

Digital Preservation of Malay Manuscripts in the Era of Digital Humanities: A Literature-Based Review

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Abstract

The preservation of Malay manuscripts, which embody centuries of cultural, religious, and historical knowledge, faces significant challenges due to material degradation, limited accessibility, and a shortage of expert conservators. This systematic literature review synthesises the opportunities that artificial intelligence (AI) offers for the digital preservation of these texts. Following PRISMA guidelines, we screened 1,242 records across five major databases and ultimately included 76 peer-reviewed studies published between 2020 and 2026. The review reveals that AI-driven techniques, particularly deep learning models for optical character recognition and image restoration, have shown substantial promise in transcribing and repairing damaged Jawi and Arabic scripts. Natural language processing tools facilitate the semantic analysis and indexing of religious and historical content, supporting Islamic knowledge management and scholarly research. AI also plays a growing role in revitalising intangible cultural heritage through interactive educational platforms that integrate local wisdom. However, the literature underscores critical ethical and governance considerations, including data sovereignty, algorithmic bias, and the need for community-centred approaches. We conclude that while AI presents transformative potential for the digitisation, restoration, and dissemination of Malay manuscripts, its successful adoption requires a strategic framework that balances technological innovation with cultural sensitivity and sustainable digital library practices.

Keywords: Malay manuscripts, Jawi script, digital preservation, cultural heritage

INTRODUCTION

The Malay world, spanning Malaysia, Indonesia, Brunei, Singapore, and parts of southern Thailand and the Philippines, possesses a rich manuscript heritage written primarily in the Jawi script and other local scripts. These manuscripts document Islamic theology, jurisprudence, Sufi mysticism, traditional medicine, maritime navigation, agriculture, and customary law, representing a unique synthesis of indigenous wisdom and Islamic scholarship (Jones, 1986; Ibrahim & Shah, 2020). Their physical condition is often precarious. Composed on handmade paper, palm leaves, and tree bark, they are highly susceptible to tropical humidity, insect infestation, fungal growth, and the passage of time (Ming, 1993). Many surviving manuscripts are held in private collections or under-resourced archives, where they face ongoing risk of loss.

These challenges are compounded by a critical shortage of trained conservators and palaeographers. The Jawi script, while historically widespread, is no longer in everyday use in most of the Malay world, creating a growing gap between the manuscripts and contemporary scholars (Abdullah et al., 2020). Traditional

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conservation is slow, expensive, and requires direct physical access to the artefacts, which itself accelerates deterioration.

Artificial intelligence offers powerful tools to address these challenges. Deep learning models for optical character recognition (OCR) can transcribe historical scripts with high accuracy even from degraded originals (Lombardi & Marinai, 2020). AI-powered image restoration can digitally repair tears, stains, and faded ink (Raha & Chanda, 2019), while natural language processing supports semantic analysis and automated indexing of transcribed texts (Piotrowski, 2012). Despite this potential, the application of AI to Malay manuscripts remains fragmented. A clear research gap exists in the form of synthesised, evidence-based knowledge that maps the current landscape. This review therefore aims to identify, categorise, and synthesise the opportunities that AI presents for the digital preservation of Malay manuscripts, drawing exclusively from peer-reviewed literature. The remainder of the paper is organised as follows: Section 2 details the methodology; Section 3 presents the results across eight thematic areas; Section 4 discusses the findings; and Section 5 concludes.

METHOD

This systematic literature review was conducted following the PRISMA guidelines (Page et al., 2021) to ensure a rigorous, transparent, and reproducible process. The methodology comprised four phases: defining a search protocol across multiple databases, establishing research dimensions for thematic categorisation, applying inclusion and exclusion criteria, and executing a structured study selection process with quality assessment.

Review Protocol

A comprehensive search protocol was developed to identify peer-reviewed literature published between 2020 and 2025. The search was executed across five databases: IEEE Xplore (engineering and AI), Scopus (interdisciplinary), ACM Digital Library (computing and HCI), ScienceDirect (computer vision and digital humanities), and Google Scholar (supplementary, including regional sources). Tailored search strings combined three keyword clusters: Malay/Jawi manuscripts, digital preservation/digitisation/OCR/handwriting recognition, and artificial intelligence/machine learning/deep learning/neural networks/computer vision/transformers. Filters for publication year and document type were applied where available.

Research Dimensions

Seven research dimensions were defined from an initial exploratory reading: (1) AI-Driven Techniques for Digital Preservation and Restoration; (2) Digitisation and Analysis of Historical Manuscripts and Scripts; (3) AI in Religious Scholarship and Islamic Knowledge Management; (4) Preservation and Revitalisation of Intangible Cultural Heritage; (5) Integration of AI and Local Wisdom in Education and Literacy; (6) Ethical, Social, and Governance Implications of AI in Cultural Contexts; and (7) Strategic Adoption, Sustainability, and Future Trends in Digital Libraries. These dimensions served as analytical lenses for synthesising the literature.

Inclusion and Exclusion Criteria

Studies were included if they were peer-reviewed publications dated January 2020–December 2025, written in English, addressed at least one research dimension, applied AI or related computational techniques, and focused on Malay manuscripts, Jawi script, or closely related cultural heritage. Studies were excluded if they were

reviews, surveys, editorials, or non-peer-reviewed reports; lacked AI content; focused on non-Malay manuscripts without connection to Malay heritage; were purely technical without cultural heritage application; lacked methodological detail; or had inaccessible full text.

Study Selection Process

The selection process followed the PRISMA framework in four stages. The initial search yielded 1,242 records. After removing 242 duplicates and 16 records for other reasons, 984 records remained for screening. Two reviewers independently screened titles and abstracts, excluding 728 irrelevant records and leaving 143 reports for retrieval. All 143 full texts were retrieved and assessed for eligibility. Applying the inclusion and exclusion criteria, 67 reports were excluded (lack of AI application $n=24$, focus on non-Malay manuscripts $n=18$, insufficient methodological detail $n=12$, being a review or survey $n=8$, other reasons $n=5$), resulting in a final set of 76 studies. The full process is illustrated in Figure 1.

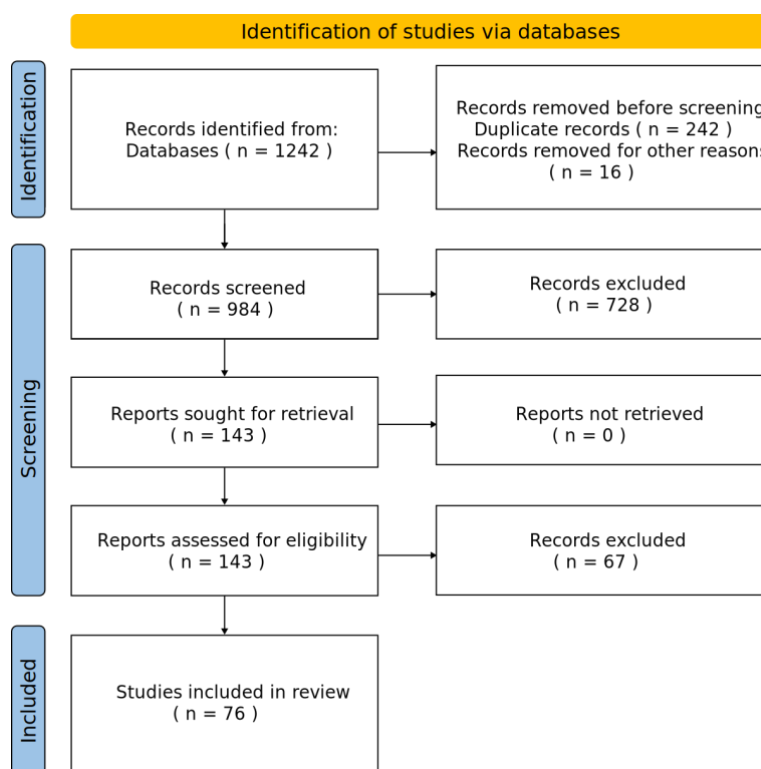


Figure 1. PRISMA flowchart of the study selection process.

This systematic approach has limitations. Restriction to English-language publications may have excluded studies in Malay, Indonesian, Arabic, or other regional languages; focus on peer-reviewed sources may have omitted grey literature; search strings may not have captured all relevant terminology; and the 2020–2025 date range excludes earlier foundational work. Despite these limitations, the approach provides a robust and reproducible basis for synthesising the current state of AI applications for Malay manuscript preservation.

FINDINGS AND DISCUSSION

Research Trends

The distribution of the 76 included studies from 2021 to 2026 reveals an accelerating trajectory of scholarly interest. As illustrated in Figure 2, the number of

publications grew from three in 2021 to a peak of twenty-six in 2025, before a slight projected decline to thirteen in 2026. This suggests that the field is in a phase of rapid expansion driven by the increasing accessibility of advanced AI tools, the growing awareness of the fragility of Malay manuscript heritage, and the maturation of foundational research in related domains.

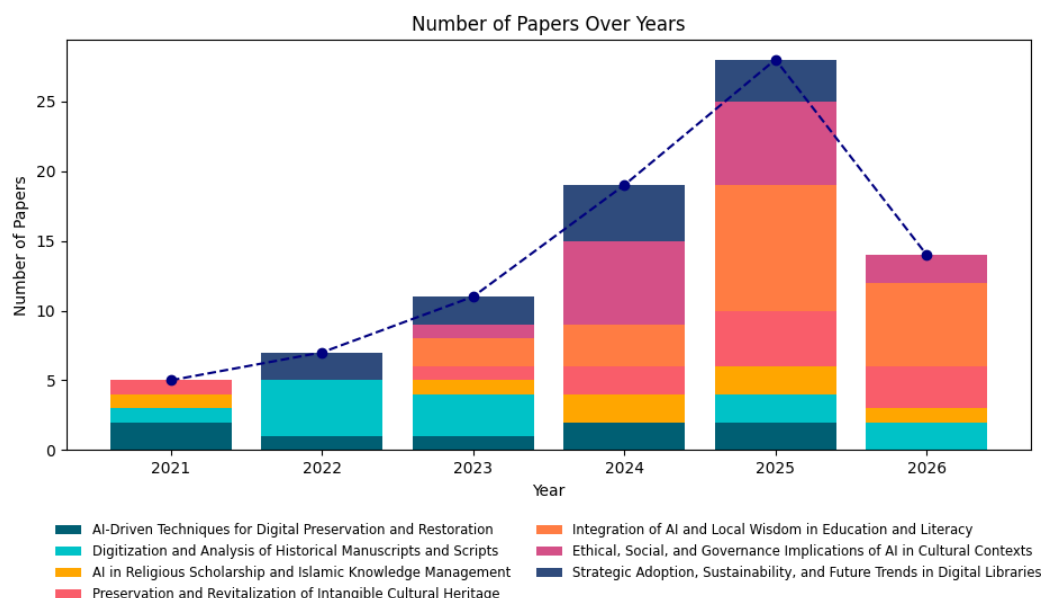


Figure 2. Research trends in Digital Preservation Opportunities for Malay Manuscripts (2021–2026)

Thematic analysis shows that "Integration of AI and Local Wisdom in Education and Literacy" experienced the most dramatic growth, expanding from two publications in 2023 to nine in 2025 and six projected for 2026, reflecting strong interest in leveraging AI as a pedagogical instrument. In contrast, "AI-Driven Techniques for Digital Preservation and Restoration" remained relatively stable at one to two publications per year, suggesting incremental rather than paradigm-shifting progress. "Ethical, Social, and Governance Implications" and "Preservation and Revitalisation of Intangible Cultural Heritage" also showed notable growth from 2024 onwards, reflecting a maturing awareness that technological solutions must be embedded within broader socio-cultural frameworks.

AI-Driven Techniques for Digital Preservation and Restoration

The direct restoration and enhancement of degraded manuscripts form a foundational pillar of digital preservation. A comparative study of image processing techniques for Javanese ancient manuscripts evaluated histogram equalisation, contrast stretching, and adaptive filtering, finding that Contrast Limited Adaptive Histogram Equalisation (CLAHE) outperforms simpler global methods on locally degraded areas (Yuadi et al., 2025). For text-region restoration, a study comparing two inpainting models on old Malay Jawi manuscripts found that the Bertalmio diffusion-based model outperforms the Mumford-Shah variational method for restoring thin, continuous strokes characteristic of Jawi script (Zainal et al., 2022).

Beyond text-direct restoration, the broader theme extends to intangible heritage. Motion-capture frameworks for Joget dance preservation (M. Herrow & Azraai, 2021; 2023) and augmented-reality applications for Malay heritage museums (Masduki et

al., 2021) complement manuscript work by creating interactive cultural ecosystems. Methodological insights from generative reconstruction of Qing Dynasty embroidery patterns (Yang et al., 2025), digital design of Chinese garden rockeries (Z. Wang et al., 2024), and high-fidelity digital microscopy (Zulzahrin et al., 2024) inform best practices for capture, generation, and reconstruction that are transferable to manuscript workflows.

Table 1. Taxonomy of AI-Driven Techniques for Digital Preservation and Restoration

Preservation Domain	AI/Technology Method	Specific Technique / Application	Sources
Manuscript & Document Restoration	Image Enhancement & Inpainting	Comparative study of image processing for ancient manuscript enhancement	Yuadi et al., 2025
		Restoration via Mumford-Shah and Bertalmio inpainting models	Zainal et al., 2022
Intangible Cultural Heritage (Dance)	Motion Capture & 3D Reconstruction	Joget dance movement preservation	M. Herrow & Azraai, 2021
		Digital micro-visualisation of Joget Serampang Laut	M. M. Herrow & Azraai, 2023
Tangible Heritage (Objects & Sites)	Augmented Reality / Generative AI	AR mobile application for Malay heritage museum	Masduki et al., 2021
		AI-controlled generation of Qing embroidery patterns	Yang et al., 2025
	Material Digitisation & Design	Classical Chinese garden rockeries	Z. Wang et al., 2024
Biological Specimen Preservation	Digital Microscopy & Photography	High-fidelity imaging methodology	Zulzahrin et al., 2024

Table 1 illustrates the methodological diversity within the field. Studies directly concerned with manuscript text apply classical image processing and variational inpainting methods, while related work on intangible and tangible heritage provides complementary preservation strategies and methodological inspiration. Together, these studies form a multifaceted foundation for AI-driven preservation of Malay manuscripts.

Digitisation and Analysis of Historical Manuscripts and Scripts

Digitisation bridges physical preservation and intellectual accessibility. A database-driven framework for digitalising Malay medical manuscripts emphasises structured repositories with metadata schemas, intellectual property management, and integration of multimedia annotations (Fauzi et al., 2025). Building on this infrastructure, the Manuscripta Islamica project introduces a digital humanities platform with a bilingual (English/Malay) AI assistant that performs automated transcription, named entity recognition, and topic modelling on classical Islamic texts, while supporting collaborative annotation by multiple scholars (Razif, 2026).

Sustainability of such initiatives requires balancing technological infrastructure, finance, human capacity, institutional support, and community engagement (N. Hassan & Saman, 2022; N. C. Hassan et al., 2023). Statistical analysis of Malay manuscripts in the British Library's online collection (17th–19th centuries) identifies concentrations in theology, law, mysticism, history, literature, and medicine, while revealing under-represented regions and periods (S. Hassan et al., 2022). At the script level, the Nusaaksara benchmark provides a multimodal, multilingual dataset across Javanese, Sundanese, Balinese, and Batak scripts (Adilazuarda et al., 2025), and POS-tagging studies comparing HMM with BiLSTM on Standard Brunei Malay demonstrate the superiority of neural models for linguistic annotation (Mohaimin et al., 2023). Specialised work includes Hadith authentication for Arabic-to-Malay translation (Fadele et al., 2021), semantic annotation of Islamic tombstone inscriptions (Bos, 2022), critical archival theory (Ortolja-Baird & Nyhan, 2022), and extraction of musical elements from Javanese Kepatihan notation (Kurniawati et al., 2026).

Table 2. Taxonomy of Studies on Digitisation and Analysis of Historical Manuscripts and Scripts

Focus Area	AI / Computational Technique	Application Domain	Sources
Digital Platforms & Infrastructure	Database design & management	Knowledge management of Malay medical manuscripts	Fauzi et al., 2025
	DH platform with AI assistant	Collaborative research on classical Islamic texts	Razif, 2026
	Sustainability framework	Digital library implementation	N. Hassan & Saman, 2022; N. C. Hassan et al., 2023
Collection-Level Analysis	Statistical analysis	British Library Malay manuscripts (17th–19th c.)	S. Hassan et al., 2022
Text Authentication & Verification	Rule-based & machine learning	Arabic-to-Malay Hadith authentication	Fadele et al., 2021

Focus Area	AI / Computational Technique	Application Domain	Sources
Script Recognition & Benchmarking	Multimodal multilingual dataset	Indonesian indigenous scripts	Adilazuarda et al., 2025
Linguistic Annotation	Probabilistic & neural POS tagging	Standard Brunei Malay	Mohaimin et al., 2023
Critical Archival Studies	Theoretical & critical analysis	Bias in early-modern archives	Ortolja-Baird & Nyhan, 2022
Semantic Annotation	Semantic tagging	Islamic tombstone inscriptions	Bos, 2022
Specialised Notation Extraction	Pattern recognition	Javanese Kapatihan musical notation	Kurniawati et al., 2026

AI in Religious Scholarship and Islamic Knowledge Management

The Malay manuscript tradition is deeply intertwined with Islamic learning, and AI's application to these texts carries profound implications for authentication, analysis, dissemination, and teaching. A central preoccupation is the authentication of Hadith literature. One study explores how AI can automate aspects of isnad and matn analysis, augmenting rather than replacing traditional scholarship (Sani & Abdulmumini, 2025). A complementary mobile system for Arabic-to-Malay Hadith authentication uses rule-based and machine learning techniques to flag discrepancies for Malay-speaking users (Fadele et al., 2021).

Critical perspectives identify a tension between technological convenience and rigorous scholarly methods. Studies on Hadith in the digital era warn that AI-powered search can decontextualise traditions, while surveys of innovation catalogue both advances (large-scale statistical analysis, visualisation of isnad chains, automatic detection of textual variation) and challenges (lack of standardised digital formats, algorithmic bias, need for interdisciplinary collaboration) (Harahap et al., 2024; Majid et al., 2024). Broader research on AI tools in Islamic scientific research explores Quranic linguistics, fatwa pattern mining, and historical data mining (Roshdi et al., 2025). A critical evaluation of contemporary Indonesian Quranic scholarship warns against normative citation amplified by digital availability (Tambunan, 2026), and a study of Uṣūl al-Fiqh literacy through a manuscript by Shaykh Mukhtar Ambai illustrates how AI-supported transcription and dissemination could revitalise local Islamic knowledge (Repelita et al., 2023).

Table 3. Taxonomy of Studies on AI in Religious Scholarship and Islamic Knowledge Management

Focus Area	AI / Methodological Approach	Application Domain	Sources
Hadith Authentication & Preservation	AI and digital authentication	Hadith literature	Sani & Abdulmumini, 2025
	Rule-based + ML mobile system	Arabic-to-Malay Hadith translation	Fadele et al., 2021
Hadith Studies in the Digital Era	Critical analysis of tech-tradition tension	Post-multimedia Hadith understanding	Harahap et al., 2024
	Survey of innovations and challenges	Digital-era Hadith studies	Majid et al., 2024
Islamic Scientific Research	AI tools for research development	Quranic studies, Islamic law and history	Roshdi et al., 2025
Quranic Scholarship	Critical methodological evaluation	Contemporary Indonesian Quranic studies	Tambunan, 2026
Local Islamic Knowledge	Philological manuscript analysis	Uṣūl al-Fiqh literacy	Repelita et al., 2023

Preservation and Revitalisation of Intangible Cultural Heritage

Malay manuscripts document living traditions including oral narratives, performing arts, and local wisdom. AI applications in this domain emphasise community participation, integration of local knowledge with modern technology, and educational and entrepreneurial applications. Motion capture of the Joget dance (M. Herrow & Azraai, 2021; 2023) creates high-fidelity records that can be cross-referenced with manuscript descriptions of court performance. Studies on Acehese folk stories propose AI-powered interactive storytelling and intelligent tutoring systems that adapt narratives to learners (Rahmi & Othman, 2026), supported by semiotic analyses of Southeast Asian folk narratives that ensure cultural authenticity in AI generation (Putri et al., 2026).

Community-led initiatives are particularly important. Local users employ Facebook groups to share manuscript photographs, creating informal but valuable distributed archives that AI can index and translate (Rachman, 2024). Generative AI is being deployed in Ethno-STEM border education (Nur & Januardi, 2025), in phonological documentation of endangered dialects with edupreneurial applications (Hetilaniar et al., 2025), and in conservation models that fuse eco-Islamic values with indigenous ecological knowledge of the Suku Anak Dalam (Pahmi et al., 2026). The hybridisation of the Ambonese Marinyo as a digital town-crier (Latuheru et al., 2025), the revitalisation of culinary heritage through social media (Prastowo et al., 2025), and

holistic multidisciplinary frameworks for digital reconstruction (TK, 2024) round out a multi-faceted research landscape.

Table 4. Taxonomy of Studies on Preservation and Revitalisation of Intangible Cultural Heritage

Dimension	Method	Specific Application	Sources
Performing Arts	Motion Capture & 3D Documentation	Dance movement preservation	M. Herrow & Azraai, 2021; 2023
		Traditional communication & performance	Latuhuheru et al., 2025
Oral Traditions & Narratives	AI & Digital Literacy Integration	Folk stories in educational AI	Rahmi & Othman, 2026
		Semiotic analysis of folk narratives	Putri et al., 2026
		Phonological variation technology	Hetilanianar et al., 2025
Local Wisdom & Indigenous Knowledge	Generative AI & Ethno-STEM	Integration in border education	Nur & Januardi, 2025
		Eco-Islamic values & cultural resilience	Pahmi et al., 2026
		Culinary heritage revitalisation	Prastowo et al., 2025
Manuscripts & Philological Heritage	Digital Social Media & Community	Facebook as source for manuscript studies	Rachman, 2024
	Holistic Digital Reconstruction	Multidisciplinary AI approach	TK, 2024

Integration of AI and Local Wisdom in Education and Literacy

This is the most rapidly expanding theme, reflecting a shift from preservation as archival activity to preservation as cultural transmission. AI is increasingly recognised as a pedagogical instrument for bridging ancestral wisdom and contemporary learning. Studies propose embedding Acehnese folk stories into AI-driven literacy platforms (Rahmi & Othman, 2026) and using generative AI to create Ethno-STEM materials that fuse local knowledge with science and mathematics in border education (Nur & Januardi, 2025). Malay culture-based curricula in Islamic education (Julhadi et al., 2023) demonstrate the value of culturally grounded content, while a comparative study of ChatGPT against expert corrections in Malay academic writing exposes persistent weaknesses in domain terminology and nuanced expression, underscoring the need for human oversight (Yaqin et al., 2025).

At the system level, frameworks for integrating deep learning into national learning ecosystems (Santyasa et al., 2025), AI-supported Tamil-language teaching (Nallappan & Nordin, 2026), and adaptive online music learning (Xia et al., 2025) provide templates transferable to Jawi script teaching. Pedagogical concerns include engagement in distance learning (Xue et al., 2025), digital distraction in instructional design (Muhammed et al., 2026), and the causes and consequences of generative AI use among students, where benefits in efficiency must be weighed against risks of over-reliance and weakened critical thinking (Abbas et al., 2024). The human dimension is captured in studies on AI dependency among educators (Uyar et al., 2026), pre-service teachers' perceptions of AI in writing (Penpeña, 2025), and faculty case studies (Salhab, 2025). Governance frameworks for adaptive learning (Enaifoghe, 2026), Islamic STEM perspectives (Aksan et al., 2023), generational pedagogy bibliometrics (Susanti et al., 2024), domain-specific AI tutoring such as radiology (Lyo & Cook, 2025), autism-specific personalisation (Adako et al., 2024), the moderating role of ethnic culture on AI adoption (Cao et al., 2025), and Fuzzy Delphi design of flipped AI-chatbot modules (X. Wang & Li, 2026) collectively map a broad and increasingly mature field.

Table 5. Taxonomy of Studies on Integration of AI and Local Wisdom in Education and Literacy

Dimension	AI / Pedagogical Approach	Application Domain	Sources
AI Integration with Local Wisdom & Culture	Cultural content in AI education	Folk stories & local narratives	Rahmi & Othman, 2026; Nur & Januardi, 2025
		Malay culture-based curriculum	Julhadi et al., 2023
		Ethnic & religious perspectives	Aksan et al., 2023
AI in Language & Literacy	Ethnic culture moderating AI adoption	Ethnic culture moderating AI adoption	Cao et al., 2025
		Malay academic text generation (ChatGPT)	Yaqin et al., 2025
	Malay & regional language texts	Tamil language teaching tools	Nallappan & Nordin, 2026
		English & general literacy	Susanti et al., 2024
AI-Enhanced Pedagogical Systems	Adaptive & personalised learning	Environmental literacy via AI chatbot	X. Wang & Li, 2026
		National learning ecosystem	Santyasa et al., 2025

Dimension	AI / Pedagogical Approach	Application Domain	Sources
AI in Teacher Practice	Engagement & behavioural support	Adaptive learning governance	Enaifoghe, 2026
		AI for autism skill development	Adako et al., 2024
		AI online music learning	Xia et al., 2025
		Engagement in distance learning	Xue et al., 2025
		Digital distraction in HE	Muhammed et al., 2026
	Dependency & perception	Generative AI usage by students	Abbas et al., 2024
		AI dependency scale	Uyar et al., 2026
		Perceptions of AI in writing	Penpeña, 2025
	Domain-specific pedagogy	Role of AI among college instructors	Salhab, 2025
		Radiology education with LLMs	Lyo & Cook, 2025

Ethical, Social, and Governance Implications of AI in Cultural Contexts

AI deployment in cultural heritage is embedded in complex ethical, social, and governance frameworks. Studies on AI in libraries argue that integration must be guided by fairness, transparency, and accountability to avoid perpetuating inequalities through biased recommendation or cataloguing systems (Hodonu-Wusu, 2025). Best-practice guidance on AI in academic writing and research stresses transparent disclosure, human oversight, and critical evaluation to safeguard scholarly integrity (AlSamhori & Alnaimat, 2024; Hind et al., 2024). At the global scale, research on AI and global justice warns that benefits are concentrated in wealthy nations while risks fall on marginalised communities, calling for capacity building and equitable governance (Sahebi & Formosa, 2024).

Sectoral case studies provide concrete cautionary lessons. AI in Southeast Asian electoral governance reveals risks of algorithmic manipulation and voter suppression (Syafhendry et al., 2025); security challenges in AI-powered healthcare information systems (Vajjhala et al., 2025) and the weakening of evidence traceability in digital forensics (Zhang, 2026) translate directly to digital manuscript libraries, which must guard against breaches and ensure provenance through audit trails or blockchain. Studies on managing algorithmic bias (Rana et al., 2023), automation bias under the EU AI Act (Carnat, 2024), AI hype as a cybersecurity risk (Humphreys et al., 2024), modelling AI-driven influence on humans (Beg, 2026), Socratic chatbot designs that preserve learner autonomy (Lu & Hu, 2025), human-AI civic communication

(Overney, 2025), and frameworks centred on human autonomy in AI governance (Subías-Beltrán et al., 2025) together provide an ethical and governance toolkit for deploying AI responsibly in Malay manuscript preservation.

Table 6. Taxonomy of Studies on Ethical, Social, and Governance Implications of AI in Cultural Contexts

Dimension	Specific Issue	Proposed Approach / Framework	Sources
Ethical Implications	AI bias & fairness	Managing and mitigating algorithmic bias	Rana et al., 2023
		Automation bias in generative AI	Carnat, 2024
	Credibility & responsibility	Evidence traceability and accountability	Zhang, 2026
		Moral responsibility in AI deployment	Humphreys et al., 2024
	Autonomy & human oversight	Upholding human autonomy in governance	Subías-Beltrán et al., 2025
		Autonomy risks in chatbots (Socratic method)	Lu & Hu, 2025
Social Implications	Best practices in research/writing	Ethical use of AI in academia	AlSamhori & Alnaimat, 2024; Hind et al., 2024
	Empowerment & inclusion	Community participation in preservation	Rachman, 2024
		Empowering library users through AI	Hodonu-Wusu, 2025
	Human vulnerability & influence	Modelling AI influence and resilience	Beg, 2026
Governance Implications	Civic & community engagement	Constructive civic communication via AI	Overney, 2025
	Global justice & equity	AI and global justice considerations	Sahebi & Formosa, 2024
		AI in electoral governance (SEA)	Syafhendry et al., 2025
		AI in healthcare information systems	Vajjhala et al., 2025

Dimension	Specific Issue	Proposed Approach / Framework	Sources
	Regulatory frameworks	EU AI Act and automation bias	Carnat, 2024

Strategic Adoption, Sustainability, and Future Trends in Digital Libraries

The long-term viability of digital preservation depends on strategic planning, sustainable implementation, and forward-looking institutional thinking. The sustainability framework proposed for Malay manuscript digital libraries identifies five interdependent dimensions—technological infrastructure, financial resources, human capacity, institutional support, and community engagement—and argues that all must be addressed in concert (N. Hassan & Saman, 2022; N. C. Hassan et al., 2023). A regional survey of AI adoption in ASEAN libraries documents a substantial gap between vision and practice, with common barriers including funding shortages, skill gaps, infrastructure deficits, and unclear policy, alongside success factors such as strategic partnerships and in-house capacity building (Xu et al., 2025).

Forward-looking studies argue for human-machine collaboration in which generative AI augments rather than replaces librarians and curators through synthetic training data, automated metadata, multilingual translation, and interactive virtual exhibits (Goh et al., 2023). Multidimensional frameworks for internet information behaviour (Liao et al., 2025) and surveys of lecturers' perceptions of digital libraries (Aliyyah et al., 2024) provide user-centred design principles. Lessons from the transition to interactive digital mapping in tourism (Tarmizi et al., 2025), metatags-based research-topic analysis (Mukherjee et al., 2024), big data analytics in library knowledge management (AKANBIEMU, 2024), librarian thinking skills for Industry 4.0 (Mohideen et al., 2022), and AI-driven sustainable human resource management (Jia & Hou, 2024) collectively map the strategic, sustainable, and future-oriented considerations required to make Malay manuscript digital libraries institutionally viable and socially relevant.

Table 7. Taxonomy of Studies on Strategic Adoption, Sustainability, and Future Trends in Digital Libraries

Dimension	Specific Issue	Proposed Approach / Framework	Sources
Sustainability Frameworks	Balancing sustainability factors	Holistic framework for digital library implementation	N. Hassan & Saman, 2022; N. C. Hassan et al., 2023
Strategic Adoption	AI adoption in ASEAN libraries	Survey of drivers, barriers, best practices	Xu et al., 2025
	Human-machine collaboration	Generative intelligence in digital libraries	Goh et al., 2023
	Lecturers' perceptions	Digital libraries as Industry 4.0 learning resources	Aliyyah et al., 2024

Dimension	Specific Issue	Proposed Approach / Framework	Sources
Future Trends & Analysis	Transition from traditional to digital	Digital project adoption in tourism	Tarmizi et al., 2025
	Internet information behaviour	Multidimensional behaviour framework	Liao et al., 2025
	Research topic analysis	Multi-module ML for metatags analysis	Mukherjee et al., 2024
	Big data analytics in libraries	Integration into knowledge management	AKANBIEMU, 2024
	Librarian skills for Industry 4.0	Thinking skills for the future	Mohideen et al., 2022
	AI-driven sustainable HRM	AI, conscientiousness, and engagement	Jia & Hou, 2024

Discussion

The synthesis across the seven thematic areas reveals a complex and rapidly evolving landscape. The field has moved beyond isolated technical experiments toward a more integrated and socially conscious agenda. A consistent pattern is the recognition that AI technologies, while powerful, are not a panacea; the most promising pathways involve careful orchestration of technical innovation, cultural sensitivity, community engagement, and institutional sustainability.

Three overarching insights emerge. First, deep learning models, particularly CNNs and GANs, offer substantial promise for the core tasks of manuscript restoration and transcription, but performance depends critically on the quality and representativeness of training data; collaborative data curation across computer scientists, palaeographers, and cultural heritage professionals is essential. Second, the surge in publications on integrating AI with local wisdom and education signals a shift from preservation as an end in itself to preservation as cultural transmission; digital library initiatives should be designed from the outset with educational applications in mind. Third, ethical, social, and governance considerations are central rather than peripheral; without robust safeguards there is a real risk that AI becomes a tool of digital colonialism, extracting value from cultural heritage without returning benefits to source communities.

The theoretical implications challenge purely technocentric views. The sustainability framework of N. Hassan and Saman (2022) is a useful step, but more sophisticated models drawing on science and technology studies, critical heritage studies, and information science are needed to understand the mutual shaping of AI technologies and their social contexts. The concept of human-machine collaboration (Goh et al., 2023) provides a promising lens: the goal is to augment, not replace, human expertise in culturally appropriate and ethically sound ways.

Practically, the findings provide a clear roadmap. The most immediate and impactful applications are image restoration and OCR for Jawi script, but technical work must be coupled with investment in local capacity (Mohideen et al., 2022) and partnerships with computer science groups. Educators can draw on Ethno-STEM

materials (Nur & Januardi, 2025) and folk-story integration (Rahmi & Othman, 2026) for culturally relevant learning. Policymakers should support national and regional strategies for sustainable adoption, addressing funding, infrastructure, and human resources alongside ethical oversight and community participation.

Limitations of this review must be acknowledged. Restriction to English-language sources may have excluded substantial Malay and Indonesian scholarship; the focus on peer-reviewed material excludes informative grey literature; search strings may not capture all relevant terminology; quality assessment is unavoidably subjective; and the 2020–2025 window omits earlier foundational work. Future research should include multilingual systematic reviews, target grey literature, conduct longitudinal real-world evaluations, extend coverage to scripts beyond Jawi (Rencong, Rejang, Lontara), employ participatory action research with manuscript-owning communities, and explore multimodal models that integrate text, image, and audio for richer heritage experiences.

CONCLUSION

This systematic review synthesised 76 peer-reviewed studies to map the opportunities and challenges that artificial intelligence presents for the digital preservation of Malay manuscripts. AI-driven techniques, particularly deep learning for image restoration and OCR, have demonstrated substantial technical promise for transcribing and repairing damaged Jawi scripts. Natural language processing supports semantic analysis and knowledge management of religious and historical content, while AI-powered educational platforms open novel pathways for transmitting local wisdom and script literacy. The field has also matured beyond purely technical concerns to embrace ethical, social, and governance considerations, including data sovereignty, algorithmic bias, and community-centred design.

Successful AI adoption requires a strategic framework that balances technological innovation with investments in human capacity, sustainable infrastructure, and robust ethical oversight. Digital library initiatives should be holistically designed to integrate restoration and transcription with educational applications and community engagement. The theoretical contribution lies in demonstrating that the most promising pathways involve human-machine collaboration rather than full automation. Future work should address gaps in multilingual coverage, longitudinal evaluation, and participatory co-design, and should advance comprehensive annotated datasets for the diverse scripts of the Malay archipelago. By addressing these priorities, the research community can ensure that artificial intelligence becomes a responsible and effective ally in safeguarding this irreplaceable cultural heritage for future generations.

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