

Analyzing Deterioration in Ancient Documents through Preservation and Conservation Practices: A Systematic Literature Review

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Abstract

[Analyzing Deterioration in Ancient Documents through Preservation and Conservation Practices: A Systematic Literature Review] This study analyzes deterioration in ancient documents and the preservation–conservation practices used to address it through a systematic literature review of 14 selected articles published between 2022 and 2025. Ancient documents remain highly vulnerable to complex deterioration mechanisms, including chemical degradation, ink corrosion, fungal activity, environmental instability, and mechanical fragility. Using the PRISMA framework, this review identifies recurring deterioration patterns, evaluates the effectiveness of preservation and conservation strategies, and highlights challenges in their implementation. Findings reveal that integrated approaches combining physical conservation, such as deacidification, fiber strengthening, fumigation, and antifungal treatments with digital methods, including high-resolution digitization, OCR, NLP, multispectral imaging, and AI-based restoration, provide the most effective protection. Scientific innovations, including nanocellulose and TiO₂-based treatments, show promising results in stabilizing aged documents, while digital preservation reduces physical handling and improves long-term accessibility. However, limitations remain, particularly in regions with restricted resources, where high equipment costs, limited expertise, and inconsistent conservation standards hinder optimal implementation. In the Indonesian context, tropical climatic conditions further increase the risk of biodeterioration and emphasize the need for scalable and sustainable preservation methods. This review concludes that future research must prioritize affordable conservation technologies, long-term evaluation of nanomaterials, enhancement of AI datasets for local scripts, and the integration of traditional, scientific, and digital approaches. These efforts are essential to ensure the long-term survival and accessibility of ancient documentary heritage.

Keywords: deterioration, ancient documents, preservation, conservation, digital restoration, nanotechnology

Abstrak

Studi ini melakukan analisis terhadap kerusakan pada dokumen kuno serta praktik pelestarian dan konservasi yang diterapkan untuk mengatasinya melalui tinjauan literatur sistematis dari 14 artikel terpilih yang diterbitkan antara tahun 2022 dan 2025. Dokumen kuno sangat rentan terhadap berbagai mekanisme kerusakan yang kompleks, seperti degradasi kimia, korosi tinta, aktivitas jamur, ketidakstabilan lingkungan, dan kerapuhan mekanis. Dengan menggunakan kerangka PRISMA, tinjauan ini mengidentifikasi pola kerusakan yang berulang, mengevaluasi efektivitas strategi pelestarian dan konservasi, serta menyoroti tantangan dalam penerapannya. Temuan menunjukkan bahwa pendekatan terintegrasi yang mengombinasikan konservasi fisik, seperti deasidifikasi, penguatan serat, fumigasi, dan perawatan antibakteri dengan metode digital, termasuk digitalisasi resolusi tinggi, OCR, NLP, citra multispektral, dan restorasi berbasis AI, memberikan perlindungan yang paling efektif. Inovasi ilmiah, termasuk perlakuan berbasis nanoselulosa dan TiO₂, menunjukkan hasil yang menjanjikan dalam menstabilkan dokumen tua, sementara pelestarian digital mengurangi penanganan fisik dan meningkatkan aksesibilitas jangka panjang. Namun, masih ada keterbatasan, terutama di daerah dengan sumber daya terbatas, di mana biaya peralatan yang tinggi, kurangnya keahlian, dan standar konservasi yang tidak konsisten menghambat penerapan yang optimal. Dalam konteks Indonesia, kondisi iklim tropis semakin meningkatkan risiko biodeteriorasi dan menekankan pentingnya metode pelestarian yang dapat diskalakan dan berkelanjutan. Tinjauan ini menyimpulkan bahwa penelitian mendatang harus memprioritaskan teknologi konservasi yang terjangkau, evaluasi jangka panjang terhadap nanomaterial, peningkatan dataset AI untuk aksara lokal, dan integrasi pendekatan tradisional, ilmiah, dan digital. Upaya ini sangat penting untuk memastikan kelangsungan hidup dan aksesibilitas jangka panjang warisan dokumenter kuno.

Kata kunci: deteriorasi, dokumen kuno, preservasi, konservasi, restorasi digital, nanoteknologi

1. Introduction

The deterioration of ancient documents has become one of the most widely discussed issues in preservation research today due to the increasingly complex forms of physical decay, environmental threats, and the growing urgency to protect fragile historical materials. Ancient documents are evidence of the rich thoughts and high intellectual attitudes of the nations that created them (Pandanwangi, A., et al. 2022). Indonesia is one of the countries rich in ancient documents (Yanuarmi, D., 2020). Based on the Indonesian Data Portal website, inventory data compiled by the National Library of Indonesia in 2024 shows that the number of preserved library materials, specifically ancient documents in the form of palm leaves, reached 606 copies, while paper documents reached 870 copies. However, this number is still relatively small when compared to the estimated total number of ancient documents scattered across various regions, especially in East Java, both in formal institutions and private collections. Meanwhile, on the Satu Data Indonesia Portal website, inventory data collected from various regencies and cities in East Java shows that in 2024, there was only 1 active ancient document in Blitar Regency, and in 2024, there were 2 active ancient documents in Malang City. Based on the statistical findings, the need to preserve existing ancient collections printed is becoming increasingly apparent. Where preservation strategies and conservation practices for ancient documents can effectively preserve and address future fragility.

Over the past several decades, research on the preservation of ancient documents has increasingly focused on identifying the chemical, environmental, and biological mechanisms that accelerate the deterioration of fragile manuscript materials (Yan, Y., et al. 2025). The intersection between preservation science and documentary heritage management is grounded in the urgency to address critical issues such as paper acidification, ink corrosion, fungal contamination, fluctuating temperature and humidity, and inadequate storage conditions problems that remain prevalent in many archival and library institutions across developing regions (Putra, E. & Widya A. 2023). However, this intersection also raises further questions about how preservation and conservation strategies are implemented, what scientific diagnostics are used to assess degradation, the extent of institutional capacity, and how decision making affects the long-term survival of ancient materials.

Rapid advancements in conservation chemistry and non-invasive analytical technologies have offered new pathways for mitigating deterioration. Studies in conservation chemistry have shown that paper degradation is strongly influenced by oxidative reactions and residual acids in cellulose, highlighting the need for scientifically grounded deacidification and stabilization methods (Di Turo, F., et al. 2025). Similarly, innovations such as multispectral imaging and spectral diagnostics have provided conservators with deeper insights into hidden text features, ink corrosion patterns, and structural weaknesses that are not visible to the naked eye (Di Turo, F., et al. 2025). Other research has demonstrated that nanocellulose-based reinforcement can significantly enhance the mechanical strength of aged paper, making it a promising method for modern conservation practices (Jiang, M. et al. 2025).

In the Indonesian context, preservation challenges are further compounded by tropical climatic conditions, limited storage infrastructure, and uneven implementation of conservation standards across

institutions. Studies conducted at the National Library of Indonesia and regional archival centers reveal recurring issues such as uncontrolled humidity, dust accumulation, biological infestations, and restricted access to specialized conservation equipment (Putra, E. & Widya A. 2023). These findings highlight ongoing gaps in both technical capacity and resource availability, underscoring the need for integrated preservation conservation frameworks that combine scientific diagnostics, environmental monitoring, and sustainable management practices.

Therefore, the present study aims to contribute to the growing body of scholarship on ancient document preservation by presenting a systematic literature review that examines how deterioration is addressed through combined preservation and conservation strategies. This study additionally explores unresolved issues such as limited institutional readiness, insufficient application of diagnostic technologies, the complexity of restoring severely damaged artifacts while maintaining authenticity, and the challenges surrounding digital preservation initiatives in resource-limited environments. The paper is structured into five sections, the background and context of the study, a review of related works on degradation mechanisms and preservation–conservation approaches, the research methodology, the presentation of results, and finally, a discussion of findings, implications for future conservation practices, and recommendations for further research.

2. Literature Review

2.1. Deterioration in Ancient Documents

Deterioration in ancient documents is a multifaceted process involving physical, chemical, and biological degradation that impacts materials such as paper, parchment, bamboo, and silk. These substrates are vulnerable due to their organic nature and varying production quality. Environmental fluctuations, particularly changes in temperature and humidity, cause fibers to expand and contract, which leads to brittleness and structural weakening. Additionally, prolonged exposure to light, especially ultraviolet rays, accelerates chemical reactions that deteriorate inks and pigments, causing fading and discoloration (Abdel-Maksoud et al. 2022). Intrinsic factors, or inherent vice, also play a crucial role in the degradation process. Many ancient documents were created using acidic materials or low-quality fibers that naturally break down over time, regardless of external conditions. Unstable inks and pigments may fade, bleed, or flake, further reducing legibility (Liu et al. 2025).

2.2. Preservation and Conservation Practices

Preservation and conservation practices are essential to stabilize, protect, and prolong the life of ancient documents through a combination of preventive and interventive approaches (Zakiyyah, 2022). Preservation primarily aims to maintain optimal storage and environmental conditions to minimize deterioration risks. This includes regulating temperature and humidity levels, using protective enclosures,

implementing disaster preparedness plans, and promoting digitization to reduce handling of fragile originals.

Contemporary preservation and conservation increasingly emphasize scientific analysis and the use of sustainable, reversible materials that minimize harm to documents. Minimally invasive techniques are preferred to maintain both the physical condition and authenticity of ancient texts. This integrated approach ensures that interventions not only prevent further decay but also preserve the cultural and historical significance of the documents for future generations (Nurpratama, 2025).

3. Research Method

Throughout this systematic review, PRISMA is followed as a guide because it is commonly used in educational research projects due to its three advantages. First, it helps to check large research databases of articles and other literature. Second, clearly answer research questions for a smooth and systematic research process, and finally make researchers able to identify literature-related inclusion and exclusion criteria (Ramalingam et al., 2022). For resources, this study relied on four pages as the main data, namely Google Scholar, IEEE Xplore, and Scopus, and to make it more thorough, the PRISMA guide was used in the literature collection to identify Preservation and Conservation as the practice of preserving ancient manuscripts exposed to deterioration.

3.1. Research Questions

Based on the research questions formulated in this study, we seek to explore the various dimensions related to the destruction of ancient documents and the efforts made to preserve their longevity. The first step is to identify the various preservation and conservation practices used to address the physical, chemical, and biological damage in ancient documents. This allows for a comprehensive understanding of the methods commonly adopted in archives, libraries, and museum settings.

Q1: What recurring deterioration patterns are observed in ancient documents according to existing preservation studies?

Q2: How effective are the preservation and conservation practices reported in previous studies in slowing down or preventing the deterioration of ancient documents?

Q3: What challenges are encountered in implementing preservation and conservation practice to address the deterioration of ancient documents?

3.2. Search Strategy

3.2.1. Search Terms

The search on the article page is required to be specific, this is so that the search results can be according to the author's wishes and can be reviewed. Therefore, it is formulated the keywords that will be used with the help of Boolean search operators. The Boolean search operators, 'AND,' 'OR,' and 'NOT,' are

used to make very broad findings narrow and specific to keywords (Uegaki, 2022). The keywords used to perform the search can be seen in table 1 below.

Table 1. Boolean AND

No	Database	Kata Kunci
1	Google Scholar	"Deterioration" AND "Ancient Documents" AND "Preservation" AND "Conservation"
2	IEEE Xplore	Deterioration AND Ancient Documents AND Preservation AND Conservation
3	Scopus	TITLE-ABS-KEY ((Deterioration) AND (Ancient Documents) AND (Preservation) AND (Conservation))

3.2.2. Eligibility Criteria

In determining the eligibility of the literature, we formulated some exclusion criteria. We excluded studies that focus on materials other than ancient documents, such as artifacts, buildings, or photographs unrelated to ancient documents. We also excluded studies that mention preservation or conservation but do not describe specific methods, techniques, or strategies used to address deterioration. Furthermore, studies that do not evaluate the effectiveness or challenges of preservation and conservation practices were excluded. Lastly, we limited our scope to recent publications from 2022 onward, excluding studies published before 2022 to focus on the latest research and developments in the field. The following are the criteria for articles to be considered worthy of being a source of research data:

Table 2. Exclusion Table

No	Criteria	Explanation
1	Focuses on materials other than ancient documents	Studies discussing the preservation of artifacts, buildings, photographs, or other cultural objects that are not related to ancient documents.
2	Does not describe preservation or conservation practices	Studies that mention preservation and conservation in general but do <i>not</i> explain the methods, techniques, or strategies used to address deterioration
3	Does not discuss the effectiveness or challenges of preservation and conservation practices	Studies that do <i>not</i> evaluate how effective the preservation and conservation methods are or do <i>not</i> describe challenges encountered during their implementation
4	Published before 2022	Studies published before 2022 and therefore outside the selected publication range (2022–2025).

3.2.3. Review Strategy

The systematic literature review process has two stages. In the first stage, the author downloads all the literature searched with keywords on various existing journal pages, then assesses the title and abstract based on exclusion criteria. In the second stage, after the title and abstract have been reviewed by the author, the literature that meets the eligibility criteria goes through the review process. In the review process, the author reads the entire text in the literature and makes an assessment with reference to the exclusion criteria.

Finally, literature that meets these criteria is then reviewed in more depth to ensure that the author comprehensively understands the content of the literature.

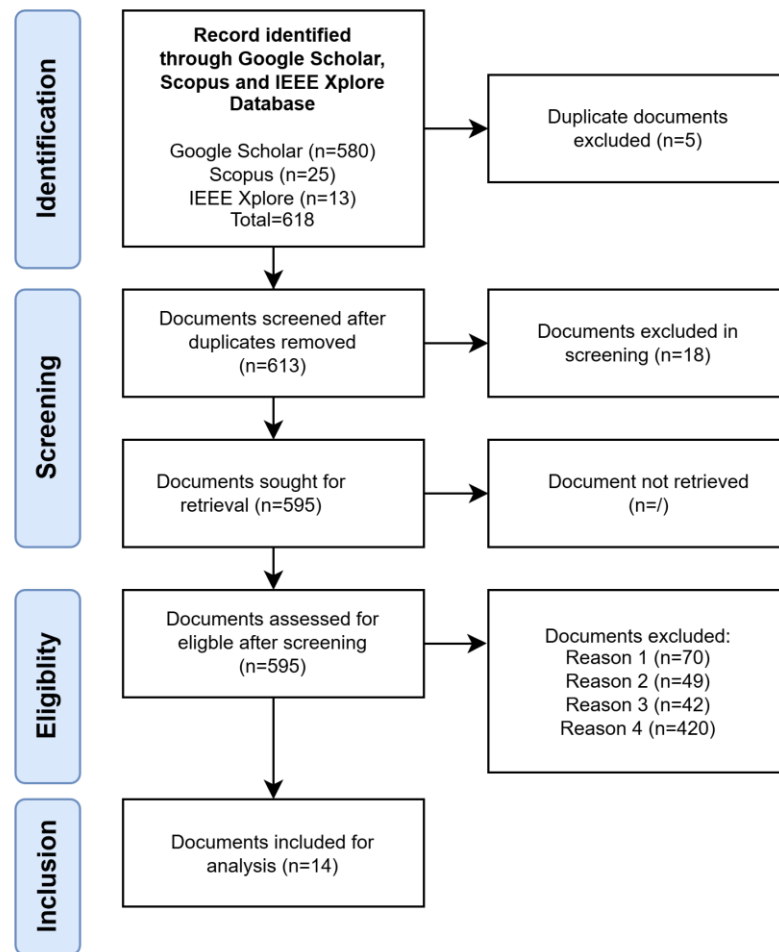


Figure 1. PRISMA diagram of review result

4. Result and Discussion

4.1. Result

4.1.1. General Findings

Table 3. Documents reviewed based on journals, titles, & citations

No	Article title	First Author	Publication	Year	Citations
1	Ancient Chinese Document Enhancements Analysis: Techniques, Challenges, and Future Directions	Huize Hou	International Journal Document Analysis and Recognitions	2025	1
2	Preserving Historical Documents Using OCR and Natural Language Processing (NLP)	Mirzokhid Askarov	International Conference on Computational Innovations and Engineering Sustainability (ICCIES)	2025	0

3	Document Deterioration Classification Using Gabor Filters and Ensemble Classifiers Integrated With LIME	Anantha Hothri Inuguri	International Conference on Machine Learning and Data Engineering	2025	1
4	The chemistry behind paper restoration: diagnostic techniques and cutting-edge innovation	Francesca Di Turo	ChemTexts: The Textbook Journal of Chemistry	2025	2
5	Application of AI in the Field of Documentary Heritage: A Review of the Literature	Yaohan Lu	Journal of Artificial Intelligence Research	2024	1
6	Preserving the Heritage for the Future: A Case Study on the Light of the State Archives, West Bengal	Tathagata Dhar	International Journal of Information Studies & Libraries	2022	0
7	Evolution of the Hanji-making Technology, from Ancient Times to the Present	Oh-Kyu LEE	Journal of the Korean Wood Science and Technology	2023	6
8	Textual heritage and digital archives – the case of the Hyakugo Archive in Kyoto	Edoardo GERLINI	Open Resource Europe	2023	1
9	ArchiVico Digitale: a comprehensive and synergistic approach for the preservation and dissemination of local memory to strengthen identity	Claudio Loconsole	CINECA IRIS Institutional Research Information System	2023	0
10	Deteriorated characters restoration for early japanese books using enhanced cyclegan	Hayata Kaneko	Journal Heritage	2023	19
11	An Eco-Friendly Approach Utilizing Green Synthesized Titanium Dioxide Nanoparticles for Leather Conservation against a Fungal Strain, <i>Penicillium expansum</i> AL1, Involved in the Biodeterioration of a Historical Manuscript	Amr Fauda	Journal Biology	2023	20
12	Preservation of Ancient Manuscripts “Sanghyang Siksa Kandang Karesian” at the National Library of Indonesia	Yohana Grace Cristianingtyas	Indonesian Journal of Humanities and Social Sciences	2024	0
13	<i>Pinus Rigida</i> Wood Extract as an Antifungal Activity for a Model Paper and Leather That is Comparable to Historical Manuscripts: An Experimental Research	Ayman Salah Taha	Egyptian Journal of Chemistry	2025	2

14	A Brief Review of Artificial intelligence Applied to Digital Conservation and Restoration of Cultural and Artistic Heritage	Fuentes Penna	International Journal of Combinatorial Optimization Problems & Informatics	2025	0
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Note. *Citations are based on Google Scholar data retrieved on December 4, 2025

4.1.2. Main Findings

Table 4 shows a list of the main statements that discuss the preservation and conservation practices that the author considers to be the most effective in overcoming the problem of deterioration of ancient documents.

Table 4. Findings of the systematic review of selected documents

No	Practices Examined	Main Statements	Short Summary
1	Digital Preservation and Conventional Conservation	“Ideally, digital and physical conservation strategies should proceed in tandem, with digitization acting as both a safeguard (through creating high-quality surrogates) and a research catalyst (by enabling new analytical procedures).” (Hou, H. & Xie, Y. 2025).	Ancient Chinese documents face major preservation challenges due to the fragile nature of their materials, such as bone, bamboo, silk, and paper, which are prone to weathering, ink fading, insect damage, and fragmentation over time. This complexity is exacerbated by changes in the shape of scripts throughout history, so their analysis and interpretation require special expertise. To address such vulnerabilities, preservation must combine physical and digital conservation simultaneously, where digitization serves as a form of protection through the creation of high-quality copies as well as as a research drive that enables new methods of analysis.
2	Digital Preservation and Conservation using NLP algorithms and OCR.	“An option that can be considered to enhance this includes the application of Natural language Processing (NLP) algorithms to the processes of OCR.” (Askarov, M. 2025).	These papers collectively examine advanced, cross-disciplinary methods for digitizing, preserving, and analyzing ancient Chinese and historical manuscripts. They showcase the use of multispectral imaging, 3D scanning, LiDAR, and AI-driven OCR, NLP, and deep learning (including GANs) to enhance text capture, recognition, and reconstruction for long-term digital access. They also underscore the need for collaboration among archaeologists, paleographers, and

			digital humanities experts to overcome challenges related to material fragility, complex layouts, and deteriorating conditions, ensuring the preservation and understanding of cultural heritage for future generations.
3	Digital Preservation and Conservation	"The novel technique combines Gabor feature extraction with an ensemble classifier, providing a more accurate solution for identifying and enhancing deteriorated manuscripts." (Inuguri, A. H. 2025).	This article discusses ancient manuscripts that are vulnerable to natural damage, making identification and analysis difficult. To address this, the study introduces a technique combining gabor feature extraction with an ensemble classifier to improve accuracy in detecting, recognizing, and clarifying heavily degraded text. By using more adaptive texture pattern calculations, the model produces more stable and effective restoration results, supporting the preservation, digitization, and reuse of ancient manuscripts.
4	Digital Preservation and Traditional Conservation	"Moreover, modern restoration methodologies such as deacidification, nanotechnology, and other advanced chemical treatments have introduced promising solutions that extend the lifespan of paper-based works" (Di Turo, F., et al. 2025).	The collection of documents outlines the chemical, environmental, and technological factors that influence paper and cultural heritage deterioration. It explains mechanisms such as acid hydrolysis, oxidation, and the roles of lignin, hemicelluloses, and cellulose in aging. It also highlights conservation techniques including nanotechnology-based coatings, eco-friendly cleaning, deacidification, and digital restoration, emphasizing minimally invasive and sustainable methods. Analytical tools like SEM, EDS, FTIR, NMR, and XRD are used to evaluate artifact conditions, supporting preservation strategies that combine chemistry, nanomaterials, and digital technologies for long-term conservation.
5	Digital Preservation and Conservation	"It is certain that the application of AI in the field of document protection will definitely develop in a diversified direction" (Lu, Y. 2024).	The collection of documents explores the application of artificial intelligence (AI) in the preservation, analysis, and restoration of documentary heritage and cultural artifacts.

			They highlight trends in research, technological methods such as deep learning and image processing, and the distribution of scholarly activity across different countries. The studies emphasize the potential of AI to improve digital restoration, content recognition, and long-term preservation, while also identifying challenges and future directions for integrating AI into heritage conservation strategies.
6	Digital Preservation and Conservation	“The main obstacle to the archivists is the increasing volume of records, and the simultaneous decrease in space” (Dhar, T. 2022).	This article outlines the comprehensive efforts made by the State Archives of West Bengal in preserving historical documents that are vulnerable to physical and chemical damage. Preservation begins through records management, then the process is carried out by the conservation unit, which implements preventive, restorative, and curative measures to address environmental threats and repair damaged documents. The technical methods used include fumigation, lamination, manual repair, and paper leveling, as well as deacidification procedures using the Aqueous (Barrow's Method) and Non-Aqueous methods to neutralize the acidity of the paper.
7	Traditional Preservation and Conservation	“Consequently, traditional pretreatment methods are adhered to as much as possible to produce high-quality traditional Hanji” (Lee, O. 2023)	The document presents an overview of traditional Korean Hanji papermaking, outlining its historical development, manufacturing techniques, and cultural significance. It describes the evolution of molds such as Heulimtteugi, Gadoomtteugi, and Moknamutteugi, noting their features, operational differences, and Chinese and Japanese influences. It also addresses technological changes during the Japanese occupation, including chemical bleaching and mechanical beating, which affected Hanji quality. Overall, it highlights the need to preserve traditional methods while understanding their historical

			context to maintain Hanji's cultural and functional integrity.
8	Digital Preservation and Conservation	“Many programs for the digitization of documents and archives, especially those funded by public organizations and governments, go to great lengths to demonstrate the positive impact that these initiatives have on society and local communities” (Garlini, E. et al. 2023).	The collection of texts explores the multifaceted concept of textual and cultural heritage, emphasizing its evolving nature in the digital age. It discusses how heritage is constructed through processes like preservation, digitization, and heritagization, which transform physical documents and archives into symbols of cultural identity, political significance, and collective memory. The case study of the Hyakugo Archive of Tōji Temple exemplifies how digital technologies and heritage recognition influence the preservation and accessibility of historical documents, highlighting the dynamic, contested, and socially constructed aspects of heritage. The texts also analyze the distinctions between material and intangible heritage, the political implications of heritage practices, and the importance of community participation in shaping heritage narratives.
9	Digital Preservation and Conservation	“In order to preserve and disseminate the cultural and historical memory preserved in the HAV, the ‘ArchiVico Digitale’ project proposes a comprehensive and synergistic approach for the process of digitisation, cataloguing, web publication and dissemination of archival material providing the possibility of continuous interventions over time thanks to the provision of a permanent digitization ‘station’ with a planetary scanner” (Loconsole, C. et al. 2023).	The collection of texts explores the evolving relationship between heritage, particularly textual and digital archives, and their cultural, social, and political significance. It emphasizes that heritage is a dynamic, interpretive process shaped by active selection, contextualization, and contemporary recognition, rather than merely material preservation. The discussion highlights how digitization and heritagization transform archives into cultural assets, influencing collective memory, identity, and heritage practices, with case studies like the Hyakugo Archive illustrating these processes within UNESCO's Memory of the World framework.
10	Digital Preservation and Conservation	“However, the early Japanese books have been damaged, and some Kuzushi-ji are scratched and faded due to deterioration over the years. The damage increases the difficulty of	The "ArchiVico Digitale" project (2019-2022) focused on digitizing, restoring, cataloging, and publicly sharing documents from the Historical Archive of Vicopisano

		Kuzushi-ji recognition and prevents early Japanese book re-organization accuracy” (Kaneko, H. et al. 2023).	to preserve local history and foster community identity. It involved selecting key documents, restoring fragile materials, digitizing them, creating thematic paths, and publishing them on an Omeka-based online platform. The project resulted in 12 thematic paths with 194 documents and over 6,000 images, restored six archives, and engaged more than 160 students and teachers through educational activities, emphasizing collaboration among public and private entities and utilizing advanced digitization tools like a planetary scanner.
11	Digital Preservation and Conservation	“This enhanced CycleGAN enables high-quality restoration compared with the standard CycleGAN and binarization in the actual early Japanese book” (Fauda, A. 2023).	The document provides an in-depth exploration of the utilization of green synthesized titanium dioxide nanoparticles (TiO ₂ -NPs) for the conservation of leather artifacts, specifically targeting the fungal strain <i>Penicillium expansum</i> AL1, which contributes to the deterioration of historical manuscripts. It discusses the eco-friendly synthesis of TiO ₂ -NPs using <i>Lactobacillus plantarum</i> and their characterization through various techniques such as UV-Vis spectroscopy and transmission electron microscopy.
12	Digital Preservation and Traditional Conservation	“The existence of ancient manuscripts needs to be preserved considering that information about the history of past civilisations will still be needed to support science, both education, research, and other knowledge in the present and future” (Cristianingtyas, Y. H. 2024).	The document provides a comprehensive overview of the preservation activities for the "Sanghyang Siksa Kanda Karesian" (SSKK) manuscripts at the National Library of Indonesia. It emphasizes the importance of preserving these ancient manuscripts as cultural artifacts that convey historical knowledge, cultural values, and insights into the lives of past civilizations. The research highlights the methods used for both preventive and curative preservation, detailing specific practices employed by the library.
13	Traditional Preservation and Physical Conservation	“Pinus rigida wood extract was prepared in the current study at concentrations of 0.25%, 0.5%, and 1%. These extract concentrations were applied to model reference leather	This article examines the effectiveness of Pinus rigida wood extract as a natural antifungal agent for paper and leather that resembles historical manuscripts.

	Using Pinus Wood Extract	samples and generated cotton paper that was similar to the reported historical text” (Taha, A. et al. 2025).	Three types of fungi, namely <i>Aspergillus flavus</i> , <i>A. niger</i> , and <i>Fusarium culmorum</i> were tested on treated sheets of paper and leather. As a result, <i>Pinus rigida</i> extract at a concentration of 0.5-1% was able to significantly inhibit the growth of <i>A. niger</i> and <i>F. culmorum</i> . SEM, FTIR, digital microscopy, and HPLC analyses support the findings of the extract's bioactivity. The study concludes that natural materials can be an environmentally friendly alternative to the conservation of historic documents and manuscripts.
14	Digital Preservation and Conservation using Artificial Intelligence (AI)	“In conclusion, it is necessary to carry out a reflection in cultural institutions towards the expansion of access to cultural and scientific heritage that, if it were not for digital platforms, such access would be limited” (Fuentes Penna, A., et al. 2025)	This article discusses how artificial intelligence is used in the conservation and restoration of cultural heritage, both tangible and intangible. AI is used for object classification, 3D reconstruction, simulation of environmental conditions that cause damage, metadata optimization, text digitization, and multispectral image-based damage detection. The article also highlights the socio-political risks associated with digital technology adoption, including privacy issues, data extractivism, and social bias. Overall, the article confirms that AI can improve the efficiency, accuracy, and scale of heritage preservation.

Note. *Citations are based on Google Scholar data retrieved on December 4, 2025

4.2. Discussion

Research has been collected by the author in the form of 14 articles published in the form of a table showing that the correlation between the deterioration of ancient documents, preservation practices and conservation has a close relationship in implementing the preservation of past written cultural heritage actions in the modern era. The findings of the study show that external factors have an influence on the damage of ancient documents, such as environmental conditions, biological attacks, chemical composition of materials, and digital transformation play a major role in determining preservation and conservation strategies that can be implemented based on the level of physical damage to documents. In addition, the limitations of traditional methods that are inadequate for today's damage can open up opportunities for

technological developments such as OCR, NLP, Artificial Intelligence (AI)-based restoration techniques, and nanotechnology to build new insights into understanding, analyzing, and preserving ancient documents.

The collected research opens up a variety of new perspectives, showing that physical and digital preservation are not two separate approaches, but rather complementary in which manual restoration, material stabilization, and environmental control work in tandem with digitization, image processing, and long-term digital archival media transfer. By knowing the many scientific perspectives from the collected literature, a more detailed mapping can be prepared of how chemical, biological, environmental, and technological factors are intertwined in building modern preservation and conservation strategies.

4.2.1. Patterns of Deterioration

The findings in the studies studied showed a relatively consistent pattern of damage across different regions and document types. Common damage that occurs includes ink fading, acidification of paper that has cellulose material, and biological damage such as fungal growth or insect infestation. Damage from ink oxidation is also related to environmental degradation of materials such as bamboo, silk, and paper that complicates the process of interpreting ancient documents in China (Hou & Xie 2025). It is known that as a result of a decrease in pH, ink oxidation and continuous degradation of cellulose can make old paper brittle due to the weakening of the cellulose structure (Mou, H. et al. 2024).

The main causes of the deterioration of historical documents, namely ink fading and physical degradation sourced from extreme weather conditions analyzed using OCR and NLP (Askarov, 2025). In addition, environmental exposure in the form of pollutants, light, humidity, fluctuating RH and temperature can accelerate oxidation and degradation of materials (Fornari, A. 2022). Not stopping at damage due to natural factors, physical and mechanical damage such as tears, fragile paper, and loss of paper's strength to fold due to weakening of cellulose are also reasons for the deterioration of ancient manuscripts (Jiang, M. et al. 2024).

Other research was also conducted on ancient documents that had skin material, where it was found that biodeterioration due to fungi such as *Penicillium expansum* is a major threat to organic artifacts, confirming that biological organisms remain the most significant damage factor for organic documents (Fauda, 2023). Biodeterioration is also caused by the attack of microorganisms and bacteria caused by uncontrolled storage of humidity and temperature (Kanth, A. P. 2023).

4.2.2. Effectiveness of Preservation and Conservation

One of the most promising recent developments in document conservation is the use of nanocellulose and nanomaterials. Research by Turo (2025) shows that deacidification, stabilization, cellulose, and nanotechnology-based coatings can slow down the oxidation stage and increase the strength of ancient documents with significant results. In addition, the use of natural extracts such as *Pinus rigida* has been shown to be effective as an anti-fungal agent in inhibiting the growth of *Aspergillus* and *Fusarium*, thus

providing a more eco-friendly alternative in physical conservation. The practices of using nanotechnology-based coatings and pine extracts not only improve the mechanical stability of the document, but are also able to inhibit the growth of microorganisms that are the main cause of biodeterioration.

Technically, digital preservation includes, high-resolution scanning, creation of digital metadata or catalogs, transliteration or transliteration, online publishing for information dissemination, and long-term digital storage. Digital preservation efforts allow ancient documents to survive in the modern era, as well as play a role in reducing physical pressure on the original manuscript, and democratizing access to knowledge (Putra, E. 2023).

In digital preservation, the use of OCR and NLP can also significantly improve the clarity of writing in manuscripts, especially in documents with characters that have been damaged, faded, or even invisible (Askarov, 2025). In addition, Artificial Intelligence (AI) technology, especially generative models and image enhancement, has proven to be effective for character reconstruction and advanced visual analysis. AI techniques such as CycleGAN, deep learning, and image reconstruction have also been proven to be able to recover lost characters and map damaged areas automatically, providing a non-invasive solution that complements physical conservation (Kaneko, 2023).

However, many studies emphasize that digital methods do not replace physical conservation, where the two are complementary and must be designed within a mutually supportive framework. Thus, conservation effectiveness is most optimally seen when physical and digital methods are used simultaneously, physical to save materials, and digital to save information.

4.2.3. Relevance to the Indonesia Context

Based on the article *Preservation Sanghyang Siksa Kandang Karesian* and other related studies, the challenge of document preservation in Indonesia is hampered by a humid tropical climate, which can trigger fungal growth, accelerated ink oxidation, and similar biological damage. In addition, preventive methods such as temperature and humidity regulation, document surface cleaning, and the use of acid-free storage materials are the main steps to keep manuscripts made of palm and paper to remain stable.

Although it is difficult to face climate challenges, the potential for digitalization in Indonesia is still huge. As research conducted by Askarov (2025) and Loconsole (2023) shows that digital preservation can help reduce the risk of physical handling as well as increase public access to local collections through online platforms based on modern digital archives. The combination of digital or traditional use of preservation and conservation practices is seen to be of the highest relevance in the Indonesian context, especially when environmental and facility constraints do not allow the use of advanced scientific conservation methods such as nanomaterials or spectroscopy.

4.2.4. Limitations in Implementation

Several challenges arise in implementation practices on preservation, especially in environments that have limitations in resources. First, the majority of conservation techniques are science-based and require

relatively high cost laboratory facilities, chemical materials, and scientific equipment, making them difficult to apply to small-scale institutions. The cost of scientific analysis equipment such as SEM, FTR, and XRD is very high, so not all institutions are able to implement the practice routinely every day (Di Turo, F., et al. 2025). Second, digital technologies such as multispectral imaging and AI require high-capability hardware and quality datasets, which are not always available. Third, in conservation activities, there are limitations of the physical nature of documents which are the main challenge.

Other challenges related to the inconsistency of conservation standards between institutions, the lack of trained human resources and researchers with interdisciplinary backgrounds (chemistry, materials, conservation, or digital humanities) are often rare, as well as technical risks such as the potential loss of authenticity when digital reconstruction is carried out excessively (Cristianingtyas, 2024). In addition, most of the studies reviewed did not discuss the long-term impact of the methods used, so empirical evidence on long-term effectiveness is limited, so it cannot be guaranteed to be beneficial for sustainability in the future.

4.2.5. Implication and Future Research Directions

Based on the findings of the Systematic Literature Review, there are several important implications that can be applied to subsequent research. First, future conservation strategies require a clear integration of physical methods, scientific diagnostics, and digital technologies to ensure the comprehensive protection of document materials and information. Second, further research needs to evaluate the long-term effectiveness of nanomaterials such as TiO₂ and nanocellulose, as tested by Taha (2025) and Turo (2025), so that their use can be standardized across the different types of materials used in the document. Third, research needs to develop local script datasets to improve OCR and AI performance in Javanese, Balinese, Bugis, or Malay scripts. Finally, a study of conservation technology at low cost is needed, especially for regional institutions that do not have access to modern laboratories, so that conservation strategies can still be carried out efficiently and sustainably.

5. Conclusion

This systematic review has provided a comprehensive understanding of how deterioration in ancient documents is addressed through a wide range of preservation and conservation practices across different disciplines. The analysis and findings show that deterioration, whether caused by chemical degradation, ink corrosion, biological infestation, environmental instability, or mechanical fragility continues to pose a major threat to the survival of documentary heritage worldwide. Among the fourteen selected studies, most authors emphasize that traditional conservation methods, when combined with modern scientific diagnostics and digital technologies, represent a new era in heritage preservation. These studies consistently support the view that integrated approaches such as deacidification, nanotechnology-based strengthening, antifungal treatments, high-resolution digitization, OCR, NLP, multispectral imaging, and AI-assisted restoration are essential for improving both material stability and informational accessibility. Therefore, the present review provides a consolidated overview of recent

literature (2022–2025) that systematically maps the strategies, effectiveness, and emerging innovations used to safeguard ancient documents facing complex deterioration patterns.

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Daftar Pustaka

- Abdel-Maksoud, G., et al. (2022). Fungal Biodeterioration of a Historical Manuscript Dating Back to the 14th Century: An Insight into Various Fungal Strains and Their Enzymatic Activities. *Life*, 12(11). <https://doi.org/10.3390/life12111821>
- Ariyani Iskandar, F., & Irawati, I. (2023). Penelitian Etnografi Virtual dalam Mengkaji Fenomena Masyarakat Informasi di Media Sosial: Tinjauan Literatur Sistematis. *Anuva*, 7(4), 679–696. [10.14710/anuva.7.4.679-696](https://doi.org/10.14710/anuva.7.4.679-696)
- Askarov, M., et al. (2025, December 6). Preserving Historical Documents Using OCR and Natural Language Processing (NLP). 2025 International Conference on Computational Innovations and Engineering Sustainability, ICCIES 2025. <https://doi.org/10.1109/ICCIES63851.2025.11032769>
- Cristianingtyas, Y. G. (2024). Preservation of Ancient Manuscripts “Sanghyang Siksa Kandang Karesian” at the National Library of Indonesia. *Indonesian Journal of Humanities and Social Sciences*, 5(3). <https://ejournal.uit-lirboyo.ac.id/index.php/IJHSS>
- Dhar, T., & Roy, S. (2022). Preserving the Heritage for the Future: A Case Study on the Light of the State Archives, West Bengal. *International Journal of Information Studies & Libraries*, 7(1). https://www.academia.edu/104183672/Preserving_the_Heritage_for_the_Future_A_Case_Study_on_the_Light_of_the_State_Archives_West_Bengal
- Di Turo, F. (2025). The chemistry behind paper restoration: diagnostic techniques and cutting-edge innovation. *ChemTexts*, 11(3). <https://doi.org/10.1007/s40828-025-00203-9>
- Fornari, A., et al. (2022). A Review of Applications of Nanocellulose to Preserve and Protect Cultural Heritage Wood, Paintings, and Historical Papers. *Applied Sciences (Switzerland)*, 12(24). <https://doi.org/10.3390/app122412846>
- Fouda, A., et al. (2023). An Eco-Friendly Approach Utilizing Green Synthesized Titanium Dioxide Nanoparticles for Leather Conservation against a Fungal Strain, *Penicillium expansum* AL1, Involved in the Biodeterioration of a Historical Manuscript. *Biology*, 12(7). <https://doi.org/10.3390/biology12071025>

- Fuentes Penna, A., et al. (2025). A Brief Review of Artificial intelligence Applied to Digital Conservation and Restoration of Cultural and Artistic Heritage. *International Journal of Combinatorial Optimization Problems & Informatics*, 16(1). search.ebscohost.com
- Gerlini, E. (2023). Textual heritage and digital archives – the case of the Hyakugo Archive in Kyoto. *Open Research Europe*, 20. <https://doi.org/10.12688/openreseurope.16820.1>
- Hou, H., & Xia, Y. (2025). Ancient Chinese Document Enhancements Analysis: Techniques, Challenges, and Future Directions. *International Journal Document Analysis and Recognitions*, 28. <https://link.springer.com/journal/10032/volumes-and-issues/28-4>
- Imran, M., & Almusharraf, N. (2023). Analyzing the role of ChatGPT as a writing assistant at higher education level: A systematic review of the literature. *Contemporary Educational Technology*, 15(4), 1–4. <https://doi.org/10.30935/cedtech/13605>
- Jiang, M., et al. (2025). Recent Advances in Paper Conservation Using Nanocellulose and Its Composites. *Molecules*, 30(2). <https://doi.org/10.3390/molecules30020417>
- Kaneko, H., et al. (2023). Deteriorated Characters Restoration for Early Japanese Books Using Enhanced CycleGAN. *Heritage*, 6(5), 4345–4361. <https://doi.org/10.3390/heritage6050230>
- Kanth, A. P., & Soni, A. K. (2023). Application of nanocomposites for conservation of materials of cultural heritage. In *Journal of Cultural Heritage* (Vol. 59, pp. 120–130). Elsevier Masson s.r.l. <https://doi.org/10.1016/j.culher.2022.11.010>
- Kementerian PPN/Bappenas (2024). Jumlah Bahan Perpustakaan dan Naskah Kuno yang di Preservasi milik Kabupaten/Kota Malang. <https://data.go.id/dataset/dataset/pelestarian-naskah-kuno-milik-kabupaten-kota2>
- Kementerian PPN/Bappenas (2024). Jumlah Bahan Perpustakaan dan Naskah Kuno yang di Preservasi milik Perpustakaan Nasional Republik Indonesia. data.go.id/dataset/dataset/jumlah-bahan-perpustakaan-dan-naskah-kuno-yang-dipreservasi2
- Lee, O. K., et al. (2023). Evolution of the Hanji-making Technology, from Ancient Times to the Present. *Journal of the Korean Wood Science and Technology*, 51(6), 509–525. <https://doi.org/10.5658/WOOD.2023.51.6.509>
- Liu, P., et al. (2025). Characterisation and restoration of a severely damaged paper archive from the Qing Dynasty. *Scientific Reports*, 15(1). <https://doi.org/10.1038/s41598-025-92134-1>
- Loconsole, C., et al. (2023). ArchiVico Digitale: a comprehensive and synergistic approach for the preservation and dissemination of local memory to strengthen identity. *Human Factors in Communication of Design*, 90, 89–95. <https://doi.org/10.54941/ahfe1003699>
- Lu, Y. (2024). Application of AI in the Field of Documentary Heritage: A Review of the Literature. *Journal of Artificial Intelligence Research*, 1(2), 15–21. <https://doi.org/10.70891/jair.2024.110005>
- Nurpratama, M. R. (2025). Strategi pelestarian naskah kuno di Indonesia dalam tinjauan literatur sistematis. *Daluang: Journal of Library and Information Science*, 5(1), 53–69. <https://doi.org/10.21580/daluang.v5i1.2025.25419>

- Pandanwangi, A., et al. (2022). Batik Naskah Kuno: Transformasi Iluminasi dari Naskah Kuno ke dalam Motif Batik. *Jurnal Panggung*, 8(4), 4. <https://jurnal.isbi.ac.id/index.php/panggung/issue/view/204>
- Putra, E., & Widya, A. (2023). Preservasi Koleksi Naskah Kuno (Manuskrip) dalam Bentuk Digital di Perpustakaan Nasional Republik Indonesia (Studi pada Pusat Preservasi dan Alih Media Bahan Perpustakaan). *Hybrid International Conference on Library and Information Science*, 355, 355–366. <https://doi.org/10.24252/literatify.vi.42828>
- Ramalingam, S., et al. (2022). Blended Learning Strategies for Sustainable English as a Second Language Education: A Systematic Review. *Sustainability (Switzerland)*, 14(13), 1–17. <https://doi.org/10.3390/su14138051>
- Taha, A. S., et al. (2025). Pinus Rigida Wood Extract as an Antifungal Activity for a Model Paper and Leather That is Comparable to Historical Manuscripts: An Experimental Research. *Egyptian Journal of Chemistry*, 68(1), 29–41. ejchem.journals.ekb.eg
- Yan, Y., et al. (2025). Chemical Conservation of Paper-Based Cultural Heritage. *Molecules*, 30(1). <https://doi.org/10.3390/molecules30010122>
- Yanuarmi, D. (2020). Aplikasi Motif Manuskrip pada Batik: Pewarisan Budaya melalui Proses Pembelajaran terhadap Mahasiswa ISI Padangpanjang. *Jurnal Studi Budaya Nusantara*, 4(1). <https://doi.org/10.21776/ub.sbn.2020.004.01.03>
- Zakiyyah, F. N., et al. (2022). Preservasi naskah kuno pada Yayasan Sastra Lestari berbasis digital. *Al-Kutab: Jurnal Kajian Perpustakaan, Informasi, Dan*, 4(2). <https://doi.org/10.24952/ktb.v4i2.4845>