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CULTURAL HERITAGE AND ENVIRONMENTAL CHALLENGES ON CONSERVATION PROCESS OF BATIK: GROUND WATER AND SUBSIDENCE IN PEKALONGAN

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Abstract

Batik, a traditional Indonesian textile art, significantly contributes to local employment and national exports. However, its production processes, which involve intensive water use and dyeing techniques, have raised environmental concerns. This study investigates the environmental impacts of batik production in Pekalongan City, focusing on its role in surface water pollution, groundwater exploitation and land subsidence. It aims to propose sustainable solutions that balance the preservation of cultural heritage with environmental protection. Utilizing a multi-faceted approach, this research includes mapping batik production sites and examining data on groundwater extraction and land subsidence. Key findings reveal that batik production significantly contributes to severe surface water pollution through the discharge of untreated wastewater. This pollution exacerbates groundwater reliance, leading to substantial land subsidence. Over 80% of the water used in batik production is sourced from groundwater wells, with extraction rates causing 1-2cm subsidence per year. This subsidence increases vulnerability to flooding and coastal inundation, adversely affecting infrastructure and local communities. The study underscores the need for sustainable water management practices, improved regulatory frameworks to mitigate environmental damage and stakeholder engagement to promote sustainable practices in Pekalongan. Collaborative and innovative solutions are crucial for achieving a sustainable and resilient future for the city.

Keywords*: Batik production; Environmental Impact; Water Pollution; Groundwater Extraction; Land subsidence.*

Introduction

Batik, a traditional textile art form as shown in figure 1, holds a significant cultural and economic position in Indonesia, with Pekalongan being one of the central hubs of batik production. Studies have shown that the batik industry significantly contributes to local and national economies. According to a report by the Ministry of Industry of Indonesia [1], batik exports reached approximately USD 52.44 million in 2020, indicating its importance as an export product. The industry also provides livelihoods for over 15,000 artisans in Pekalongan alone, highlighting its role in employment generation.

A study examining the socio-cultural impacts of batik production in Pekalongan found that batik-making fosters a sense of community and cultural pride among residents [2]. It also emphasized the role of batik in promoting gender equality, as it provides economic opportunities for women, who form the majority of the workforce in the industry. While batik production has positive social and economic impacts, it also poses environmental challenges.

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The environmental pollution caused by batik production in Pekalongan, particularly the discharge of untreated wastewater into local water bodies [3].

Fig. 1. Various Batik Patterns in Indonesia

The intricate patterns and unique dyeing techniques employed in batik-making have not only made it a valuable cultural heritage but also a vital source of livelihood for many in the region. However, the environmental implications of batik production have raised concerns, particularly regarding water quality. The dyeing process in batik production involves the use of various chemicals, leading to the discharge of untreated wastewater into surface water bodies, thus deteriorating water quality.

Surface water pollution in Pekalongan has been exacerbated by the high levels of pollutants from batik industries, including dyes, heavy metals and organic compounds. This has resulted in the degradation of local rivers and water bodies, making the water unsafe for consumption and ecological sustainability. Surface water quality is evaluated using the Water Quality Index (WQI). The parameters included in WQI encompass dissolved oxygen, biochemical oxygen demand, total phosphorus and various pollutants, which are compared against established standards from the World Health Organization.

The poor quality of surface water has driven the local population and industries to increasingly rely on groundwater for their needs. Numerous studies have investigated the environmental impacts of batik production, particularly focusing on water pollution, highlighting the presence of toxic dyes and heavy metals in rivers around batik production areas and revealing significant deviations from permissible water quality standards [4]. Similarly, another study documented the adverse effects of batik wastewater on aquatic ecosystems, including reduced biodiversity and altered water chemistry [5].

The extensive extraction of groundwater in response to surface water pollution has led to a critical environmental issue: land subsidence. Land subsidence, the gradual sinking of the ground, has been observed in various parts of Pekalongan, causing infrastructural damage and increasing vulnerability to flooding. The batik dyeing process involves the use of various chemicals, which often end up as untreated wastewater discharged into surface water bodies. This practice has resulted in severe surface water pollution in Pekalongan, deteriorating the quality of rivers and other water sources. As surface water quality declines, the dependence on groundwater for industrial and domestic use intensifies, leading to extensive groundwater extraction. This over-extraction of groundwater has been identified as a major cause of land subsidence, a phenomenon where the ground sinks due to the removal of subsurface materials. Land subsidence in Pekalongan has led to significant infrastructural damage, increased flood risks and adverse socio-economic consequences for local communities.

The correlation between groundwater extraction and land subsidence has also been extensively studied. Some studies discussed how excessive groundwater withdrawal in Jakarta leads to significant land subsidence, providing insights into similar dynamics in other Indonesian cities [6]. Advances in GNSS technology have enabled precise monitoring of land subsidence rates, offering valuable data for assessing the extent of this issue [7].

The interplay between batik production, groundwater exploitation and land subsidence presents a multifaceted problem. The economic benefits derived from batik are overshadowed by the environmental degradation and social issues arising from water pollution and land subsidence. This situation necessitates a balanced approach that addresses both the conservation of cultural heritage and the protection of environmental resources. The pressing issues include ensuring sustainable water use, mitigating pollution and preventing further land subsidence while maintaining the socio-economic benefits of batik production.

The primary research problem is the environmental degradation caused by batik production, particularly its contribution to surface water pollution and groundwater exploitation, leading to land subsidence. Existing studies propose solutions such as introducing eco-friendly production methods and enhancing regulatory frameworks for water use. However, these solutions often overlook the socio-economic dynamics of the region, resulting in limited success and acceptance among local communities.

This study aims to address the identified research gaps by investigating the complex conservation processes required to balance batik production, groundwater use and land subsidence in Pekalongan City. The research will explore innovative and context-specific solutions that consider the socio-economic realities of the region. The novelty of this research lies in its holistic approach to addressing the interconnected issues of batik production, groundwater exploitation and land subsidence. By combining technical, social and economic perspectives, the study aims to propose sustainable solutions that are both effective and acceptable to local stakeholders. The scope of the research encompasses a detailed analysis of current practices, the implementation of pilot conservation projects and the development of policy recommendations to ensure the long-term sustainability of batik production in Pekalongan.

Experimental part

Materials

The study on the impacts of batik production on groundwater exploitation and land subsidence in Pekalongan City will utilize several key datasets. Firstly, data on the geographical locations of batik production facilities, workshops and small-scale artisanal operations within the city will be collected from local government databases, industry associations, satellite imagery and field surveys. Secondly, information on surface water pollution and pollutant levels in nearby rivers, lakes and canals will be sourced from environmental monitoring agencies and academic studies. Thirdly, the study will analyze data correlating groundwater exploitation and land subsidence, which includes information on groundwater extraction rates, well depths and recorded instances of subsidence, obtained from geological surveys and hydrological studies. Fourthly, land subsidence data will be interpolated using spatial techniques like kriging or inverse distance weighting (IDW) to create continuous surfaces that illustrate subsidence patterns across Pekalongan. This data will be sourced from GNSS measurements, InSAR dat and geodetic surveys. Data to map coastal inundation due to subsidence will be integrated, including topographic maps and land elevation data from in-situ coastal surveys and models.

Methods

This study will employ a multi-faceted methodological approach to comprehensively understand the impacts of batik production on groundwater exploitation and land subsidence in Pekalongan City. The first step involves mapping the locations of batik production facilities throughout the city, utilizing local government databases, industry associations, satellite imagery and field surveys to identify areas with potential environmental impacts. Concurrently,

surface water pollution in nearby rivers, lakes and canals will be studied. To establish the relationship between groundwater exploitation and land subsidence, a correlation analysis will be conducted, using data on groundwater extraction rates and recorded instances of subsidence obtained from water table analysis. Following this, an interpolation of land subsidence data will be performed using spatial techniques like kriging or inverse distance weighting (IDW) to create detailed maps illustrating subsidence patterns across Pekalongan. Finally, the study will map coastal inundation risks by integrating the interpolated subsidence data with topographic maps and land elevation data, sourced from coastal surveys and models. This comprehensive approach will provide insights into the environmental and socio-economic impacts of batik production, guiding the development of effective policies and conservation strategies.

Results and Analysis

Batik direct contribution to surface water pollution and groundwater exploitation

Pekalongan is a coastal city located on the northern coast of Central Java. Pekalongan lies at approximately 6°52' S latitude and 109°40' E longitude, facing the Java Sea. The city is about 96,40 kilometers west of Semarang, the capital of Central Java. As of recent estimates, Pekalongan has a population of around 317.524 in 2023. The city's economy is strongly tied to the batik industry, which employs a large portion of the population. Small and medium enterprises dominate the market.

From the list of small and medium batik industries (IKM) in Pekalongan Regency, there are 1,824 batik companies distributed across various villages, including Medono, Podosugih, Tirto, Pringrejo, Sapuro Kebulen, Bendan Kergon, Pasirkratonkramat, Kauman, Poncol, Klego, Gamer, Noyontaansari, Setono, Kali Boros, Jenggot, Banyurip, Buaran Kradenan, Kuripan Kertoharjo, Kuripan Yosorejo, Sokoduwet, Bandengan, Kandangpanjang, Panjang Wetan, Degayu, Krapyak and Padukuhan Kraton, as can be seen in Figure 2.

Fig. 2. The Small and Medium Batik Industries Area in Pekalongan

Batik production processes have been identified as significant contributors to both surface water pollution and groundwater exploitation. Batik production is a water-intensive process, requiring substantial amounts of water for dyeing, washing and rinsing fabrics. The

traditional batik dyeing process can consume up to 200 liters of water per kilogram of fabric, underscoring the high water demand [8]. Due to inadequate surface water supplies, batik producers in Pekalongan heavily rely on groundwater. Over 80% of water used in batik production is sourced from groundwater wells [9]. This dependency is exacerbated by the declining quality of surface water, further driving the reliance on groundwater.

The disposal of batik waste, which has a large water footprint, directly leads to water pollution, as can be seen in Figure 3. [10]. Due to the lack of proper wastewater treatment facilities, most batik producers dispose of their wastewater directly into rivers, exacerbating water pollution issues [11]. The effluents from batik processing activities contain chemicals that are discharged into rivers, impacting aquatic life and human health [12].

Fig. 3. Field documentation shows how surface water being polluted (e.g., colored) by Batik Industries in Pekalongan

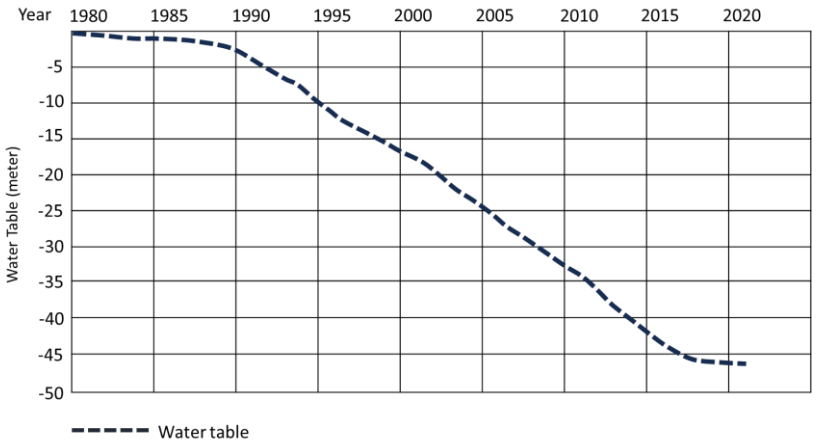

Fig. 4. Result of reconstruction of water table dynamic due to exploitation of groundwater in Pekalongan

The overexploitation of groundwater, along with the direct discharge of effluents, contributes to groundwater pollution [13]. The exploitation of groundwater has been linked to severe subsidence in certain regions, highlighting the detrimental effects of groundwater exploitation [14]. Additionally, the heavy exploitation of groundwater wells increases the risk of aquifer contamination at various depths [15].

From the reconstruction of the water table dynamics due to groundwater exploitation in Pekalongan over 20 years, from 1980 to 2020, a significant decline in the water table can be observed, especially between the years 2005 and 2015. Groundwater levels dropped by an average of 4 meters annually in the affected areas, as can be seen in Figure 4.

Batik indirect contribution to land subsidence and coastal inundation

Batik production indirectly contributes to land subsidence and coastal inundation through various mechanisms. The overexploitation of groundwater for batik production can lead to land subsidence, as seen in Jakarta, Indonesia, where groundwater extraction has resulted in spatial and temporal variations of land subsidence [16]. This land subsidence can exacerbate the risk of coastal inundation, especially in low-lying coastal areas, by reducing the elevation of the land and increasing the vulnerability to flooding. Heritage objects are successively becoming more vulnerable due to environmental decay and deterioration, the effects of climate change and human-persuaded impacts [17].

Furthermore, the extraction of water for batik production, along with other industrial and agricultural activities, can contribute to subsidence in delta regions, such as the Mekong Delta in Vietnam, where land-use changes amplify natural subsidence processes [18]. This subsidence, coupled with sea level rise, can increase the risk of inundation in these areas [19]. The cumulative effects of land subsidence from various activities, including batik production, can lead to increased vulnerability to sea level rise and coastal flooding, as observed in Cartagena, Colombia, where subsidence rates have reached up to 72.3mm [20]. This subsidence, combined with sea level rise, can significantly heighten the risk of coastal inundation and exacerbate flooding in coastal regions [21].

Extensive groundwater extraction has led to a significant decline in water tables. The study documented a drop in groundwater levels by approximately 2-3 meters over the past decade in areas with concentrated batik production [22]. This decline threatens the sustainability of groundwater resources. Land subsidence, a direct consequence of excessive groundwater extraction, poses severe risks. Another study reported subsidence rates of 1-2cm per year in Pekalongan, correlating these rates with intensive groundwater pumping for industrial purposes, including batik production [23]. Subsidence leads to infrastructure damage, increased flood risks and disruptions to daily life.

As can be seen from figure 5. The significant rate of groundwater extraction in the past 40 years has led to a substantial decline in the water table, averaging 1.25 meters per year. This has also contributed to land subsidence, with the ground surface sinking by a total of 2 meters over the same period. The correlation between the rapid depletion of groundwater and the observed land subsidence highlights the urgent need for sustainable water management practices to mitigate further environmental degradation and prevent long-term damage to the region's infrastructure and ecosystems.

From figure 6, it can be seen that by modeling the data on subsidence growth around Pekalongan derived from interpolation and extrapolation of GNSS measurements and land use changes from 1990 (A) to the changes observable from the subsidence growth and land use change modeling from 1995 to 2020 (F), it can be seen that areas with ground subsidence exceeding 2 meters have spread to many places outside Pekalongan, particularly along the northern coast of Java from Ujungnegoro Beach, Pasir Kencana Beach, Wonokerto Beach, to Blendung Beach. Other areas with ground subsidence exceeding 2 meters include vital areas around the Pemalang-Batang toll road.

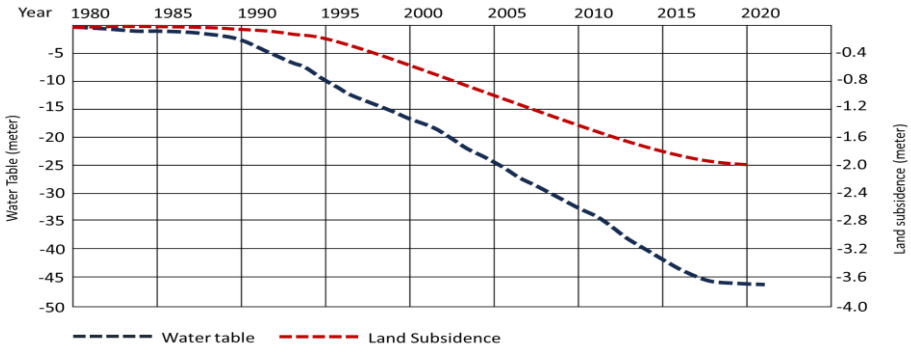

Fig. 5. Result of reconstruction of water table dynamic versus land subsidence due to the exploitation of groundwater in Pekalongan

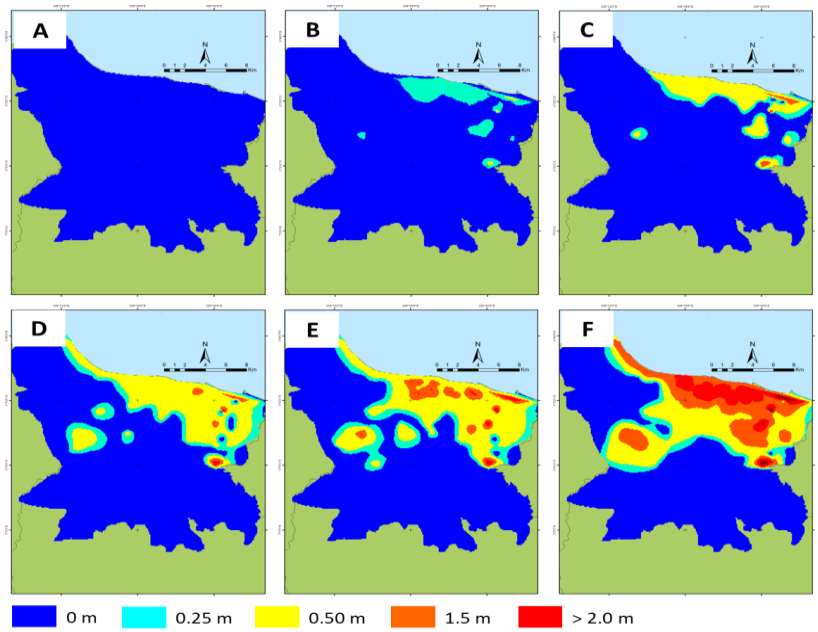

Fig. 6. Model of subsidence growth around Pekalongan derived from interpolation, extrapolation, GNSS measurements and Land Use Change
(A = 1990, B = 1990-1995, C = 1990-2000, D = 1990-2005, E = 1990-2010, F = 1995-2020)

The modeling data indicates that the phenomenon of land subsidence in the Pekalongan area has significantly worsened over the decades, spreading beyond the city to other critical coastal and infrastructural regions. This trend underscores the urgent need for comprehensive mitigation strategies to address the expanding impact of land subsidence on the northern coast of Java and key infrastructural areas such as the Pemalang-Batang toll road.

Figure 7 illustrates the drastic changes in the Pekalongan area over a span of 20 years through satellite imagery. In 2003, the satellite image depicts a clearly defined coastline with no evidence of coastal inundation, indicating that the land areas were unaffected by seawater. However, the satellite image from 2023 shows a stark contrast, with many places now experiencing coastal inundation, i.e., Jeruksari, Bandengan, Kali Pencongan, Wonokerto, Desa Semut, Depok Siwalan and Kandang Panjang. This significant transformation highlights the intrusion of seawater, which has altered the coastline and impacted the local environment and infrastructure.

Fig. 7. (A) Satellite images show the condition of the Pekalongan area in 2003 with no coastal inundation existing, (B) Satellite images show the condition of the Pekalongan area in 2023 with many places experiencing coastal inundation

Fig. 8. Field documentation shows an example of sinking houses, where it can be seen in this image that only part of the house door is visible, as the rest has sunk into the ground.

Figure 8 provides Field documentation shows an example of sinking houses, where it can be seen in this image that only part of the house door is visible, as the rest has sunk into the ground. It is essential to mention that sociocultural values are not limited to cultural ecosystem services but are linked to all interactions with nature [24].

The images depict houses that have been submerged, with water reaching significant levels inside the living spaces. Additionally, there are poignant photographs of children attempting to adapt to these challenging conditions, illustrating their resilience as they navigate through the flooded areas of their homes. These visual records highlight the severe impact of coastal flooding on the daily lives and living conditions of the local residents.

Conserving Batik: The Environmental and Community Challenges

To address the environmental challenges associated with batik production and to promote good water management practices without exploiting groundwater excessively, several solutions can be implemented. One effective solution is to focus on reducing the water footprint of the batik-making process through proper water management practices. This includes conserving water resources for both human consumption and ecosystem preservation while also safeguarding batik as a cultural heritage. Implementing sustainable and clean production practices, along with improved water management and waste handling, can significantly contribute to the sustainability of the batik industry [25].

Efficiency in treating batik wastewater can be achieved through innovative methods such as using Aspergillus sp. to reduce harmful components like chromium, sulfide, ammonia, phenol and fat from batik wastewater [26]. Additionally, membrane filtration, such as ultrafiltration, has shown promise in treating batik industry wastewater effectively, offering a cost-effective and high-quality treated water solution [27].

To effectively conserve traditional batik practices while addressing environmental and community challenges, integrating cultural heritage with modern sustainability efforts is essential. This study proposes the initiative called "Batik Cinta Bumi". This initiative can provide a comprehensive solution by first assessing current batik production methods, their environmental impacts and community needs to establish actionable goals for improvement.

It engages local batik artisans, environmental experts, community leaders and government bodies to ensure diverse input and forms partnerships with NGOs, academic institutions and businesses dedicated to sustainability and cultural preservation. By introducing eco-friendly techniques, such as natural dyes and low-impact water treatments and implementing resource management strategies to reduce waste and pollution, the initiative promotes sustainable practices.

Educational programs, as shown in figure 9, must be developed to enhance awareness of these practices and the importance of cultural preservation, supported by workshops and events to foster community involvement.

Fig. 9. Community activities that offer free batik drawing workshops and allow participants to take their work home have a significant impact in leaving a lasting impression and fostering a love for batik and Pekalongan

The initiative will track progress with established metrics, gather feedback for ongoing improvement and promote its successes while advocating for policy changes that support sustainable batik production. This holistic approach ensures that "Batik Cinta Bumi" addresses both environmental and community challenges effectively.

Conclusions

This study has elucidated the complex interplay between batik production, groundwater exploitation and land subsidence in Pekalongan. While batik production remains a significant cultural and economic asset, it also presents considerable environmental and infrastructural challenges. The research highlights that the traditional batik dyeing process, which relies heavily on water, contributes significantly to surface water pollution through the discharge of untreated wastewater. This pollution deteriorates water quality, leading to an increased reliance on groundwater, which in turn accelerates land subsidence. Key findings include the severe degradation of surface water quality due to the release of toxic dyes, heavy metals and other pollutants from batik production. The consequent reliance on groundwater has been linked to substantial land subsidence in Pekalongan, resulting in infrastructural damage and heightened vulnerability to flooding. Furthermore, the subsidence exacerbates the risk of coastal inundation, particularly in low-lying areas, by reducing land elevation and increasing flood risks.

The study contributes to existing knowledge by integrating technical, social and economic perspectives to address the environmental challenges of batik production. It underscores the need for enhanced regulatory frameworks to manage wastewater treatment and groundwater use, promoting sustainable practices and enforcing stricter environmental standards. Additionally, adopting eco-friendly techniques, such as natural dyes and advanced wastewater treatment methods, can mitigate environmental impacts. Engaging local artisans and stakeholders in sustainability efforts is crucial to ensure that solutions are both practical and culturally acceptable. Future research should focus on evaluating the effectiveness of proposed sustainable practices and policy changes, as well as expanding studies to other batik-producing regions in Indonesia to provide a broader perspective on the national implications of these issues. The proposed initiative, "Batik Cinta Bumi," aims to harmonize traditional practices with modern sustainability efforts, addressing both environmental and community challenges. Through collaborative efforts and innovative solutions, it is possible to preserve the cultural heritage of batik while ensuring a sustainable and resilient future for Pekalongan.

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