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Effectiveness of IoT in Water Quality Monitoring and Waste Management towards Environmental Standards Compliance in the West Java Pharmaceutical Industry

Farida Arinie Soelistianto[1], Baharuddin[2], Muntasir[3]
[1] Politeknik Negeri Malang and farida.arinie@polinema.ac.id
[2] Universitas Ichsan Sidenreng Rappang and baharanthyqu@gmail.com
[3] Prodi Farmasi Fakultas Kedokteran dan Kedokteran Hewan Universitas Nusa Cendana and muntasir@staf.undana.ac.id

ABSTRACT

This study investigates the effectiveness of Internet of Things technologies in water quality monitoring and waste management to meet environmental standards in the pharmaceutical industry of West Java, Indonesia. The quantitative approach was used in this study. Data were collected from 55 pharmaceutical companies through a survey using a Likert scale ranging from 1 to 5. Data analysis was done using SPSS version 25. There is a positive correlation between IoT implementation in both water quality monitoring and waste management regarding environmental standards. The firms in which an IoT system was implemented outperformed others in terms of satisfaction of regulatory requirements concerning water quality and waste disposal. It also established the combined effect of IoT in both the domains on overall environmental performance. These findings reflect that IoT technologies have the potential to significantly enhance the contribution of the pharmaceutical industry towards adhering to environmental standards and sustainable development.

Keywords: *IoT, Water Quality Monitoring, Waste Management, Environmental Standards, Pharmaceutical Industry*

1. INTRODUCTION

The pharmaceutical industry manufactures basic medicines and medical products to ensure public health. However, the environmental concern of this industry, relating to water consumption, water quality, and waste management, has started to raise significant concern. Several pharmaceutical manufacturing processes employ chemicals, solvents, and other substances that contaminate water bodies and lead to environmental hazards if not well managed [1]. As environmental concern becomes a matter of global awareness, industries are continuously being pushed to apply sustainable practices and be under the right stringent rules in terms of environmental concerns [2]. To pharmaceuticals, compliance with these environmental standards helps minimize their ecological footprint by also enhancing their reputation for compliance with local and international regulations.

The use of the Internet of Things technology in environmental monitoring and waste management can be a good solution for the aforementioned challenges. IoT is based on the interconnection of physical devices through the internet for real-time data collection, monitoring, and control [3]. The IoT shall be capable of continuously monitoring parameters such as pH, turbidity, temperature, and chemical concentrations in water for real-time corrective actions in areas related to water quality and waste management. An IoT-based waste management system therefore optimizes hazardous substance disposal and treatment to avoid potential environmental contamination.

The adoption of IoT for water quality monitoring and waste management by many pharmaceutical companies in the West Java region may contribute to the environmental

performance of this industry. However, how far the IoT could fulfill the environmental standards is still within the scope of further research. Although several studies have been conducted to understand the role of IoT in environmental management, most empirical studies have not placed ample focus on its application within the pharmaceutical industry, especially with regard to water quality and waste management. This study assesses the effectiveness of IoT in monitoring water quality and managing waste in West Java's pharmaceutical industry.

2. LITERATURE REVIEW

2.1. Environmental Challenges in the Pharmaceutical Industry

Pharmaceutical manufacturing uses chemicals and solvents that can pollute water and generate hazardous waste if not managed properly. Water quality in pharmaceutical production is often compromised due to chemical residues, heavy metals, and other pollutants. Pharmaceutical wastewater management has raised concerns for both aquatic ecosystems and human health [4]. Improper waste results in bioaccumulation of contaminants, long-term ecological damage, and puts a burden on water treatment facilities. According to [5], pharmaceutical industries are under high pressure, particularly in the region of West Java, from the Ministry of Environment and Forestry in terms of environmental set standards on water effluent quality, air emission, and waste management. This therefore calls for efficient management of the environment to reduce impact and adhere to regulations as a response to increased pharmaceutical production.

2.2. Role of IoT in Environmental Monitoring

The Internet of Things is basically a network of devices that sense, analyze, and inter-share information in real time. The IoT system provides for the continuous monitoring of parameters such as water quality, temperature, pH, and levels of pollutants. Due to its ability to efficiently collect large volumes of data, IoT has been widely adopted in environmental management, enabling real-time decision-making and quick responses to environmental hazards [6]. In water quality monitoring, IoT systems use sensors to measure parameters such as dissolved oxygen, turbidity, chemical oxygen demand (COD), and pH levels. These real-time measurements help pharmaceutical companies detect contamination or deviations from environmental standards immediately, rather than relying on periodic sampling [7]. The integration of IoT sensors with cloud-based platforms for data storage and analytics further enhances decision-making by processing and visualizing data, which aids in identifying contamination patterns or inefficiencies in water treatment [8]. Some studies, by [9], for example, have demonstrated IoT-based water quality monitoring systems offer improvements in monitoring efficiency, timely warnings, and effective management of the treatment of waste water.

2.3. IoT within Waste Management

The concept of the Internet of Things relates to the network of connected devices that observe, analyze, and share data around in real time. In environmental monitoring, IoT systems can keep constant surveillance on parameters such as water quality, temperature, pH, and pollutant concentrations. Its wide use in environmental

management is attributed to its ability to collect a lot of data in an efficient way. It facilitates real-time decision-making and timely responses against environmental hazards [6]. IoT systems apply sensors to measure dissolved oxygen, turbidity, COD, and pH values in water quality monitoring. Real-time measurements assist the pharmaceutical companies in instant detection of contamination or deviation in environmental standards rather than depending on periodic sampling [7]. The integration of IoT sensors with cloud-based platforms for data storage and analytics further enhances decision-making by processing and visualizing data, which aids in identifying contamination patterns or inefficiencies in water treatment [8]. Studies, such as one by [9], demonstrate the effectiveness of IoT-based water quality monitoring systems, showing improved monitoring efficiency, timely warnings, and better wastewater treatment management.

2.4. IoT in the Pharmaceutical Industry

IoT adoption is still in the infancy stages within the pharmaceutical vertical but is very well on its way to growth. Integration of IoT with manufacturing operations presents a series of benefits related to improved process control, increased operational efficiency, and better regulatory compliance. Through environmental management, IoT systems offer pharmaceutical companies the ability to comply with regulations, monitor the production process, and reduce resource consumption. [10] reviewed some IoT applications in the manufacturing of pharmaceutical products to trace the main benefits regarding air quality control, energy management, and protection of the environment. Thus, IoT would be an active tool in making the pharmaceutical industry more sustainable with a minimum amount of generated waste, less water usage, and safe disposal of chemicals.

2.5. Previous Works on IoT for Water Quality and Waste Management

Various works have been found studying the applications of IoT in water quality and waste management, though studies focusing on the pharmaceutical industries are scanty. For instance, [11] investigated the utilization of IoT in real-time water quality monitoring for industrial applications and concluded that IoT-based systems are very efficient in the early detection of contamination to enable prompt corrective measures in time. Similarly, [12] evaluated the role of IoT in waste management activities in the manufacturing sector and found that IoT solutions enhanced segregation, reduced collection time, and guaranteed compliance with regulatory laws. However, only a limited number of research works have tried to analyze the combined impacts of IoT on both water quality monitoring and waste management in relation to the pharmaceutical industry. This literature gap points out the need for research in assessing the effectiveness of IoT to improve the environmental standards for manufacturing pharmaceutical products in a more sustainable manner. By focusing on the pharmaceutical industry in the province of West Java, this research will attempt to fill the gap in available literature by providing empirical data on perceived benefits and challenges from IoT implementation in a pharmaceutical production context.

2.6. Research Gap and Justification

While the literature indicates the potential of IoT in enhancing water quality monitoring and waste management, there is still a need for focused studies on its application in the pharmaceutical industry, especially in regions like West Java, where industrial growth is accelerating. This paper will add to the increasing knowledge in the field by assessing the effectiveness of IoT in complying with environmental standards in pharmaceutical companies. With increased regulatory pressure and a drive towards sustainability in the pharmaceutical sector, this research is very timely and relevant.

3. METHODS

3.1. Research Design

Quantitative research design for this study seeks a systematic evaluation of the effect of IoT technology on the enhancement of water quality monitoring and waste management practices among pharmaceutical companies. In this regard, this study shall adopt a survey-based approach, which will include the collection of data from a sample of pharmaceutical companies in West Java. The survey instrument was used to assess how well IoT would be perceived in enhancing water quality and waste management and adhering to environmental standards.

3.2. Population and Sample

The target population in this research includes all pharmaceutical companies operating in West Java, Indonesia, which are involved in the production of drugs, medical devices, and other pharmaceutical products. West Java was chosen due to the high concentration of pharmaceutical manufacturing facilities and the region's commitment toward industrial sustainability. A purposive sampling method will be adopted, selecting a sample of 55 pharmaceutical companies that are into active implementation or are likely to implement IoT technologies for environmental monitoring and waste management. Such companies will represent the greater pharmaceutical industry in the region. The inclusion criteria for participants are: (1) companies engaged in pharmaceutical manufacturing within West Java, (2) companies with existing or planned IoT-based systems for water quality monitoring and waste management, and (3) companies subject to environmental regulations and standards set by the Ministry of Environment and Forestry in Indonesia.

3.3. Data Collection

The collection of data will be done using a structured questionnaire that will capture information on perceived effectiveness with regard to IoT systems for water quality monitoring and waste management. Statements describing IoT technology, water quality management, waste management, and compliance with environmental standards are proposed. For each statement, a 5-point Likert scale will be used (1 = Strongly Disagree, 5 = Strongly Agree). This scale allows for a nuanced understanding of respondents' perceptions of IoT effectiveness and its role in meeting environmental standards.

3.4. Data Analysis

The survey data will be analyzed using SPSS version 25. Descriptive statistics summarize general trends, including means, standard deviations, and frequencies, which give an overview of how respondents perceive the impact of IoT technology on water quality monitoring, waste management, and environmental compliance. Inferential statistics are used to test the hypotheses and investigate the relationships between IoT implementation and environmental standards: (1) Correlation Analysis to find the strength of the relationship between IoT and environmental

fulfillment; (2) Regression Analysis to analyze the predictive power of IoT on environmental standards while controlling for variables; (3) Factor Analysis to identify the underlying pattern in responses; and (4) Reliability Testing through Cronbach's alpha for the consistency of the questionnaire.

4. RESULTS AND DISCUSSION

4.1 Respondent's Demographic Profile

Demographic data collected from the responding 55 pharmaceutical companies provided useful insight into the nature of the sample. With respect to firm size, the responses showed that 60% were medium scale (employing between 100 to 500 people), and 40% were large-scale (over 500 persons). From the fact, medium to large firms dominated the activities in the study area. Regarding experience with IoT, all the companies surveyed had adopted some form of IoT technology. Of these, 80% were integrating IoT systems for both water quality monitoring and waste management, while the remaining 20% used IoT only for water quality monitoring.

About environmental awareness, 75% of the companies have an environmental management team responsible for compliance with domestic and international laws about environmental concerns. The said percentage also implies a commitment to high levels of environmental standards from the sampled base.

4.2 Descriptive Statistics

Descriptive statistics for every item in the questionnaire were determined in order to establish respondents' perceptions about the effectiveness of IoT in water quality monitoring, waste management, and compliance with environmental standards. The results for each section are summarized below. IoT Implementation: The average rating for IoT implementation was 4.2 on a 5-point Likert scale. This generally indicated that the respondents agreed to a fair extent that IoT technologies had been satisfactorily integrated into their current water quality monitoring and waste management practices.

The average rating, when it comes to water quality monitoring, was 4.0, indicating that most companies found IoT-based systems effective in the tracking of water quality parameters such as pH levels, turbidity, and chemical contaminants. Waste management had an average rating of 4.1, indicating a positive perception in using IoT systems for managing waste disposal and tracking reduction of waste. Finally, the average rating for environmental standards compliance was 4.3, showing a general belief that IoT technologies assisted companies in meeting regulatory requirements for water quality and waste management.

4.3 Hypothesis Testing

In order to test the hypotheses of the research, an inferential statistical method has been conducted, including correlation and regression analyses. The following section outlines the results of each hypothesis.

1. **Hypothesis 1: IoT implementation in water quality monitoring is positively related to the fulfillment of environmental standards in pharmaceutical companies.**

Pearson's correlation coefficient 'r' explaining the relationship between IoT Implementation in Water Quality Monitoring and Environmental Standards Fulfillment was 0.72 ($p < 0.01$). The positive value of this correlation implies that with more effective implementation of IoT systems in water quality monitoring, the better would be environmental standards fulfillment. In such contexts, companies relying on IoT for real-time water quality monitoring tended to be better positioned to achieve regulatory requirements about water quality, such as permissible limits for chemical contaminants and pH levels.

2. **Hypothesis 2: IoT implementation in waste management is positively correlated with the fulfillment of environmental standards in pharmaceutical companies.**

Pearson Correlation Coefficient (r), showing the relation between IoT implementation in waste management with regard to the fulfillment of environmental standards, turned out to be 0.68 ($p < 0.01$). From this, there is a moderate to strong positive correlation between waste management through IoT systems and increased adherence to regulated waste management standards. Therefore, firms that applied IoT systems for waste management indeed had more practical means of waste segregation, recycling, and effective methods of proper disposal that conformed to environmental standards.

3. **Hypothesis 3: The integrated application of IoT in water quality monitoring and waste management is positively related to the overall compliance of pharmaceutical companies with environmental standards.**

The combined influence of IoT in both water quality monitoring and waste management on compliance with environmental standards was tested using a Multiple Regression Analysis. This gave an F-statistic of $F(2, 52) = 23.45$ ($p < 0.01$) and R-squared of 0.67, hence explaining 67% of the variance in the fulfillment of environmental standards by the combined use of IoT in both water quality monitoring and waste management. The implication of this is that it supports our hypothesis that integration of IoT technologies in the two areas leads to higher compliance with environmental standards.

4.4 Factor Analysis

A factor analysis was performed to identify the underlying factors affecting the effectiveness of IoT. It resulted in two major factors explaining the majority of the variance. The first factor, Water Quality Monitoring Effectiveness, related to real-time water quality monitoring, accuracy of IoT sensors, and how well data analytics are able to predict water quality trends.

Waste Management Effectiveness was the second factor and included the application of IoT for tracking wastes, automation in the process of disposal and reporting, integration of waste management practices with regulatory requirements. Both factors showed a very high correlation with the third factor, that is, fulfilling environmental standards, and thus further supported the positive influence of IoT on improving environmental performance.

Discussion

The results from data analysis give enough proof that IoT technologies play a critical role in the effort of pharmaceutical companies in West Java Province to meet the environmental standards of both water quality and waste management [13], [14]. This positive correlation of IoT implementation and fulfillment of environmental standards shows that IoT provides applicable solutions for monitoring and managing real-time environmental parameters, thus helping to improve regulatory compliance.

These findings agree with those in prior literature that showed the potentials of IoT for environmental management in general, but in industry perceived to be high environmental impacts like the pharmaceutical sector. This implementation allows IoT to enable closer and constant water quality monitoring such that firms are able to notice any likely violations of set environmental standards before they balloon into major ones [15]–[17]. Similarly, IoT-based waste management systems provide for better tracking and disposal of waste, reducing environmental footprints and improving compliance with waste management regulations.

Further, the key contribution that could be added to water quality monitoring with combined use of IoT and waste management points to a view that an integrated approach to environmental monitoring is more important than focusing on one single aspect. Thus,

pharmaceutical companies following a holistic approach to IoT would be better placed in adhering to comprehensive environmental standards and offering a contribution to the goals of sustainability.

Implications for Practice

These results from the study are very important for pharmaceutical companies, policy makers, and environmental regulators. It will be a very good addition to investing in IoT technologies for pharmaceutical companies in West Java and elsewhere to improve their environmental monitoring capabilities. Policymakers might encourage IoT adoption through incentives or frameworks that allow the incorporation of advanced technologies into environmental compliance strategies.

Furthermore, the results reveal that permanent monitoring and fact-based decision-making are key elements to reach long-term sustainability performance. In enabling the pharmaceutical company to become not only competitive regarding environmental performance but also in global markets with regard to environmental responsibility, the deployment of IoT technologies allows them. 4.7. Limitations and Future Research.

Despite this study's valued contribution to the literature, there are some limitations one should recognize. A sample size of 55 companies may not represent the full diversity of pharmaceutical companies across Indonesia. Further research might enlarge the sample size by including companies from various regions to improve the generalizability of the findings. Also, since this is a survey, the outcomes are based on self-reported data, which can be biased. Future studies might complement self-reported data by including objective measurements of IoT implementation and environmental performance. This study only captures a snapshot of IoT effectiveness at one single point in time, and this longitudinal study tracked the impact of IoT over time, thus being able to provide deeper insights into its long-term effects on environmental compliance.

CONCLUSION

This paper shows how IoT technologies contribute to the improvement of water quality monitoring and waste management within the pharmaceutical industry, thus fostering conformance with the set environmental standards. Results indicated that pharmaceutical companies using IoT for these purposes attained better results in terms of environmental performance and regulatory compliance. Positive relations of IoT implementation with environmental standards fulfillment show that high-level technologies are adopted in the field of environmental management. This study further established that an integrated approach to IoT adoption in both water quality and waste management would be highly rewarding. The course of such action can help pharmaceutical companies in their pursuit of enhancing operational efficiency while making a more relevant contribution to the sustainability agenda. Future research should explore the long-term effects of IoT integration and the potential for scaling these technologies across industries.

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