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Enhancing the Efficiency of Digital Land Administration for Sustainable Territorial Development in Kazakhstan's Small Settlements

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ABSTRACT

Digital land administration can support sustainable territorial development, but its potential benefits depend on local institutional capacity, infrastructure, data quality, and workforce competence. This study examined the status of land-administration digitalization in small settlements in Kazakhstan and explored experts' perceptions of its relationship with selected Sustainable Development Goals (SDGs). A mixed-methods design combined an expert questionnaire (n = 45) with four focus groups (n = 36). Quantitative data were summarized descriptively, and Spearman rank correlations were calculated using 35 complete questionnaires. Focus-group transcripts were analyzed thematically. Electronic cadastral systems (mean = 3.71) and geographic information systems (GIS; mean = 3.62) received the highest adoption ratings, whereas blockchain technologies (mean = 1.84) and digital twins (mean = 1.76) received the lowest. Higher perceived GIS adoption was strongly associated with higher perceived contribution to SDG 11 (Spearman's r = 0.78). In comparison, higher perceived remote-sensing adoption was strongly associated with higher perceived contribution to SDG 15 (Spearman's r = 0.82). The thematic analysis identified institutional, technological, socioeconomic, and informational barriers, with regulatory constraints (86.1%), shortages of qualified personnel (83.3%), and inadequate digital infrastructure (80.6%) reported most frequently. These associations reflect expert perceptions and do not establish causal effects of digitalization on SDG performance. The findings support a phased digitalization strategy for Kazakhstan's small settlements, prioritizing interoperable cadastral data, GIS, remote sensing, workforce development, and institutional coordination before broader deployment of less mature technologies.

Keywords: *Geographic information systems, Digital cadastre, Remote sensing, Land administration, Small settlements, Sustainable development, Kazakhstan*

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INTRODUCTION

Digitalization is increasingly incorporated into strategies for implementing the Sustainable Development Goals (SDGs), although progress remains uneven across goals and territories (Carlsen & Bruggemann, 2022). In land administration, digital systems can improve the availability, integration, and analysis of spatial and administrative data, thereby supporting more transparent and environmentally informed decisions (Mondejar *et al*., 2021). Geospatial technologies are now used in spatial planning, land-cover assessment, cadastral modernization, and land-resource monitoring (de Vries, 2021). Their adoption, however, depends on local institutional and technical capacity. Evidence from local-government digital transformation shows that infrastructure, skills, leadership, and organizational coordination jointly shape implementation (Kabwe *et al*., 2024; Huy *et al*., 2025). At the same time, internet penetration remains a basic enabling condition for digital participation and economic development in rural and agricultural settings (Ilham *et al*., 2025).

These constraints are particularly relevant in Kazakhstan, where large distances, heterogeneous settlement patterns, and uneven administrative capacity complicate the creation of a nationally coherent land-information environment. National land reports document the scale and diversity of thecountry's land resources (Committee for Land Resources Management, Ministry of Agriculture of the Republic of Kazakhstan, 2024). Studies of peri-urban land-cover change demonstrate the need for reliable spatial monitoring (Alipbeki *et al*., 2020). At the same time, research on agricultural information systems and GIS-based arable-land management indicates that digital tools are already contributing to land-data organization and decision support in Kazakhstan (Imanbayeva *et al*., 2024; Tuleyeva *et al*., 2024). The central policy problem is therefore not whether digital technologies are relevant, but how to implement them equitably and effectively in small settlements with limited resources.

Land-administration digitalization is also a governance reform. Electronic records, interoperable databases, and open access can improve traceability and service delivery, but they may also reproduce exclusion when connectivity, data protection, procedural safeguards, or public access are inadequate. Digitalization must therefore be aligned with legal and institutional arrangements, particularly those related to transparency, access to information, and the rule of law (Meskic *et al*., 2022; Do, 2025). Technology adoption alone cannot compensate for fragmented mandates, weak data standards, or limited local implementation capacity.

This study focuses on four SDGs directly relevant to the investigated land-administration functions: SDG 9 (industry, innovation, and infrastructure), SDG 11 (sustainable cities and communities), SDG 15 (life on land), and SDG 16 (peace, justice, and strong institutions).The analysis treats these relationships as expert perceptions of potential contributions rather than as observed changes in national or municipal SDG indicators. This distinction is essential because the cross-sectional design cannot demonstrate that technology adoption caused progress toward any SDG.

Despite growing scholarship on digital land governance,relatively little empirical research has examined technology maturity, implementation barriers, and perceived sustainability contributions within a single framework tailored to small settlements. The present study addresses this gap by evaluating the current adoption of selected technologies, examining associations between expert ratings of adoption and perceived SDG contribution, identifying implementation barriers, and formulating context-sensitive priorities for Kazakhstan.

Literature review

International experience shows that the functions and constraints of digital land management vary by territorial context. In Africa, digital platforms have supported urban planning, climate adaptation, and agricultural services, but their diffusion remains constrained by connectivity, finance, and institutional capacity (Balogun *et al*., 2022). GIS and remote sensing can create inventories and monitor land-cover change (Mustafayeva *et al*., 2024), while cloud-based processing can reduce the local computing burden associated with large Earth-observation datasets (Barboza *et al*., 2024). In agricultural landscapes, digital monitoring is also relevant to water-use planning (Ahmed *et al*., 2022) and erosion assessment (Yildirim & Tufekcioglu, 2024). Studies from Kazakhstan demonstrate the operational potential of unmanned aerial vehicles for monitoring rangelands (Janteliyev *et al*., 2022) and modern surveying technologies for cadastral and land-management tasks (Sagandykova *et al*., 2024).

Effective digital land administration requires more than isolated applications. The Land Administration Domain Model provides a standardized conceptual basis for structuring rights, restrictions, responsibilities, parties, and spatial units; its application in Pakistan illustrates how a country profile can support cadastral modernization (Ahsan *et al*., 2024). Research in Kenya similarly emphasizes data exchange and interoperability across organizations (Okembo *et al*., 2024). Linked open-government data can further improve the discoverability and integration of public information, although data quality, maintenance, licensing, and long-term institutional responsibility remain important constraints (Quarati & Albertoni, 2024).

Legal and distributive considerations are equally important. Comparative legal research shows that land digitization affects access, tenure security, administrative accountability, and human rights (Kavuri & Ramanathan, 2024). Analysis of digital land certificates in Indonesia likewise highlights the need to align modernization with procedural and distributive justice (Martin *et al*., 2025). A comparison of Bangladesh and Indonesia identifies organizational, technical, and service-delivery barriers to digital land administration (Akter, 2022). Together, these studies indicate that digital systems should be evaluated not only for efficiency, but also for inclusiveness, reliability, and institutional legitimacy.

Emerging technologies may extend these capabilities, but their levels of readiness differ. Blockchain has been proposed for tamper-evident land records and transaction traceability in developing-country land registries (Mansoor *et al*., 2023). A Namibian case study indicates potential practical value while also identifying institutional and implementation constraints (Paavo *et al*., 2025). Broader rural-governance and agricultural literature discusses decentralization, traceability, smart contracts, and supply-chain applications (Merrell, 2022; Bekkali & Lasri, 2025; Gurusamy *et al*., 2025); these findings do not, by themselves, establish feasibility for Kazakhstan's municipal cadastres. Digital-twin research has expanded in industrial systems (Kazakov *et al*., 2024) and regional food supply chains (Monteiro & Barata, 2025), but deployment requires high-quality data, connectivity, modeling capability, and sustained maintenance. Artificial intelligence may support SDG 11-related urban functions (Leal Filho *et al*., 2024), and satellite services can expand remote connectivity and Earth observation (Morea

& Sciortino, 2021), yet affordability and governance remain central to equitable use.

The wider literature also clarifies the boundary conditions of territorial digitalization. Agribusiness and food-security studies emphasize context-specific economic and institutional variables (Efani *et al*., 2024; Nguyen *et al*., 2024), while agricultural land-management research shows that local practices and stakeholder conditions influence implementation (Ebasan & Otadoy, 2024). Peri-urban agriculture illustrates the need to coordinate land-use, ecosystem, and development objectives (Miralles-Garcia, 2023), and village-organization research demonstrates the importance of local collective capacity in natural-resource governance (Zamir *et al*., 2022). Digital strategy, leadership, and organizational agility affect whether technological investments become sustained organizational change (Zulkifli *et al*., 2025); comparable evidence from construction highlights the interaction of digitalization, environmental innovation, and regulation (Nikiforova *et al*., 2024). ESG-oriented risk governance (Vaslavskaya *et al*., 2025), land-resource management for food security (Tleshpayeva *et al*., 2025), and the management of biological collections for agroforestry (Khuzhakhmetova *et al*., 2024) further show that land decisions integrate economic, environmental, and institutional objectives. General accounts of GIS-based land monitoring reinforce its operational relevance (Zabidullaeva, 2024). A 2023 conference preface identifies innovation, investment, and regional competitiveness as broad development priorities, but it is contextual rather than empirical evidence (Abdullayev *et al*., 2023).

The study had four objectives:

- Assess the current adoption of selected digital technologies in land administration acrossKazakhstan's small settlements;
- Examine associations between expert-rated technology adoption and perceived contributions to selected SDGs;
- Identify institutional, technological, socioeconomic, and informational barriers to implementation; and
- Develop phased, context-sensitive recommendations for improving digital land administration in small settlements.

MATERIALS AND METHODS

A sequential mixed-methods design combined an expert questionnaire with focus-group discussions. The quantitative component described perceived technology adoption and examined associations with perceived SDG contributions. The qualitative component interpreted the survey patterns, identified implementation barriers, and developed mitigation proposals.

For this study, small settlements comprised cities of regional significance with populations up to 10,000, towns with at least 3,000 inhabitants, and rural settlements with at least 50 residents. The analysis focused on these localities because their infrastructure, staffing, fiscal resources, and access to specialized digital services differ substantially from those of major cities.

The expert survey included 45 participants from five professional groups. Government officials responsible for land administration and spatial planning constituted the largest group (n = 12; 26.7%), followed by academic researchers and university faculty in Kazakhstan (n = 10; 22.2%). GIS and digital-transformation specialists and private-sector professionals engaged in land management or spatial planning each contributed eight participants (17.8% per group). Seven participants specialized in sustainable development or environmental management (15.6%).

Participants were selected through purposive stratified sampling based on professional specialization, work experience, and geographic location. Mean professional experience was 8.3 years. The composition of the expert panel is presented in **Table 1**.

Table 1. Expert panel by professional category (n = 45).

Expert category	Number of participants	Proportion (%)
Officials from governmental organizations involved in land administration and spatial planning	12	26.7
Specialists in geographic information systems (GIS) and digital transformation	8	17.8
Professionals specializing in sustainable development and environmental management	7	15.6
Representatives of private-sector organizations engaged in land management and spatial planning activities	8	17.8
Academic researchers and university faculty members from Kazakhstan	10	22.2
Total	**45**	**100.0**

Four focus groups included 36 participants representing municipal authorities, information-technology and digitalization specialists, sustainability and environmental professionals, and users of land-information systems **(Table 2)**. The questionnaire contained 26 items organized into four thematic sections **(Table 3)**.

Table 2. Focus-group participants by category (n = 36).

Participant category	Number of participants	Percentage (%)
Representatives of municipal authorities	9	25.0
Specialists in information technologies and digitalization processes	8	22.2
Professionals in sustainable development and members of environmental organizations	10	27.8
Users of land information systems, including business representatives, construction professionals, and architects	9	25.0
Total	**36**	**100.0**

The questionnaire combined closed-response items rated on a 5-point Likert scale and open-ended questions. Internal consistency for the reported multi-item instrument was Cronbach's alpha = 0.82. A structured focus-group guide addressed six thematic areas and included follow-up questions informed by the preliminary survey findings.

Table 3. Structure of the expert questionnaire (26 items).

No.	Questionnaire section	Number of questions	Percentage (%)
1	Evaluation of the existing degree of digital transformation in land management	7	26.9
2	Analysis of the connection between digitalization processes and the achievement of selected Sustainable Development Goals (SDGs)	9	34.6
3	Identification of obstacles and limitations affecting successful digitalization implementation	5	19.2
4	Proposed measures and recommendations aimed at enhancing operational efficiency	5	19.2
Total		**26**	**100.0**

The expert survey was administered remotely through a digital research platform. Each participant received an individualized survey link and completion instructions. Data collection lasted 14 days, with response monitoring on days 7 and 12. Focus groups were conducted after preliminary analysis of the questionnaire data and used a hybrid format that combined in-person and videoconference participation. All sessions were digitally recorded with participants' explicit prior consent and transcribed verbatim. **Figure 1** shows the analytical workflow.

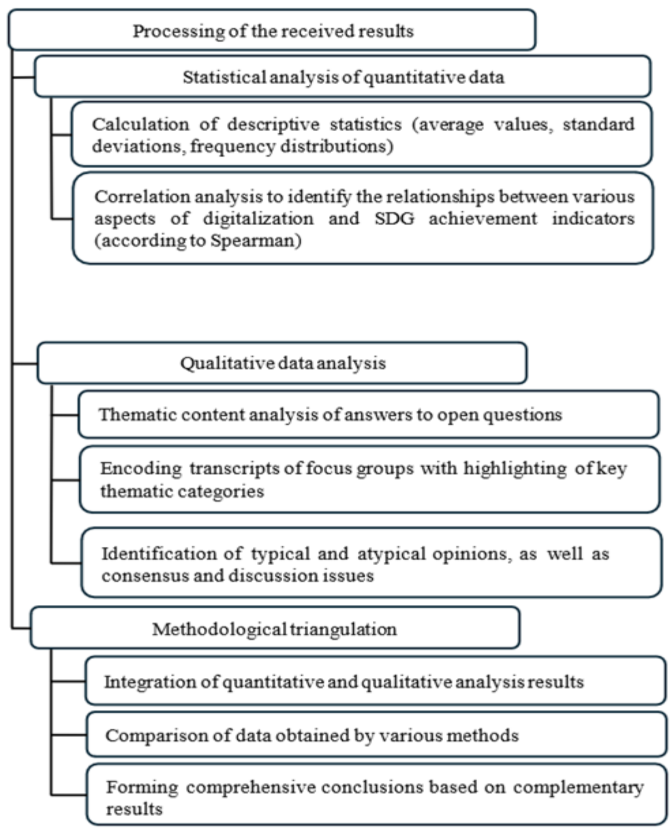

Figure 1. Workflow for quantitative and qualitative data processing.

Quantitative analyses were performed in SPSS version 26.0. Means, standard deviations, and coefficients of variation were used to summarize the expert ratings. Spearman rank-order correlations were calculated using complete cases. Ten questionnaires with missing data on at least one variable in the correlation matrix were excluded, leaving 35 observations for that analysis. Qualitative data were managed in NVivo version 14 and analyzed thematically. Barrier frequencies represent the proportion of the 36 focus-group participants whose contributions were coded to each theme.

RESULTS AND DISCUSSION

Table 4 summarizes expert ratings of the current adoption of seven digitalization components on a scale from 1 (lowest) to 5 (highest).

Table 4. Expert ratings of digital land-administration adoption inKazakhstan's small settlements (n = 45).

Digitalization component	Mean score	Standard deviation	Variation coefficient (%)
Geographic Information Systems (GIS)	3.62	0.73	20.2
Blockchain technologies	1.84	0.91	49.5
Digital twin technologies	1.76	0.83	47.2
Remote sensing technologies and related data resources	2.94	0.76	25.9
Electronic cadastral information systems	3.71	0.64	17.3
Digital platforms for land-use monitoring	2.78	0.85	30.6
Digital transformation of urban planning documentation	3.25	0.71	21.8

Electronic cadastral information systems received the highest mean rating (3.71; SD = 0.64), followed by GIS (3.62; SD = 0.73) and the digital transformation of urban-planning documentation (3.25; SD = 0.71). Remote sensing (2.94; SD = 0.76) and digital land-use monitoring platforms (2.78; SD = 0.85) ranked in the middle. Blockchain (1.84; SD = 0.91) and digital twins (1.76; SD = 0.83) had the lowest mean ratings. Coefficients of variation were lowest for electronic cadastral systems (17.3%) and GIS (20.2%), suggesting greater agreement among experts about these established technologies. Variation was substantially higher for blockchain (49.5%) and digital twins (47.2%), indicating more heterogeneous experience or expectations. Spearman correlations based on 35 complete questionnaires are presented in **Table 5**.

Table 5. Spearman correlations between technology-adoption ratings and perceived SDG contributions (n = 35).

Technology-adoption rating	SDG 9 (Industry, innovation, technology, and infrastructure)	SDG 11 (Sustainable cities and communities)	SDG 13 (Climate action)	SDG 15 (Life on land)	SDG 16 (Peace, justice, and strong institutions)
Geographic Information Systems (GIS)	0.67**	0.78**	0.59**	0.71**	0.43*
Blockchain technologies	0.62**	0.41*	0.21	0.18	0.76**
Digital twin technologies	0.75**	0.64**	0.58**	0.46*	0.32
Remote sensing data	0.56**	0.65**	0.79**	0.82**	0.28
Electronic cadastral systems	0.53**	0.61**	0.31	0.44*	0.73**
Digital land-use monitoring systems	0.48*	0.72**	0.64**	0.69**	0.54**
Digital transformation of urban planning documentation	0.51**	0.63**	0.37*	0.42*	0.65**

Note: * P < 0.05; ** P < 0.01. Significance markers should be confirmed against the original SPSS output before submission.

The largest reported correlation coefficients were observed between remote-sensing adoption and perceived contribution to SDG 15 (r = 0.82), GIS adoption and perceived contribution to SDG 11 (r = 0.78), andblockchain adoption and perceived contribution to SDG 16 (r = 0.76). These coefficients represent associations among expert ratings and should not be interpreted as measured effects of technology on SDG indicators. The focus-group analysis identified four barrier categories and corresponding mitigation proposals **(Table 6)**.

Table 6. Digital land-administration barriers and mitigation proposals from focus groups (n = 36).

Barrier category	Identified barrier	Mention frequency (%)	Suggested measures for mitigation
Institutional	Regulatory and legal limitations	86.1	Enhancement of legal frameworks related to digital cadastral systems and electronic document management
	Insufficient inter-agency coordination	75.0	Establishment of an integrated digital platform for land management activities
	Absence of standardized procedures and requirements	63.9	Formulation and adoption of national standards for digital land administration
Technological	Inadequate digital infrastructure	80.6	Increasing investment in digital infrastructure development, particularly in smaller settlements
	Difficulties in connecting existing systems with new technologies	69.4	Creation of technical frameworks for interoperability between legacy and modern information systems
	Poor quality and reliability of initial data resources	72.2	Implementation of digital land inventories using advanced technological approaches
Socioeconomic	Shortage of skilled specialists	83.3	Designing training and educational initiatives focused on digital technologies in land management
	Unequal digital development between urban and smaller areas	77.8	Establishment of regional centers of expertise for digital land management solutions
	Insufficient financial resources	61.1	Promotion of public–private partnerships for digital transformation projects

Informational	Limited awareness among users	58.3	Organization of awareness campaigns highlighting the advantages of digitalization
	Challenges related to access to information resources	52.8	Development of open-access geoportals and publicly available digital services

The most frequently mentioned barriers were regulatory and legal constraints (86.1%; 31 of 36 participants), shortages of qualified specialists (83.3%; 30 of 36), inadequate digital infrastructure (80.6%; 29 of 36), urban-small-settlement disparities in digital development (77.8%; 28 of 36), and insufficient inter-agency coordination (75.0%; 27 of 36). Data-quality problems (72.2%; 26 of 36) and difficulties integrating legacy and new systems (69.4%; 25 of 36) were also prominent.

The results suggest that digital land administration in Kazakhstan's small settlements is characterized by selective maturity rather than uniform transformation. Established systems with clear administrative functions—particularly electronic cadastres and GIS—received higher and more consistent adoption ratings. Emerging technologies received lower and more variable ratings. This pattern supports a phased implementation logic: strengthen foundational data, interoperability, staffing, and governance before committing scarce resources to complex technologies whose local feasibility has not yet been demonstrated.

The higher ratings for GIS and electronic cadastral systems are consistent with their direct operational relevance to mapping, registration, monitoring, and planning (de Vries, 2021; Imanbayeva *et al*., 2024; Tuleyeva *et al*., 2024; Zabidullaeva, 2024). Their comparative maturity should not be equated with full effectiveness. Data completeness, positional accuracy, system integration, update frequency, and user access determine whether installed technologies improve administrative performance.

Institutional barriers were among the most frequently reported. Comparative evidence shows that digital land services depend on aligned mandates, standardized processes, legal recognition of electronic records, and cross-agency coordination (Akter, 2022; Ahsan *et al*., 2024; Okembo *et al*., 2024). ForKazakhstan's small settlements, regional support arrangements may be more feasible than requiring every municipality to maintain independent technical teams. Shared service centers could provide data stewardship, cybersecurity, procurement support, training, and system maintenance, while local authorities retain responsibility for service delivery and contextual decisions.

Infrastructure and data quality constitute a second set of interdependent constraints. Limited connectivity reduces access to centralized services, while poor source data undermine even well-designed platforms. Cloud processing and remote sensing can extend analytical capacity (Barboza *et al*., 2024; Mustafayeva *et al*., 2024), and UAV-based monitoring may support pasture and land-condition assessment (Janteliyev *et al*., 2022). These options nevertheless require validated workflows, reliable metadata, clear update responsibilities, and quality-control procedures.

The low blockchain rating warrants caution. Research describes potential benefits for record integrity, traceability, and land transactions (Merrell, 2022; Mansoor *et al*., 2023; Paavo *et al*., 2025), but agricultural supply-chain applications (Bekkali & Lasri, 2025; Gurusamy *et al*., 2025) cannot be transferred directly to cadastral administration. Before adoption, pilot studies should compare blockchain with less complex alternatives in terms of legal validity, governance, interoperability, cybersecurity, operating cost, and user access. The present findings do not support nationwide deployment.

Digital twins warrant similar caution. Reviews in industrial and regional food-supply systems describe potential applications for simulation, monitoring, and coordination (Kazakov *et al*., 2024; Monteiro & Barata, 2025). A territorial digital twin, however, depends on current, interoperable, and sufficiently granular data. Where basic cadastral and infrastructure datasets remain incomplete, investment in data foundations is likely to yield greater near-term value than a high-complexity twin platform.

Interoperability is therefore a strategic priority. LADM-oriented country profiles and data-exchange frameworks demonstrate how standardized semantics and institutional agreements can reduce fragmentation (Ahsan *et al*., 2024; Okembo *et al*., 2024). Open-government data may improve reuse and public access (Quarati & Albertoni, 2024), provided that privacy, security, licensing, provenance, and maintenance responsibilities are specified.

The correlation between GIS adoption and perceived contribution to SDG 11 was strong ($r = 0.78$), but it reflects expert judgments collected at one time point. It does not show that GIS adoption produced measurable changes in housing, transport, land-use efficiency, resilience, or other SDG 11 indicators. Future evaluation should link administrative system use to predefined service and spatial-planning outcomes.

The association between remote sensing and perceived contribution to SDG 15 ($r = 0.82$) is substantively plausible because remote sensing supports land-cover, forest, and degradation monitoring (Barboza *et al*., 2024; Mustafayeva *et al*., 2024; Yildirim & Tufekcioglu, 2024). Likewise, the association between blockchain and perceived contribution to SDG 16 ($r = 0.76$) is consistent with expectations concerning transparency and record integrity (Mansoor *et al*., 2023; Kavuri & Ramanathan, 2024; Martin *et al*., 2025). Both results remain perception-based and require validation using objective indicators and longitudinal or quasi-experimental designs.

The shortage of qualified personnel and the digital divide indicate that implementation capacity is not solely a technical issue. Local digital transformation depends on workforce competence, leadership, organizational agility, and community participation (Zamir *et al*., 2022; Kabwe *et al*., 2024; Zulkifli *et al*., 2025). Training should therefore be role-specific and continuous, covering data entry, GIS analysis, cadastral procedures, cybersecurity, public communication, and evidence-informed decision-making.

Resource constraints further support prioritization. Near-term investment should focus on improving existing cadastral systems, GIS, remote sensing, connectivity, and interoperable data exchange. Medium-term pilots may then test blockchain or digital-twin applications where a clearly defined administrative problem, legal basis, data environment, and evaluation plan are present.

Information-related barriers—limited awareness and restricted access to data or services—can reduce both uptake and legitimacy. Land digitalization must therefore include accessible public interfaces, assistance for users with limited digital skills, and transparent explanations of data use and appeal procedures. These measures align with rights-based approaches to digital land governance (Mansoor *et al*., 2023; Kavuri & Ramanathan, 2024) and broader evidence on local digital inclusion (Morea & Sciortino, 2021; Kabwe *et al*., 2024).

A coherent architecture should integrate, rather than merely accumulate, technologies. GIS, electronic cadastres, remote sensing, and modern surveying can provide the foundational spatial and administrative layers (Sagandykova *et al*., 2024; Tuleyeva *et al*., 2024). Emerging applications should connect to these layers through standards and documented interfaces. Integration must also extend to food-security, environmental-risk, and land-resource objectives (Khuzhakhmetova *et al*., 2024; Nikiforova *et al*., 2024; Tleshpayeva *et al*., 2025; Vaslavskaya *et al*., 2025), because sustainable territorial development requires decisions that cross sectoral boundaries.

For policy, the findings support differentiated roadmaps based on settlement capacity and need. A minimum national service standard could define core cadastral data, interoperability, security, and public-access requirements, while regional implementation plans specify sequencing, shared services, training, and financing. Progress should be evaluated with operational indicators—such as data completeness, processing time, update frequency, system availability, user access, and resolved land disputes—rather than technology installation alone.

CONCLUSION

Digital land administration in Kazakhstan's small settlements appears to be uneven, with expert ratings indicating greater adoption of electronic cadastral systems and geographic information systems (GIS) than of blockchain technologies and digital twins. Focus-group findings identified regulatory constraints, shortages of qualified personnel, inadequate digital infrastructure, weak institutional coordination, and data-quality problems as the most frequently reported barriers. The observed correlations indicate how experts associate specific digital technologies with selected Sustainable Development Goals (SDGs); they do not demonstrate causal effects of digitalization on sustainability outcomes.

The study has several limitations, including purposive sampling, a modest expert sample, reliance on self-reported assessments, correlation analysis based on only 35 complete questionnaires, and the absence of longitudinal or objective municipal performance data. The heterogeneity of small settlements also limits the findings' generalizability. In addition, further methodological documentation is needed regarding the full questionnaire, item-level construct definitions, exact correlation p-values, detailed qualitative coding procedures, and ethics-review information.

Based on the reported findings, a defensible implementation strategy is sequential: strengthen core cadastral data and digital connectivity; establish interoperable standards and clearly defined institutional responsibilities; develop regional technical capacity; evaluate effects on administrative and land-management outcomes; and subsequently test advanced technologies through controlled pilot projects. Future research should employ more representative sampling, validated measurement instruments, objective performance indicators, and longitudinal or quasi-experimental designs to determine whether digitalization improves administrative efficiency, equity, and sustainable territorial outcomes.

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