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The Utilization Of Artificial Intelligence As An Innovative Solution In Monitoring Mining Activities And Combating Illegal Mining (PETI)

Safriansyah Yanwar Rosyadi
Universitas Borobudur
Email: safrosi.emas@gmail.com

Ahmad Redi
Universitas Borobudur
Email: ahmad_redi@borobudur.ac.id

Korespondensi penulis: safrosi.emas@gmail.com

Abstract: *Illegal Mining (Penambangan Tanpa Izin/PETI) is a serious problem causing significant negative impacts on the environment, society, and economy in Indonesia. Conventional monitoring systems used so far face various limitations, such as a lack of human resources, infrastructure, and adequate technology, making the supervision and control of PETI less effective. This article examines the potential utilization of Artificial Intelligence (AI) technology as an innovative solution to improve the effectiveness of monitoring PETI activities. By leveraging AI, monitoring can be conducted in real-time, with accuracy, and across wide areas through the integration of satellite imagery, drones, and IoT sensors. However, the implementation of AI also faces challenges such as limited human resources, infrastructure, data security issues, and insufficient regulations. Therefore, this study recommends collaboration among government agencies, the private sector, and academia, capacity building for human resources, and the formulation of adaptive regulations as strategic steps to optimize the use of AI in monitoring and combating PETI in Indonesia. The findings of this study are expected to serve as a reference for policymakers and practitioners in integrating advanced technology to safeguard the sustainability of natural resources.*
Keywords: *Illegal Mining, Artificial Intelligence, Mining Monitoring*

INTRODUCTIONS

Illegal Mining (Penambangan Tanpa Izin, PETI) refers to the exploration and exploitation of mineral and coal resources conducted without official permits from the government as mandated by prevailing laws and regulations (Gocha Narcky Ranggalawe, 2023). This activity typically occurs in areas rich in mining potential, whether within officially designated Mining Business License Areas (WIUP) or in regions untouched by legal mining operations. Characteristics of PETI include informality, lack of professional organization, limited technology use, and often involvement of local communities with limited technical knowledge (H.S., 2010). Moreover, PETI is associated with poor environmental management, unsafe working conditions, and mining product marketing systems that operate outside official distribution channels. Because it is illegal, PETI activities often evade official oversight and present major challenges for law enforcement and sustainable natural resource management (Sari, 2022).

Quantitatively, PETI activities in Indonesia show a concerning trend. According to data from the Directorate General of Minerals and Coal at the Ministry of Energy and Mineral Resources, there are more than 2,500 PETI sites spread across Indonesia, with the highest concentration in Kalimantan, Sumatra, Sulawesi, and Papua. Provinces such as West Kalimantan, East Kalimantan, and Southeast Sulawesi are reported as PETI hotspots,

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particularly for commodities like gold, coal, and nickel (Sutrisno, 2023). Some PETI areas are even located within protected forests or conservation zones, directly contradicting environmental preservation principles. The lack of control over the distribution of mining products from PETI also causes losses to the state revenue, as these commodities are not recorded in the taxation system nor contribute to Regional Original Revenue (PAD) (Rahman, 2023).

The negative impacts of PETI are broad and complex, spanning environmental, social, economic, and legal dimensions. Environmentally, PETI often results in severe damage such as deforestation, water pollution due to mercury or cyanide use, and landscape destruction that is difficult to restore. Socially and economically, communities are affected by dependence on unsustainable illegal activities, often triggering conflicts both horizontally among communities and vertically between landowners and law enforcement (Hartono, 2021). Legally, the existence of PETI reflects weak monitoring systems and overlapping authorities between central and regional governments in mining management.

In Indonesia, PETI is explicitly categorized as an illegal activity under various laws. A key legal foundation is Law Number 3 of 2020, which amends Law Number 4 of 2009 on Mineral and Coal Mining (UU Minerba). This legislation imposes severe criminal sanctions on mining activities conducted without proper licenses, including imprisonment up to five years and fines reaching hundreds of billions of rupiah (Yulianto, 2022). Enforcement of this regulation reflects the government's seriousness in addressing PETI activities, which cause not only economic losses to the state but also potential environmental damage and complex social conflicts.

In addition to regulations under the Mineral and Coal Mining Law (UU Minerba), supervision and enforcement against illegal mining (PETI) are also governed by Law Number 32 of 2009 on Environmental Protection and Management (UU PPLH). This regulation explicitly prohibits activities that cause pollution and environmental damage. PETI often involves the use of hazardous chemicals such as mercury and cyanide, which pose significant risks to the environment, especially since these activities typically do not follow proper waste management and land reclamation procedures (Hidayat, 2024). Therefore, PETI actors can face harsher criminal sanctions if their activities cause pollution or environmental damage beyond established quality standards, with penalties including imprisonment of up to ten years and substantial fines.

Moreover, legal provisions related to PETI are reinforced by other regulations such as the Criminal Code (KUHP) and Law Number 41 of 1999 on Forestry. In forestry contexts, unauthorized mining activities in forest areas, especially protected and conservation forests, are strictly prohibited and subject to severe criminal penalties, including imprisonment of up to ten years and heavy fines. This is critical considering that many PETI activities occur in forest areas vulnerable to ecological damage (Kurniawan, 2022). This regulatory framework demonstrates that the Indonesian government has a strong legal basis to firmly act against illegal mining practices to protect natural resources, preserve the environment, and prevent harmful social impacts.

The mining supervision system in Indonesia, particularly in efforts to combat PETI, still faces fundamental limitations. A major challenge is the shortage of competent human resources, which is disproportionate to the vast mining areas that require oversight. In many regions, the number of mining inspectors is very limited, with one inspector often responsible for supervising several districts or extensive and complex mining areas. Furthermore, budget constraints often pose significant obstacles to conducting patrols, field inspections, or acquiring

monitoring equipment. Consequently, supervision tends to be passive, only carried out after violations or incidents are reported, rather than as a proactive and sustainable prevention effort (Putra, 2024).

Geographical factors also pose significant challenges to conventional mining supervision. Many PETI locations are in remote, hard-to-reach areas with difficult terrain such as hills, dense forests, or river basins. This causes field identification and verification processes to be time-consuming and require substantial logistics. On the other hand, early detection systems for illegal mining activities remain very limited. The absence of technological infrastructure such as satellite imagery monitoring, drones, or remote sensors makes it difficult for authorities to monitor mining activity changes in real time. As a result, PETI activities can continue for long periods without detection, even up to large-scale exploitation stages that cause environmental damage (Santoso, 2024).

Slow responses to PETI presence in the field further worsen the situation. When illegal activities are discovered, delays often occur in taking action due to lengthy bureaucratic procedures, weak interagency coordination, and limited transportation and communication tools. Moreover, in some areas, PETI is protected by certain individuals or involves local political and economic interests, which complicates enforcement efforts. This situation creates the impression that mining supervision is merely administrative and unable to substantially address illegal mining practices (Andriani, 2024).

Artificial Intelligence (AI) is a branch of computer science focused on developing systems or machines capable of mimicking human intelligence to perform specific tasks (Simbolon, 2022). AI operates by utilizing complex algorithms, big data, and machine learning to recognize patterns, make predictions, or make decisions automatically. AI systems can be trained using historical data or real-time sensors to continuously improve their accuracy and responsiveness over time (Muhammad Pasha Nur Fauzan, 2021). In the context of supervision, AI has the ability to process and analyze large amounts of data quickly, which is very difficult for humans to do manually (Deslaely Putranti, 2022). This makes AI a highly potential technological solution to be applied in sectors requiring speed, accuracy, and continuous monitoring, including the mining sector.

The development of AI technology in recent years has had a significant impact across various sectors, including healthcare, transportation, agriculture, environmental monitoring, and the mining industry. In healthcare, AI is used for disease detection through medical image analysis; in transportation, it serves as the backbone of autonomous vehicles. Meanwhile, in environmental monitoring and mining, AI is increasingly applied to identify land cover changes, monitor hazardous gas emissions, and optimize mineral exploration and production processes. Several major global mining companies have utilized AI to enhance operational efficiency, reduce costs, and predictively identify risk areas. Indonesia, although still in the early stages, has begun adopting AI to support mining governance and surveillance of areas vulnerable to illegal activities (Rofi Aulia Rahman, 2023).

The potential of AI in mining supervision, especially to detect illegal mining Activities (PETI), is very large because it can be integrated with other technologies such as high-resolution satellite imagery, drones, and Internet of Things (IoT)-based sensors. AI can analyze mining area imagery over time to detect suspicious changes in land or vegetation activity patterns. In drone-based monitoring, AI can recognize heavy equipment or excavation appearing in unauthorized locations. Meanwhile, IoT sensors installed in mining areas can provide environmental data such as vibrations, sounds, or gas emissions, which AI processes to detect anomalies or illegal activities. The integration of these technologies enables real-time,

efficient, and adaptive monitoring to field conditions, making AI a crucial tool in the future mining supervision revolution.

The application of AI technology to detect illegal activities has proven effective in various sectors, especially forestry and fisheries. In forestry, AI analyzes satellite imagery to detect illegal logging by monitoring periodic changes in forest cover. Systems like Global Forest Watch use AI to accelerate deforestation detection in tropical countries. In fisheries, organizations such as Global Fishing Watch employ AI to track fishing vessels operating outside authorized zones using Automatic Identification System (AIS) data. The success of AI applications in these two sectors demonstrates the high potential of similar technology for detecting PETI, which is also hidden, dynamic, and difficult to reach with conventional supervision.

In the mining context, several countries and institutions have initiated AI utilization to improve mining area surveillance. In Canada and Australia, mining companies use AI to analyze geospatial data and satellite imagery to detect unauthorized mining activities (Karun Sanjaya, 2025). In Indonesia, although still limited, trials of drone usage and AI-based image processing have been conducted by institutions such as BRIN (National Research and Innovation Agency) and several local governments collaborating with technology startups. For example, AI has been used to monitor land morphology changes in former coal mining sites in Kalimantan and assist early detection of illegal excavation. Such studies indicate that AI not only has the potential for early detection but also provides accurate analytical data to support mining policy decision-making.

The potential of AI in monitoring illegal mining activities (PETI) is very significant, especially in terms of efficiency, speed, and accuracy. AI can analyze spatial data in a short time, identify abnormal patterns of mining activity changes, and automatically send alerts to relevant authorities. This is very different from conventional methods that rely on slow and costly manual field inspections. AI can also be used to map PETI-prone areas based on historical incidents, geographical conditions, and economic activity trends, allowing surveillance to focus on high-risk areas. AI's strength in processing big data and learning activity patterns over time makes it a strategic tool for building an adaptive, responsive, and proactive mining surveillance system.

Research on the utilization of AI in PETI monitoring is crucial at this time due to the evident gap between the available technological potential and its implementation in the field. Although AI has rapidly advanced and is technically available, many government agencies and mining operators in Indonesia still lack the capacity or strategies to integrate it into monitoring systems. This lag not only impacts the effectiveness of supervision but also prolongs environmental damage caused by undetected PETI activities. Research on this topic is highly relevant to the need for more transparent, accountable, and data-based mining governance. Furthermore, this study supports the formulation of public policies that are adaptive to technological developments and encourages digital transformation in the natural resources sector, which is a vital part of sustainable development agendas and Indonesia's Vision 2045.

RESEARCH METHODS

This study uses a normative juridical method, a legal research approach that relies on the study of written legal norms as the primary object of analysis. This method focuses the analysis on primary legal materials such as legislation regulating mineral and coal mining, environmental management, and policies related to the use of technology in law enforcement. Within this framework, two main approaches are used: the statute approach and the analytical

approach. The statute approach involves reviewing the hierarchy and relevance of legal norms, such as Law Number 3 of 2020 on Mineral and Coal Mining, Law Number 32 of 2009 on Environmental Protection and Management, and regulations related to the use of technology and mining supervision. Meanwhile, the analytical approach critically examines the appropriateness and effectiveness of the application of these legal norms in the current context, including opportunities for integrating artificial intelligence technology into the PETI monitoring system.

The data sources in this study consist of primary legal materials, namely legislation; secondary legal materials such as legal literature, scientific journals, previous research results, and official government policy documents; as well as tertiary legal materials in the form of legal dictionaries or encyclopaedias. Data collection techniques are conducted through document studies (library research) by tracing and analyzing various relevant legal documents and scientific publications. The collected data is analyzed qualitatively by interpreting legal norms based on legal principles and developing doctrines, as well as comparing positive legal provisions with their implementation practices in the field. This analysis aims to identify legal gaps, regulatory disharmony, and the relevance of developing new legal instruments supporting AI integration in mining supervision. With this approach, the research is expected to provide conceptual and practical recommendations for developing legal policies that adapt to technological developments.

RESULTS AND DISCUSSION

Positive Legal Regulations in Indonesia Related to Illegal Mining Activities (PETI)

Illegal mining activities (PETI) are legally understood as the exploration, extraction, or utilization of mineral and coal resources conducted without complying with the applicable licensing provisions stipulated in Indonesian laws and regulations. Law Number 3 of 2020 concerning Amendments to Law Number 4 of 2009 on Mineral and Coal Mining (Minerba Law) explicitly states that all mining activities must have a Mining Business Permit (IUP) or a Community Mining Permit (IPR) issued by the government. PETI refers to activities conducted without such permits and is therefore categorized as an unlawful act with the potential to cause harm to both the state and society. This regulation aims to ensure the legal, measured, and sustainable use of mineral resources so as not to damage the environment or disrupt socio-economic interests.

Conceptually, PETI differs significantly from legal mining operations, especially in terms of legality and governance. Legal mining activities are conducted by business actors who have obtained permits from the government and fulfilled various technical, administrative, and environmental protection requirements, along with social obligations. These activities are strictly supervised, must report their production results, and are held accountable for land reclamation and environmental restoration after mining activities conclude. In contrast, PETI is usually carried out by individuals or groups without any legal permits, often using traditional and simple methods, and lacking adequate environmental management standards. As a result, PETI poses serious risks such as environmental pollution, ecosystem damage, and social conflicts in mining areas.

From a legal standpoint, the fundamental difference between PETI and legal mining lies not only in the licensing aspect but also in compliance with regulations and accountability. Legal mining is subject to regulations governing the lawful and responsible management of natural resources, including obligations to pay royalties and taxes to the state. PETI, on the other hand, constitutes a legal violation that results in state losses due to the absence of financial

contributions and the difficulty of monitoring such illegal activities. Therefore, legal provisions on PETI do not merely prohibit the activity but also emphasize the need for law enforcement and community empowerment to transition toward legal and sustainable mining practices.

Law Number 3 of 2020 concerning Amendments to Law Number 4 of 2009 on Mineral and Coal Mining (Minerba Law) serves as the main legal framework regulating mining activities in Indonesia, including provisions on illegal mining activities (PETI). This law provides a clear legal foundation for the governance of mineral and coal mining, which must be conducted legally and sustainably. Under the Minerba Law, any business actor intending to engage in mining activities is required to obtain a valid permit—such as a Mining Business Permit (IUP) or Community Mining Permit (IPR)—issued by the central or local government, depending on jurisdiction. This licensing requirement is intended to ensure controlled and responsible exploitation of natural resources and to prevent illegal activities such as PETI, which can harm the environment and disrupt social order.

The provisions regarding mining business permits are elaborated in detail in the Minerba Law, with certain articles explicitly stating prohibitions and sanctions for engaging in mining without permits. For example, Article 162 of the Minerba Law stipulates that any individual conducting mining activities without a valid mining business permit may be subject to criminal penalties and fines. This article affirms that unauthorized mining is a criminal offense that causes harm to the state and society. In addition to criminal penalties, there are also administrative measures such as permit revocation, enforcement actions, and confiscation of illegal mining equipment. These provisions reflect the legislators' seriousness in addressing PETI through firm and measurable legal mechanisms.

In addition to Article 162, several other articles also contain important provisions directly related to the supervision and enforcement of illegal mining (PETI). Articles 158 and 159 regulate the obligations of mining business operators to preserve the environment and carry out land reclamation after mining activities end—an area often neglected in PETI cases. Article 166 also grants the government and law enforcement authorities the power to supervise and take action against illegal mining activities. Thus, the Minerba Law not only prohibits PETI but also provides legal instruments for active oversight and consistent law enforcement.

In addition to Law No. 3 of 2020 on Mineral and Coal Mining (Minerba Law), which serves as the main legal foundation for mining regulation, there are several other supporting regulations crucial for supervising and enforcing laws against illegal mining activities. One such regulation is Law No. 32 of 2009 on Environmental Protection and Management (PPLH Law), which outlines the obligation of every business actor to protect environmental sustainability. Article 69 of the PPLH Law states that any business and/or activity with the potential to cause environmental impacts must have an Environmental Impact Assessment (AMDAL) or other environmental documents as required by applicable laws. In the context of PETI, illegal miners clearly fail to meet these requirements, making them liable to administrative and criminal sanctions under Article 98(1) of the PPLH Law, which stipulates that violations of environmental management regulations may be punished by imprisonment for up to three (3) years and/or a fine of up to IDR 3 billion.

Furthermore, Law No. 41 of 1999 on Forestry also serves as an important legal basis, especially when PETI activities occur in state forest areas. Article 50 of the Forestry Law states that individuals are prohibited from logging, utilizing timber, or conducting other activities within forest areas without legal permits. Violations of this provision, as regulated in Article 78, may result in imprisonment for up to five (5) years and/or fines of up to IDR 100 billion. Since many PETI operations are located within or adjacent to protected forest areas, this law

offers a strong legal framework for cracking down on such illegal activities. Thus, the combination of the Minerba Law, PPLH Law, and Forestry Law forms a complementary legal framework for monitoring and taking action against illegal mining activities that harm the environment and cause losses to the state.

In addition to these laws, there are also a number of government regulations and ministerial regulations that govern the technical implementation of mining supervision and law enforcement. For example, Government Regulation No. 23 of 2010 on the Implementation of Mineral and Coal Mining Business Activities contains provisions regarding business licensing, supervision, and handling of violations, including the authority of local governments to oversee mining. Moreover, Minister of Energy and Mineral Resources Regulation No. 34 of 2017 on the Supervision and Control of Mineral and Coal Mining Business Activities provides technical guidelines for inspectors in controlling activities that violate licensing regulations. Article 9(1) of this regulation emphasizes that supervision must be carried out continuously and utilize various technologies to ensure compliance by business actors. With the existence of such implementing regulations, supervision of PETI can be conducted more effectively and systematically, providing a legal basis for officers to take swift and appropriate action to curb illegal activities on the ground.

Perpetrators of illegal mining may be subject to various legal sanctions under the applicable laws and regulations in Indonesia, particularly Law No. 3 of 2020 on Mineral and Coal Mining (Minerba Law). These sanctions include criminal penalties and fines intended to create a deterrent effect while upholding the rule of law. Article 162 of the Minerba Law clearly stipulates that any person conducting mining activities without a valid permit may be sentenced to imprisonment of up to five (5) years and/or a fine of up to IDR 100 billion. The severity of this punishment reflects the government's seriousness in combating illegal mining, which causes state losses, environmental destruction, and public disorder. Additionally, perpetrators may also face administrative sanctions such as confiscation of mining equipment and forced termination of mining activities.

In addition to the Minerba Law, Law No. 32 of 2009 on Environmental Protection and Management (PPLH Law) also imposes additional sanctions on perpetrators of illegal mining (PETI) who cause environmental damage. Article 98 paragraph (1) of this law states that violations of environmental management provisions may result in imprisonment for up to 3 years and a maximum fine of IDR 3 billion. This provision further strengthens the environmental legal aspects in taking action against PETI, which often causes water pollution, land degradation, and other ecological disasters. On the other hand, Law No. 41 of 1999 on Forestry adds criminal sanctions for those engaging in mining activities without permits in forest areas, with penalties of up to 5 years' imprisonment and fines of up to IDR 100 billion, as stipulated in Article 78 of the Forestry Law. Thus, PETI offenders may face layered sanctions under mining, environmental, and forestry laws.

The role of law enforcement officers is crucial in the enforcement mechanism against PETI. The police, prosecutors, and inspectors from the Ministry of Energy and Mineral Resources (ESDM), along with other relevant agencies, have the authority to carry out raids, investigations, and prosecutions of PETI perpetrators. The enforcement process typically begins with monitoring and surveillance of areas vulnerable to PETI using various methods, followed by coordinated control operations. In addition, officers may confiscate heavy equipment, vehicles, and illegally mined materials as evidence in legal proceedings. These enforcement efforts are not only repressive but also supported by preventive measures, such as legal awareness campaigns and community empowerment programs to encourage transitions

to legal mining practices. Synergy among law enforcement agencies and stakeholders is key to successfully reducing PETI practices in the field.

Problems Faced in the Conventional Monitoring System of PETI Activities in Indonesia

Supervision of illegal mining (PETI) activities in Indonesia continues to face various complex challenges, including limited resources, technology constraints, and coordination issues among relevant institutions. The conventional monitoring system currently in use is often hindered by an insufficient number of inspectors, inadequate budget, and lack of supporting infrastructure. Furthermore, the geographical conditions of mining sites—often remote and difficult to access—add to the challenges of conducting effective supervision. As a result, efforts to prevent and crack down on PETI activities have not been optimal, allowing these illegal practices to continue growing and causing significant negative impacts on the environment, society, and the local economy.

Human resource limitations are among the main obstacles in the conventional monitoring system of illegal mining (PETI) activities in Indonesia. The number of inspectors is insufficient to monitor the vast and scattered mining areas, especially in remote regions prone to illegal practices. Beyond quantity, the quality and competence of human resources also remain a challenge, as mining supervision requires specific technical expertise, a deep understanding of regulations, and the ability to operate monitoring tools and technologies. A lack of training and capacity-building programs for inspectors affects the effectiveness of supervision, resulting in many illegal activities going undetected or unaddressed in a timely manner. This situation is worsened by the high risks and field challenges, which require inspectors to have adequate physical and mental preparedness.

In addition to human resources, budget constraints are also a significant obstacle in carrying out supervision and enforcement operations against illegal mining (PETI). The funds allocated for monitoring activities are often limited, making it difficult to procure supporting equipment, manage field operations, and cover logistics effectively. The lack of budget also restricts the frequency of patrols and routine inspections, increasing the likelihood of illegal activities taking place. This minimal financial capacity affects the ability of relevant agencies to respond quickly and effectively to reports and findings in the field. As a result, enforcement efforts tend to be reactive and limited to major cases, while small- and medium-scale PETI operations continue without proper control.

Supporting infrastructure for supervision, such as monitoring tools, operational vehicles, and communication technology, also poses a real challenge. Many mining areas, especially those far from city centers, have poor transportation access, making it difficult for inspectors to reach mining sites on a regular basis. Monitoring tools like environmental sensors, surveillance cameras, or modern communication devices remain very limited in number and distribution. This condition forces physical supervision to become the sole method used, which is highly vulnerable to human error and time constraints. The lack of infrastructure hinders the effort to collect accurate and timely data, which is crucial for decision-making in PETI enforcement.

The geographical conditions where PETI activities occur also add complexity to supervision. Many mining sites are located in remote, hilly regions or dense forests that are difficult to access with standard vehicles. Rough terrain and inadequate road conditions slow down inspector mobility and increase safety risks for officers in the field. Unpredictable weather, such as heavy rain and flooding, can also disrupt routine monitoring schedules, allowing illegal activities to proceed unhindered. These geographic barriers often give PETI

perpetrators the freedom to operate without fear of detection or interference from enforcement officers.

The lack of an adequate early detection system is also a critical issue in PETI supervision. To this day, the use of modern technologies such as satellite imagery, drones, and Internet of Things (IoT) sensors to monitor illegal mining activity remains extremely limited. Yet these technologies have great potential to provide real-time data and cover wide areas, allowing inspectors to detect and monitor suspicious activity quickly and accurately. The limited use of these technologies is due to budget constraints, a shortage of skilled personnel to operate the devices, and limited access to the latest technology at the regional level.

The impact of this lack of modern surveillance technology is the slow response of authorities in addressing PETI activity. Data obtained through conventional methods is usually not up-to-date and takes a long time to analyze and verify. As a result, illegal activity may continue for a prolonged period before enforcement action is taken, by which time environmental damage and economic losses have already occurred. The lack of technology also hampers interagency coordination in information sharing and conducting joint operations. Therefore, enhancing the use of advanced technologies in monitoring has become an urgent need to strengthen the supervision system and accelerate enforcement actions against PETI in Indonesia.

One of the significant obstacles in the monitoring and enforcement of illegal mining (PETI) is the slow response caused by complex bureaucratic procedures. In practice, the decision-making process and field operations are often hindered by a lengthy and hierarchical chain of administrative steps. Every stage—from data collection, reporting, to legal action—requires coordination involving various agencies with different authorities. This results in significant delays in enforcement, giving PETI actors sufficient time to continue or even eliminate evidence of their illegal activities before the authorities can act. These complicated procedures also create uncertainty in the law enforcement process, reducing the effectiveness of oversight.

In addition, the lack of synergy and coordination among law enforcement agencies, local governments, and the central government has become a major hindrance in comprehensively addressing PETI. Related agencies often work in silos and lack integration, resulting in delays in sharing critical and accurate information. The absence of an effective coordination mechanism weakens enforcement efforts in the field, with cases often left unresolved or ending only at the administrative stage without firm legal consequences. This issue is worsened by differences in priorities between central and regional governments, where some local governments tend to protect local economic interests or even turn a blind eye to illegal activities for various reasons.

Local political factors and conflicts of interest further complicate the enforcement of PETI. In some cases, illegal miners or mining groups have close ties with officials or local elites, which obstructs or even halts enforcement actions. Economic and sociopolitical interests at the regional level are often taken into consideration, making enforcement officers reluctant to take decisive action. This creates a dilemma between upholding the law and maintaining local political stability, ultimately weakening the position of law enforcement in acting against PETI perpetrators. Furthermore, such political interference may also lead to corruption and collusion, further reinforcing the illegal network.

The impact of these various issues in the monitoring system is the increasing prevalence of PETI across many regions in Indonesia. When oversight is weak and enforcement is slow, illegal actors feel more empowered to operate freely without fear of legal

consequences. This leads to the expansion and intensification of PETI, both in terms of the number of perpetrators and the scale of operations. Naturally, this increase correlates with the growing risk of environmental destruction due to uncontrolled exploitation of natural resources. Moreover, PETI activities also reduce state revenue from the formal mining sector, as illegal production goes unrecorded and untaxed, avoiding royalties.

From an environmental perspective, weak oversight results in significant degradation in illegal mining areas. PETI operations often fail to apply proper environmental management standards, leading to water pollution, deforestation, soil erosion, and loss of biodiversity. This damage is long-term and difficult to restore, negatively affecting ecosystems and the livelihoods of local communities who rely on natural resources. On a social level, the rise of PETI can cause conflicts among communities and between citizens and the government, while also contributing to insecurity and public disorder.

Economically, the uncontrolled existence of PETI results in significant losses for the state and society. The government loses potential revenue from taxes and royalties, while local communities often do not receive fair benefits from the mining output. On the contrary, communities frequently suffer negative impacts such as environmental damage that reduces the productivity of agricultural and fishery lands, as well as health risks due to pollution. Therefore, problems in monitoring and coordination not only hinder law enforcement but also cause widespread consequences that harm various aspects of national life.

Potential Use of Artificial Intelligence (AI) as an Innovative Solution for Monitoring and Combating Illegal Mining (PETI)

Artificial Intelligence (AI) is a branch of computer science that focuses on creating systems or machines capable of performing tasks that typically require human intelligence—such as pattern recognition, decision-making, problem-solving, and learning from data. (Zahra, 2023) AI operates by using algorithms and mathematical models to analyze large volumes of data quickly and accurately, identifying specific patterns to generate predictions or recommendations. In the context of monitoring, AI can process information from multiple sources—such as satellite imagery, surveillance cameras, IoT sensors, and reports—to automatically detect anomalies or suspicious activities without direct human intervention. (Kārkliņš, 2020)

The role of AI in the digital transformation of monitoring and security sectors continues to grow in line with advancements in sensor technology, cloud computing, and increased data storage capacity. (Arewe, 2023) AI enables real-time surveillance over wide geographic areas, far surpassing the capabilities of conventional systems that rely solely on physical and manual monitoring. In the mining sector and natural resource management, AI can analyze satellite imagery to monitor land condition changes, detect illegal activities, and predict potential environmental damage before it becomes widespread. (Erdélyi, 2021) Thus, AI serves as an innovative tool that not only improves the efficiency of monitoring but also provides faster and more accurate decision-making support for law enforcement and resource management authorities. (Junaidi, 2024)

Moreover, the implementation of AI in monitoring encourages the creation of an integrated digital ecosystem, where data from various sources can be combined and analyzed holistically. This enables the development of more adaptive and responsive monitoring systems that can operate 24/7 without fatigue or human bias. (Michael Faure, 2022) The use of AI also opens up opportunities for the development of new technologies such as autonomous drones that can conduct independent patrols and early warning systems that automatically send alerts

when indications of illegal activity are detected. (al., 2024) With all these advantages, AI becomes a key pillar in the digital transformation of modern surveillance and security, offering great potential for addressing complex challenges such as illegal mining (PETI).

The use of satellite imagery and AI-powered drones has become a significant breakthrough in monitoring mining activities, particularly in addressing the issue of illegal mining (PETI). By utilizing high-resolution satellite image data, AI algorithms can process and analyze changes in land conditions periodically, detect suspicious new activities, and monitor the development of mining sites in real-time. Drones equipped with AI technology also allow for more flexible and detailed monitoring in areas that are difficult for officers to access directly. These drones can fly autonomously, capture images and videos, which are then processed using AI models to identify traces of illegal activity, such as unauthorized land clearing and unregulated excavation.

In addition to visual monitoring, pattern recognition and data analysis-based AI algorithms are highly effective in detecting illegal field activities. AI can process big data from various sources, including satellite imagery, drone footage, field reports, and environmental sensors, to uncover patterns that indicate PETI activity. For example, AI can recognize unusual excavation patterns, suspicious vehicle movements, or sudden vegetation loss due to unauthorized land clearing. With machine learning capabilities, AI systems continuously learn from new data, thereby improving the accuracy of detecting illegal activities over time. This enables monitoring authorities to receive faster and more reliable information to respond to PETI activities effectively.

The integration of Internet of Things (IoT) sensors with AI technology opens new opportunities for real-time environmental monitoring. Sensors installed at mining sites can measure environmental parameters such as water quality, temperature, humidity, and noise levels, which can indicate illegal mining activities. The data collected by these sensors is then processed by AI systems to provide a comprehensive analysis of environmental conditions and issue early warnings when anomalies or violations are detected. This system not only aids in the early detection of PETI activities but also in ongoing monitoring of environmental impacts, enabling timely responses based on scientific evidence.

Globally, various countries have implemented AI in monitoring illegal mining and deforestation as part of efforts to conserve natural resources and enforce the law. For instance, in Brazil, AI technology is used to monitor illegal deforestation in the Amazon by utilizing satellite imagery and machine learning-based data analysis. As a result, the government can take swift action to stop illegal practices that damage the rainforest. In Australia, the use of drones and AI for mine monitoring has also been implemented to ensure that mining operations comply with regulations and environmental standards. This technology helps reduce operational costs and improve monitoring efficiency on a large scale.

In Indonesia, although still in the early stages, several initiatives and pilot projects are being developed to strengthen mining surveillance, including PETI activities. The government, together with research institutions and the private sector, has begun experimenting with AI-powered satellite imagery to monitor mining areas in Kalimantan and Sumatra, which are hotspots for PETI. Additionally, collaborations with tech startups have introduced drone-based and smart sensor solutions for real-time environmental monitoring in mining zones. Although there are still many challenges, such as limited funding and human resources with technical expertise, these initiatives demonstrate great potential for AI to enhance the effectiveness of mining oversight in Indonesia.

The application of AI in monitoring illegal mining (PETI) offers an innovative solution that addresses various limitations of conventional monitoring systems. This technology not only accelerates the detection and response to illegal practices but also improves the accuracy and scope of monitoring, and enables sustainable environmental surveillance. With the continued development of case studies and initiatives both domestically and internationally, it is expected that AI utilization will become a main foundation in the effort to combat PETI more effectively and sustainably in the future.

The use of AI in monitoring PETI activities brings significant benefits, particularly in terms of time and cost efficiency. Conventional monitoring systems often require large numbers of personnel to conduct physical patrols in the field, which are time-consuming and costly. In contrast, AI enables automated and continuous monitoring through the processing of data from satellite images, drones, and integrated sensors. With its ability to rapidly process vast amounts of data, AI allows enforcement officers to obtain the information and analysis they need without delay, thereby optimizing resource allocation and reducing operational expenses.

Beyond efficiency, AI also offers a much higher level of accuracy than traditional monitoring methods. AI technology can recognize patterns of illegal activity that are difficult for humans to detect, especially in remote and vast areas. For example, machine learning algorithms can distinguish between land changes caused by illegal mining activities and those resulting from natural processes or legal operations. The monitoring coverage enabled by AI is also much broader, as AI can integrate multiple data sources and monitor them simultaneously, without being constrained by physical or logistical factors. This allows for more comprehensive and detailed surveillance, both nationally and in remote regions.

AI's early detection capability is one of its primary advantages in monitoring PETI activities. AI-based systems can issue automatic alerts when suspicious activities or licensing violations are detected, allowing authorities to respond swiftly and effectively. A rapid response is crucial to prevent wider environmental damage and to take action against perpetrators before illegal operations escalate. With real-time monitoring systems, AI reduces reliance on manual reporting, which is often delayed and inaccurate, thereby improving the effectiveness of law enforcement and the protection of natural resources.

However, the implementation of AI in PETI monitoring also faces several challenges and obstacles that cannot be overlooked. One major constraint is the lack of adequate technological infrastructure, especially in remote areas where PETI activities are concentrated. In addition, there is still a shortage of skilled human resources capable of operating and maintaining AI technologies in Indonesia. These limitations hinder the widespread and optimal application of the technology, making it necessary to establish structured capacity-building and training programs so that human resources can keep pace with technological advancements.

Data security and privacy issues also become important concerns in the utilization of AI for monitoring. Data collected through satellite imagery, drones, and IoT sensors are highly sensitive and require protection to prevent misuse or leaks to unauthorized parties. Moreover, the use of AI technology must comply with regulations related to public privacy and data rights, so that the implementation of monitoring systems does not violate these rights. Addressing these issues requires strict cybersecurity standards as well as clear policies to ensure that AI technology can be used ethically and responsibly.

Lastly, regulatory barriers and policy adaptation also pose significant challenges in integrating AI into the PETI monitoring system. Current regulations have not fully accommodated the use of advanced technologies such as AI, so updates and policy adjustments

are needed to support innovation without neglecting legal and ethical aspects. Furthermore, coordination among government agencies responsible for monitoring and managing natural resources must be strengthened so that AI implementation can run synergistically and effectively. Responsive policy adaptation to technological developments is a key to the successful implementation of AI as an innovative solution in PETI monitoring and mitigation.

The development and utilization of artificial intelligence (AI) technology in monitoring Illegal Mining (PETI) requires close synergy and collaboration among various parties, especially government institutions, the private sector, and academia. The government, as the regulator and manager of natural resources, must take a central role in facilitating the development of this technology through supportive policies and the provision of basic infrastructure. Meanwhile, the private sector, especially technology companies and startups with capabilities in AI and geospatial information systems, can contribute by providing technical solutions and innovations that are adaptive to field conditions. Academics and research institutions are also important in conducting research and development (R&D) of AI technologies that fit the local context, as well as carrying out evaluations and testing to ensure the effectiveness of these technologies before widespread implementation. This collaboration is expected to create a sustainable innovation ecosystem to support PETI monitoring.

Capacity building for human resources (HR) becomes one of the main keys to the success of AI implementation in the mining supervision sector. The government and related institutions must invest in training and education programs specifically designed to improve the technical skills of mine supervisors, data analysts, and AI system managers. These programs can include training on the use of AI software, satellite image data analysis, drone operations, and understanding integrated IoT sensor systems. Additionally, HR development must also cover managerial and policy aspects so that stakeholders are able to manage and optimize the strategic use of AI. With adequate HR capacity building, AI technology can not only be operated effectively but also continuously developed to meet challenges in the field.

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The importance of formulating clear and comprehensive regulations and technical standards cannot be overlooked in supporting the utilization of AI in PETI monitoring. These regulations must cover legal aspects related to data usage, privacy protection, cybersecurity, as well as technical provisions concerning hardware and software standards employed. Adaptive regulations will provide legal certainty for monitoring actors while safeguarding community rights and environmental sustainability. Nationally implemented technical standards will ensure system interoperability, data quality, and accuracy of monitoring results produced by AI technology. Therefore, the formulation of regulations and standards must involve multiple stakeholders to reflect technical needs while also considering existing social and legal aspects.

Furthermore, the government needs to build an integrated data and information system connecting various agencies and monitoring devices to work synergistically and efficiently. This system will enable real-time data exchange and integrated monitoring among supervisory officers, law enforcers, and other relevant parties. With such integration, monitoring becomes more transparent, accountable, and responsive to PETI activities occurring in various regions. Adequate digital infrastructure and reliable communication networks are the fundamental foundation for the optimal operation of this integration system, enabling AI to be used as an effective tool to support strategic decision-making.

Finally, the strategy for AI development and utilization must be accompanied by mechanisms for continuous evaluation and improvement so that the technology applied remains relevant and responsive to evolving challenges in the field. The government and stakeholders need to form a dedicated team responsible for periodically monitoring, evaluating, and updating the technology. This approach should also involve input from local communities and technology users on the ground to ensure that the solutions developed truly meet real needs and are accepted by the public. With a continuous cycle of evaluation and innovation, the utilization of AI in PETI monitoring will not only serve as a short-term solution but also as a foundation for sustainable natural resource governance in the future.

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CONCLUSION

The utilization of artificial intelligence (AI) technology in monitoring illegal mining activities (PETI) offers innovative solutions capable of addressing various limitations of conventional monitoring systems, which have long been the main obstacles, such as limited human resources, budget, and infrastructure. AI enables improvements in time and cost efficiency through the automation of monitoring processes using satellite imagery, drones, and IoT sensors in real-time, thereby expanding the monitoring coverage and significantly increasing the accuracy of detecting illegal activities. Moreover, AI's ability to provide early detection and rapid response is crucial in preventing broader environmental damage caused by PETI activities and strengthening law enforcement. Thus, AI technology not only facilitates monitoring but also reinforces sustainable and equitable natural resource governance.

However, the implementation of AI in PETI monitoring also faces several challenges that must be overcome to maximize its benefits. Limitations in technological infrastructure, a shortage of competent human resources in AI operation, and issues of data security and privacy constitute significant obstacles that need attention. Furthermore, adaptive regulations and policies that support the development of this technology still need to be strengthened to ensure that AI use is legal, ethical, and effective. Therefore, strong collaboration among government, private sector, and academia, development of human resource capacity, and formulation of comprehensive regulations and technical standards are strategic steps that must be undertaken. With such integrated efforts, AI has the potential to become a primary tool in effectively monitoring and combating PETI activities, as well as supporting sustainable management of mineral and coal resources in Indonesia.

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