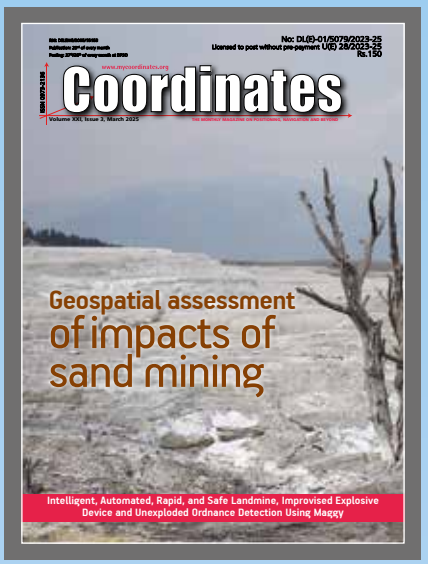
VectorNav Technologies has announced 95G and 250G accelerometer and 4000°/sec gyroscope ranges across its Tactical Series inertial measurement unit (IMU) and inertial navigation system (INS) product line. The enhancement directly addresses urgent requirements from defense contractors and platform developers operating in high-G mission profiles. *www.vectornav.com*

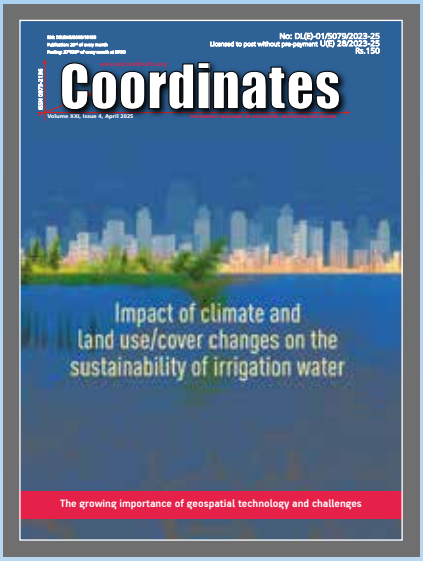
Rohde & Schwarz enables Xona Pulsar signal simulation

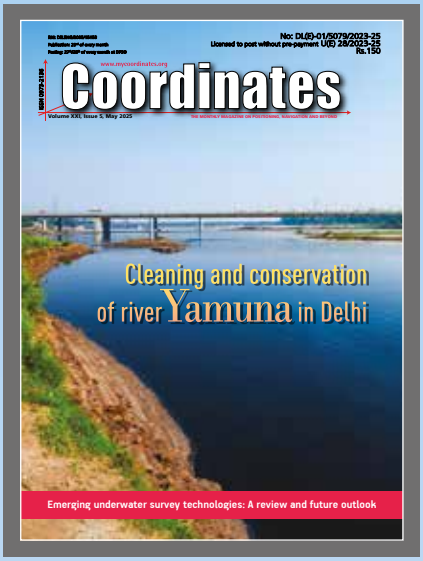
Rohde & Schwarz is providing signal simulation capabilities supporting Pulsar, the satnav service by Xona. The new functionality enables manufacturers to test Pulsar capabilities in production settings using Rohde & Schwarz signal generators, providing an accessible pathway for validating and scaling devices with next-generation positioning, navigation and timing (PNT).

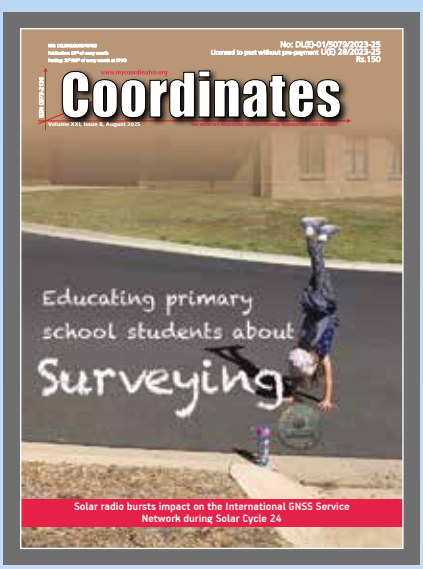
Xona's Pulsar constellation, operating in low Earth orbit (LEO), is designed to complement existing GNSS infrastructure such as GPS by delivering stronger signals, improved accuracy, and enhanced resilience against threats and interference. *www.xonaspace.com*

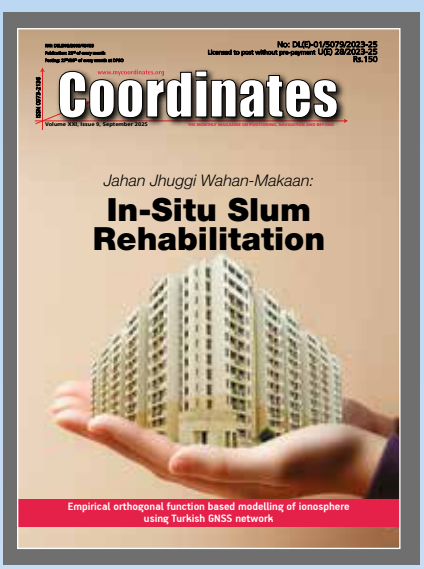












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