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Design of Automatic Irrigation System for Post-Mining Land Reclamation

Ruspita Sihombing [a,*], Amiril Azizah [a], Zainal Arifin [a], Wahyuni Eka Sari [a], Agus Wiramsya Oscar [b], Pandhu Rochman Suosa Putra [c],

[a] *Politeknik Negeri Samarinda, East Kalimantan Province, Indonesia*
[b] *PT. Insani Bara Perkasa, East Kalimantan Province, Indonesia*
[c] *Politeknik Pertanian Negeri Samarinda, East Kalimantan Province, 75131, Indonesia*
*Corresponding author: *ruspita@polnes.ac.id*

***Abstract*—post-mining land reclamation poses a challenge in restoring degraded land's ecological function and productivity, requiring optimal rehabilitation to make it productive and environmentally friendly. A key challenge in reclamation is the availability of efficient water sources to support the revegetation process. Conventional irrigation systems are inefficient and require intensive monitoring. Therefore, an innovative solution in the form of an automatic irrigation system is needed to optimize water use and support sustainable plant growth. This study aims to design and develop a technology-based automatic irrigation system that combines soil moisture sensors, water pumps, sprinklers, solar panels, solenoid valves, and microcontrollers to regulate irrigation efficiently and on time. The methodology includes hardware and software design, integration of soil moisture sensors, a microcontroller as the control unit, and system field testing. The system is designed to activate irrigation based on real-time soil moisture levels automatically, ensuring water is only applied when needed. The system is expected to reduce excess water use and improve irrigation effectiveness across large and diverse areas. Results show that this automatic irrigation system can reduce water consumption by 34.2% compared to conventional methods. In addition, farmers can remotely manage irrigation via the Internet or mobile apps, reducing irrigation time by 75 minutes. This system holds the potential to be an innovative and sustainable solution for post-mining land reclamation, ushering in a new era of efficient and sustainable agriculture**.

***Keywords*—Automatic design; irrigation system; land reclamation; post-mining.**

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I. Introduction

Environmental quality, thus negatively impacting environmental sustainability and society. Therefore, post-mining land reclamation is essential to restore and improve damaged land for reuse. An important aspect of land reclamation is water management, including adequate irrigation to support plant growth and stabilize the soil [1]. However, irrigation is complex in post-mining areas due to compacted soils, water shortages, and poor drainage. In this case, automatic irrigation technology can be an effective solution to overcome these problems [2].

Coal production in Indonesia has gradually increased over the last 10-15 years. East Kalimantan accounts for nearly 28% of Indonesia's coal reserves [3]. On the other hand, while coal contributes to the economy, it also directly impacts environmental sustainability [4]. Environmental impacts and deforestation that threaten natural sustainability are the main problems in the extractive economy, such as the mining sector [5]. Land degradation, tropical forest depletion, and post-mining reclamation are often important environmental issues discussed after mining activities have ended [6]. Mining that involves large-scale exploitation of natural resources tends to have adverse impacts on surrounding ecosystems, such as soil damage, water pollution, and loss of vegetation [7]. Not only does this environmental damage disrupt the balance of the ecosystem, but it also impacts the lives of communities around the mining area. Climate change, health risks due to pollution, and the loss of natural resources that support daily life are challenges that must be faced after mining [8]. The majority of mining companies carry out coal mining activities in an open pit mining method by changing the initial hue of a land by removing overburden and then taking the coal that is there [9]. It is essential to study the post-mining reclamation process in terms of both emission reduction and costs and benefits [10]. Rehabilitation of ex-mining land is an important step that must be taken. This rehabilitation process aims to restore land conditions to be productive and environmentally friendly. Ecosystem damage on ex-mining land can be restored through various methods, such as vegetation engineering, ecological restoration, and environmentally friendly technology [11]. The experiment of [12] compared the relationship of water absorption in plants in natural vegetation areas with post-mining rehabilitation areas, which is different, where natural vegetation sites show a better repair response than in rehabilitation land.

The development of agricultural and forestry systems is a method that is mainly applied in the scope of land reclamation and restoration in post-mining areas that have been exploited. The more combinations of methods that are applied, the more benefits are obtained [13]. The integrated spatial planning concept can be implemented on former coal mine land with the principle of sustainability, which can be supported by cultivating forest plants, eucalyptus plants, aquaculture, and cattle farming [14]. Thus, post-mining land reclamation activities are not only useful as a restoration of environmental ecosystems but also as an effort to absorb CO2 in the atmosphere and can restore carbon stocks in forest ecosystems that are lost due to mining activities [15]. The ecosystem and landscape restoration and reconstruction in mining areas must be done realistically because they have suffered severe damage. Scope for conservation and wise utilization of mineral resources can be achieved through local, regional, and national actions to achieve sustainable development in mining areas [16].

An effort that can be made in the framework of rehabilitation on post-mining reclamation land is the application of an appropriate irrigation system as an innovative step in increasing the efficiency and effectiveness of irrigation, especially on post-mining land that requires intensive rehabilitation [17]. Water management is essential for efficiency and contributing to the Sustainable Development Goals (SDGs), so the modeling and development of automation systems in irrigation systems needs to be implemented as a step to support water conservation [18]. However, conventional irrigation systems are often inefficient in water use and take a long time to irrigate large land areas. Therefore, innovations are needed in irrigation systems that can optimize the use of water resources and time [19].

One of the best options for managing water resources is to improve the productivity of water use. Automation with IoT systems can be a great way to improve the operation of irrigation systems that can be regulated based on actual crop needs and soil conditions, thereby increasing water use efficiency [20]. Designed systems incorporate soil moisture sensor technology, solenoid valves, and microcontrollers to ensure plant watering is done promptly and by the required water needs [21]. The soil moisture sensor plays a vital role in detecting real-time moisture levels. These sensors are placed in the soil at the plant's root area, and the available moisture content is continuously measured. This directly obtained soil moisture data is then sent to the microcontroller [22]. As the controlling center of the system, the microcontroller processes the data from the soil moisture sensor and determines when water should be applied to the soil. If the soil moisture level is below a preset threshold, the microcontroller will send a signal to open the solenoid valve connected to the irrigation system. If the soil moisture content reaches the desired level, the microcontroller will send a signal to close the solenoid valve and stop the water flow [23], [24] .

Implementing this automatic irrigation system allows post-mining land to be managed more efficiently. Plants get the right amount of water as needed, avoiding wastage of water resources and ensuring optimal growth (Wu et al., 2024). In addition, the automation system is capable of reducing manual labor by 82%-88% in irrigation management, enabling more sustainable, cost-effective, and productive land management [25].

This technological approach not only supports post-mining land rehabilitation by restoring soil productivity but also has a positive impact on the environment with more efficient and targeted water use [26]. The automatic irrigation system implementation is an essential solution for more innovative and more sustainable farmland management, paving the way for modern farming practices that are more environmentally friendly [27].

Furthermore, rehabilitation efforts also have the potential to create new economic opportunities for local communities through the utilization of restored land [28]. The several quality attributes, including performance, scalability, flexibility, interoperability, productivity, extensibility, and security, and maps them to the corresponding components of an IoT-based agricultural software architecture is needed to identify [29]. The system optimizes irrigation water use through comprehensive big data collection, storage, and analysis. Leveraging insights from this data can facilitate informed decision-making regarding water management, thereby driving conservation efforts, especially in dry regions [30].

The proposed system uses the data collected from the sensor units to provide optimal irrigation decisions and communicates them to the operator (farmer) through the developed IoT platform. Data from soil moisture, ambient temperature, solar irradiance, and rainfall sensors are processed through a Fuzzy Logic controller to adjust the irrigation time. Trapezoidal and triangular membership functions fuzzified the inputs and outputs [31]. This study uses multidimensional time series modeling to predict soil moisture using two years of data in US agriculture, including factors such as soil moisture, temperature, and weather [32]. The models evaluated are machine learning algorithms such as Extreme Gradient Boosting and Random Forests, Spectral Temporal Graph Neural Network (StemGNN) Deep Learning, and Vector Autoregression as a reference model [31].

The novelty of this automatic irrigation system using sprinklers can be seen in the innovation in its design. In the previous sprinkler system, each tool was not in one location or one point but scattered at several points. In the latest design of this automatic sprinkler, each component is integrated into one frame that can be moved after the completion of land revitalization and will be carried out during the next one.

This irrigation system uses two reservoirs as a water source and eco-enzyme to irrigate the plants. Each reservoir is filled with water or eco-enzyme and pumped to a sprinkler system. This system places several sprinklers at specific locations in the planting area. The water or eco-enzyme the pump delivers is sent to the sprinklers through a network of pipes connecting the pump and sprinklers. Watering is done manually by pressing a button on the control panel. However, this system has some disadvantages. It uses too many pipes and increases the risk of leakage. If a leak occurs, the repair process will take longer because you must manually find the leak's location in the pipe. In addition, this system is less mobile if the irrigation equipment needs to be moved from one field to another. Each irrigation component must be disassembled and moved one by one, which can take a long time.

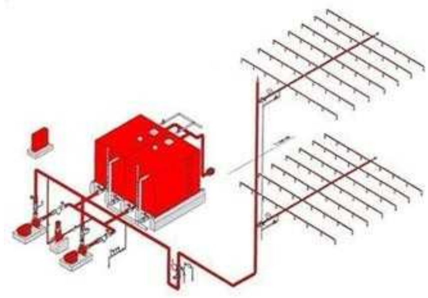

Fig. 1 Conventional sprinkler system

This is a modification of the previous automatic irrigation system where the number of sprinkles is placed at several points so that more are made into the latest design, which uses one sprinkle and uses fewer pipes and slang. This can also make maintenance easier and cheaper.

Fig. 2 Automatic Sprinkler System with Centralized Sprinkler in the Middle

The system uses two reservoirs containing water and eco enzymes and one sprinkler. Each reservoir is equipped with an electric valve that the system can control. When the watering schedule arrives, the valve on the corresponding reservoir will open for either watering with coenzyme or plain water. Once the valve is open, the pump will suck the liquid from the reservoir and deliver it to the sprinkler. The pump is powered by a battery charged by a solar panel, so it does not require electricity from an external source. The solar panel is mounted on the top of the reservoir. All device components are integrated into one support frame, making it easy to move to other areas. Solar panels are used as a power source, making them cost-effective and independent of electricity. The design is integrated where all components are in one frame that is easy to move. Watering occurs automatically according to soil inertia and a set schedule, eliminating the need for constant supervision. Working procedure of automatic irrigation system are as follows:

a. Place the automatic sprinkler in the center of the plot
b. Turn on the system connected to the automatic sprinklers.
c. Connect the automatic sprinklers with the user's device using the software provided.
d. Set the working hours and degree of sprinkler rotation. This work procedure is done only once at the beginning of the sprinkler use.

Collect data to compare conventional watering systems (human labor) with automatic irrigation systems. Measure the time and volume required to water the plants in two different ways. Data collected included the time required to water each plot and the volume of water used during the watering process. This comparative data was used to evaluate plant watering practices' efficiency and water requirements in a post-mining rehabilitation environment.

The time required was obtained by monitoring the work elements during the watering operation and recording the duration of each event and other factors affecting the sprinkler system's performance. Data were collected continuously throughout each cycle, from start to finish. Time measurement of work elements during watering operations using the continuous method by measuring pure work time (system preparation, watering), general work time (machine interruption, folded hose, idling, rest time, and personal time)

The research plot was installed with conventional watering for the first experiment, while the automatic irrigation system was installed in the center of the plot for the second experiment. Thus, it is essential for all parties involved, including the government, mining companies, and communities, to work together to carry out ex-mining land rehabilitation programs. Through synergistic cooperation, ex-mining land can be returned to a productive asset that provides long-term benefits for the environment and future generations. This study aims to design and build an automatic irrigation system that can be applied to post-mining land at PT. Insani Baraperkasa (PT. IBP) East Kalimantan. Thus, this research not only contributes to environmental rehabilitation efforts at PT. Insani Baraperkasa (PT. IBP) also provides a model that other mining companies can adopt in managing post-mining land in a sustainable and environmentally friendly manner.

II. MATERIALS AND METHOD

The materials used in this research are a set of 2200-watt water pumps, a 1000-liter water reservoir (10 dm x 10 mm x 10 dm), sprinkles with a radius of 25 cm, a solar cell, an RS485 sensor, and an ESP32 microcontroller. A research plot measuring 50 m x 50 m with an area of 2500 m² (1/4 ha) was set up in the post-mining land reclamation area of PT. Insani Bara Perkasa. For the first experiment, the research plot was watered conventionally, while the automatic irrigation system was installed in the center of the plot for the second experiment. The working principle of the automatic irrigation system is that the RS485 Soil NPK PH EC sensor detects moisture and pH, and then the ESP32 Microcontroller processes the data. If the percentage of soil moisture is < 40% and the pH value < 6-7.5 (Fajar et al., 2023)), the ESP32 Microcontroller will provide information to turn on the pump and open the Solenoid. Conversely, if the percentage of soil moisture is> 40% and the pH value is> 6-7.5, the ESP32 Microcontroller will provide information to turn off the Pump and close the solenoid, as in the flow chart in figure 3.

Based on soil moisture and pH. Here are the steps of the flowchart:

a. Prepare equipment such as an RS485 soil NPK PH EC sensor (which detects soil moisture, pH, and nutrient content), an ESP32 microcontroller, a pump, and a solenoid valve.

b. The sensor detects moisture and pH value: RS485 sensor detects soil moisture and pH value.
c. Data processing by microcontroller: The ESP32 microcontroller processes the data received from the sensors, specifically the soil moisture data.
d. Moisture and pH conditions: The microcontroller determines if the soil moisture is above 40°C and the pH is between 6 and 7.5.
e. The next step is executed if these two conditions are met (YES).
f. Otherwise (NO), the system continues the irrigation process. If the conditions are not met (NO), the ESP32 microcontroller switches on the pump and opens the solenoid valve to start the irrigation process.
g. Irrigation process: The irrigation continues until the soil moisture reaches the specified threshold.
h. Timer: Once the irrigation process is complete, the system enters the timer (planning) stage before rechecking the soil conditions.
i. Finish: The process is completed.
   If conditions are met (YES), the ESP32 microcontroller switches off the pump and closes the solenoid valve, signaling that soil conditions are sufficient and no irrigation is required.
j. Done: Process completed.

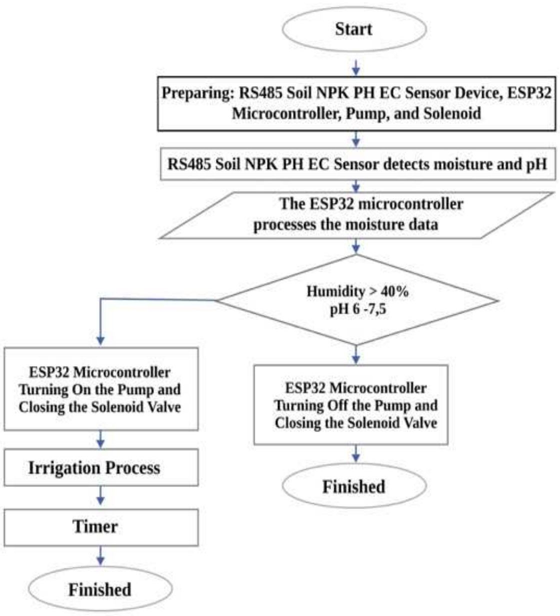

Fig. 3 Flowchart of Automatic Irrigation System on Post- Mining Land

Analytical Tools and Hypothesis Testing: this study used a T-test to analyze the difference between conventional and automatic irrigation systems on post-mining land.

Homogeneity Test Steps: The homogeneity test steps are as follows: Hypothesis

a. H0 = no difference between time and volume using conventional and automatic irrigation systems.
b. Ha = There is a difference between time and volume using conventional and automatic irrigation systems.

Hypothesis Testing: The test's conclusion is done by comparing the - t-count with the - table. If t - count < t - table, then h0 is accepted; if t - count > t - table, then ha is accepted.

III. Results and Discussion

This research aims to design and develop an effective automatic irrigation system for post-mining land reclamation. This study was conducted PT Insani Bara Perkasa Loa Janan in Kutai Kertanegara Regency, East Kalimantan Province, Indonesia. PT Insani Bara Perkasa has a total area of 93,425 ha, consisting of mining allotment of 73,420 ha and limited production forest of 20,005 ha. Based on the climate classification in Indonesia, the East Kalimantan area, especially Kutai Kartanegara, is included in the type A climate, with an average temperature between 22-27°C and an average annual rainfall between 2,500-4,000 mm. Soil types in the research location include alluvial, latosol, podzolic, lithosol, and regosol, the majority of soil textures in the mining area are sandy loam, sandy clay loam, clayey loam, and medium clay. Land with these criteria requires optimal nutrients because water from mining pits contains harmful chemicals such as Fe, Mn, SO4, Hg and Pb. Fe and Mn substances in large quantities can be toxic to plants, causing plants not to develop properly, so it is necessary to optimize the addition of nutrients so that plants can develop fertilely.

TABLE I
Conventional Watering Worktime

Elements of Work	1	2	3	4	5	6	7	Writing-Writing (hour)
Preparation (start the engine, prepare the engine)	0. 18	0.18	0.18	0.19	0.18	0.17	0.19	
Pulling Hose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Watering plants	0.37	0.37	0.37	0.38	0.38	0.38	0.38	
Winding the hose	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
TOTAL I	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
General Hours	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Engine Fault	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Stuck hose	0.37	0.38	0.37	0.38	0.37	0.38	0.37	
Missing Work Tools	0.00	0.00	0.00	0.00	0.00	0.00	0.00	
Silence (drinking, drinking, talking, resting)	0.41	0.38	0.38	0.35	0.40	0.38	0.40	
TOTAL I + II	1.33	1.30	1.31	1.29	1.33	1.30	1.34	**1.32**

TABLE II
Water Height and Volume Using the Conventional System

Experiment	Water Height in the Reservoir	Volume	Average (Liters)
1	61	610	
2	51	510	
3	56	560	
4	43	430	
5	46	46	
6	55	550	
7	44	440	
Total		3560	**508.57**

Tables 1 and 2 show that the working time of watering with conventional water is 1.32 hours (79.2 minutes), which consists of pure working time plus general time (machine interference, stuck slang, and silence). Water volume using conventional system 508.57 liters.

TABLE III
WORKING TIME OF WATERING WITH AUTOMATIC IRRIGATION SYSTEM

Elements of Work	1	2	3	4	5	6	7	Average (Minutes)
Preparation (start the engine, prepare the engine)	0	0	0	0	0	0	0	
Watering plants	4.24	3.57	4	4.3	3.58	4. 2	3.58	
TOTAL I	4.24	3.57	4	4.3	3.58	4. 2	3. 58	
General Hours								
Engine Fault	0	0	0	0	0	0	0	
Silence (drinking, drinking, talking, resting)	0	0	0	0	0	0	0	
TOTAL II	0	0	0	0	0	0	0	
TOTAL I + II	4.24	3.57	4	4. 3	3. 58	4. 2	3.58	4.2

TABLE IV
WATER HEIGHT AND VOLUME USING THE AUTOMATIC WATERING SYSTEM

Experiment	Water Height in the Reservoir	Volume	Average (liters)
1	38	380	
2	38.5	385	
3	38	380	
4	37.5	375	
5	38	380	
6	37.5	375	
7	35	350	
	Total	2625	375

Tables 3 and 4 show that the working time of watering with an Automatic Watering System is 4.2 minutes, which consists of pure working time plus general time (machine trouble, stuck hose, and idle). The water volume using the conventional system is 375 liters. Based on the data from the modification of the automatic irrigation system in post-mining land reclamation, a table and then a graph can be made as. Based on table 5 and the graph above shows that watering conventionally takes more time than the automatic irrigation system (79.2 > 4.2); this is because watering with traditional time of work consists of elements of pure work time and general time, which is relatively much. The volume of water used to water the conventional way is greater than the automatic irrigation system (508.57 > 375) due to the difficulty of controlling the volume of water released conventionally and uneven watering. Using automatic irrigation systems can reduce the time by 75 minutes and the volume of water wasted by 133.57 (34.2%). This is due to the automatic irrigation system of work elements and disturbances relatively little, watering evenly and the volume of water used remaining controlled at the same size.

TABLE V
COMPARISON OF TIME AND WATER VOLUME BETWEEN CONVENTIONAL WATERING

No	Conventional Time (minutes)	Conventional Volume (dm3)	Automatic Time (minutes)	Automatic Volume (dm3)
1	**79.2**	**508.57**	4.2	**375**

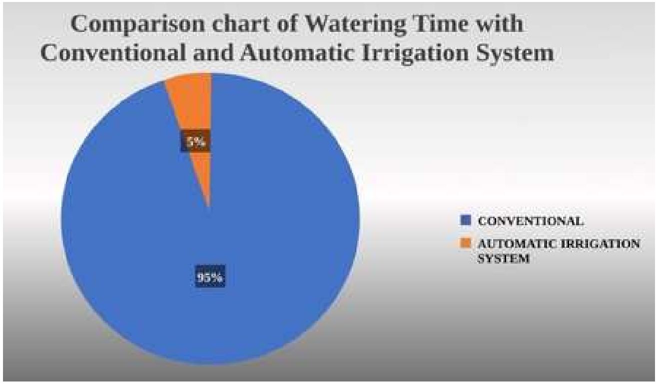

Fig. 4 Comparison Chart of Watering Time with Conventional and Automatic Irrigation System

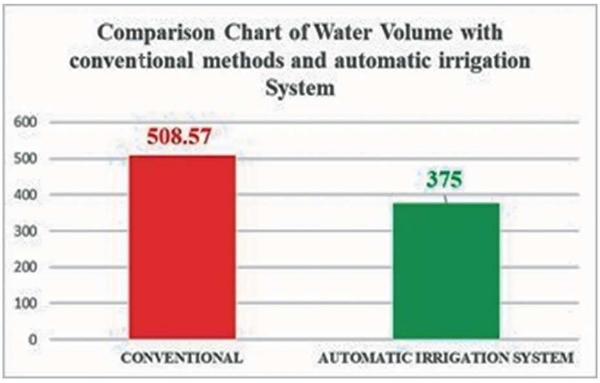

Fig 5 Comparison Chart of Water Volume with Conventional Methods and Automatic Irrigation System

The results of this study are in line with previous research. Automatic irrigation systems can optimize water use and reduce human. The technique can reduce human labor and increase water savings by efficiently watering. To test whether there is a difference in the average time and volume of water required for the irrigation process of post-mining land reclamation by conventional methods and automatic irrigation systems, the Independent Samples T Test is conducted as shown in the table below. The t table value can be seen in the statistical table for a significance level of 0.05: 2 = 0.025 with degrees of freedom (df) obtained t table 2.447. Testing criteria: if - t table <= t count <= t table, then Ho is accepted. if - t count < t table, then Ho is rejected. The t-test results show that the calculated t value is smaller than the t table value (-149.032 < -2.447), so Ho is rejected. This means that to irrigate 2500 square meters there is a long-time difference between conventional methods and automatic irrigation systems. The average watering time with an automatic irrigation system can reduce watering time by 74.93 minutes (approximately 75 minutes) compared to the traditional method. Table 7. Free Sample T Test Results for Water Volume. The value of t table can be seen in the statistical table for a significance level of 0.05: 2 = 0.025 with degrees of freedom (df) obtained t table 2.447.

TABLE VI
INDEPENDENT SAMPLES T TEST RESULTS FOR WATERING TIME

		Paired Differences							
					95% Confidence interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	Df	Sig. (2-tailed)
Pair 1	Conventional-Automatic	74.93	1.33	.50	73.70	76.16	149.03	6	.000

Testing criteria: if - t table <= t count <= t table, then Ho is accepted. if - t count < t table, then Ho is rejected. The t test results show that the calculated t value is smaller than the t table value (-5.566 < -2.447), then Ho is rejected. This means that to water 2500 meters2, there is a difference in the volume of water needed between conventional methods and automatic irrigation systems. The average volume of water needed with an automatic irrigation system can be reduced by 133.57143 liters or (34.2%) compared to the traditional way.

IV. CONCLUSION

The problem of post-mining land reclamation in East Kalimantan presents a significant challenge in restoring degraded land conditions and ensuring adequate water supply to support the growth of new vegetation. The solution is to design and develop an automatic irrigation system specifically designed for post-mining areas. The system has sensors that regulate real-time irrigation and distribute water efficiently according to plant needs. This research aims to create a system that optimizes water use and helps speed up the land reclamation process. This research on improving the automatic irrigation system can reduce water consumption by 34.2%, reduce working time by 75 minutes, and reduce the workload and irrigation process. Further development of the results of this research includes efficiency improvements and broader application to post-mining land reclamation and other lands that require efficient irrigation management.

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REFERENCES

[1] J. Wanyama et al., "A systematic review of fourth industrial revolution technologies in smart irrigation: Constraints, opportunities, and future prospects for sub-Saharan Africa," *Smart Agricultural Technology*, vol. 7, p. 100412, Mar. 2024, doi: 10.1016/j.atech.2024.100412.

[2] R. Hidayat, H. Amnur, A. Alanda, Yuhefizar, and D. Satria, "Capacity Building for Farming System Digitalization Using Farming Management System," *International Journal of Advanced Science Computing and Engineering*, vol. 5, no. 3, pp. 323–327, Dec. 2023, doi: 10.62527/ijasce.5.3.186.

[3] A. H. Abdelfattah, R. F. Sabirov, B. L. Ivanov, M. A. Lushnov, and R. A. Sabirov, "Calibration of soil humidity sensors of automatic irrigation controller," *BIO Web of Conferences*, vol. 17, p. 00249, 2020, doi: 10.1051/bioconf/20201700249.

[4] Y. P. Adhi, I. G. S. Dewi, and B. E. Turisno, "Ecological Impacts and Socio-Legal Infrastructure as an Approach to Environmental Management in Ex-Mining Land Reclamation," *International Journal of Sustainable Development and Planning*, vol. 17, no. 7, pp. 2279–2285, Nov. 2022, doi: 10.18280/ijsdp.170729.

[5] C. A. Bolu, J. Azeta, F. Alele, E. O. Daranijo, P. Onyeubani, and A. A. Abioye, "Solar Powered Microcontroller-based Automated Irrigation System with Moisture Sensors," *Journal of Physics: Conference Series*, vol. 1378, no. 3, p. 032003, Dec. 2019, doi:10.1088/1742-6596/1378/3/032003.

[6] F. P. Carvalho, "Mining industry and sustainable development: time for change," *Food and Energy Security*, vol. 6, no. 2, pp. 61–77, May 2017, doi: 10.1002/fes3.109.

[7] M. Champness, L. Vial, C. Ballester, and J. Hornbuckle, "Evaluating the Performance and Opportunity Cost of a Smart-Sensed Automated Irrigation System for Water-Saving Rice Cultivation in Temperate Australia," *Agriculture*, vol. 13, no. 4, p. 903, Apr. 2023, doi:10.3390/agriculture13040903.

[8] Y. Feng, J. Wang, Z. Bai, and L. Reading, "Effects of surface coal mining and land reclamation on soil properties: A review," *Earth-Science Reviews*, vol. 191, pp. 12–25, Apr. 2019, doi:10.1016/j.earscirev.2019.02.015.

[9] M. Gastauer et al., "Mine land rehabilitation: Modern ecological approaches for more sustainable mining," *Journal of Cleaner Production*, vol. 172, pp. 1409–1422, Jan. 2018, doi:10.1016/j.jclepro.2017.10.223.

[10] A. M. Grigg, H. Lambers, and E. J. Veneklaas, "Changes in water relations for Acacia ancistrocarpa on natural and mine-rehabilitation sites in response to an experimental wetting pulse in the Great Sandy Desert," *Plant and Soil*, vol. 326, no. 1–2, pp. 75–96, Apr. 2009, doi:10.1007/s11104-009-9957-5.

[11] A. Kodir, D. M. Hartono, H. Haeruman, and I. Mansur, "Integrated post mining landscape for sustainable land use: A case study in South Sumatera, Indonesia," *Sustainable Environment Research*, vol. 27, no. 4, pp. 203–213, Jul. 2017, doi: 10.1016/j.serj.2017.03.003.

[12] R. Koech and P. Langat, "Improving Irrigation Water Use Efficiency: A Review of Advances, Challenges and Opportunities in the Australian Context," *Water*, vol. 10, no. 12, p. 1771, Dec. 2018, doi:10.3390/w10121771.

[13] A. Hassan, W. M. Shah, N. Harum, N. Bahaman, and F. Mansourkiaie, "Using an Open Source Microcontroller," vol. 3, no. 1, 2019.

[14] R. Kurniawan, A. M. W. Saputra, A. W. Wijayanto, and W. Caesarendra, "Eco-environment vulnerability assessment using remote sensing approach in East Kalimantan, Indonesia," *Remote Sensing Applications: Society and Environment*, vol. 27, p. 100791, Aug. 2022, doi: 10.1016/j.rsase.2022.100791.

[15] F. Gao, J. Zhou, H. Jiang, W. Yang, and G. Wang, "Assessing the true value of ecological restoration in mining areas : An input-output approach based on ecosystem service valuation," no. August, 2024.

[16] C. Mestanza-Ramón et al., "Gold Mining in the Amazon Region of Ecuador: History and a Review of Its Socio-Environmental Impacts," *Land*, vol. 11, no. 2, p. 221, Feb. 2022, doi: 10.3390/land11020221.

[17] K. Obaideen et al., "An overview of smart irrigation systems using IoT," *Energy Nexus*, vol. 7, p. 100124, Sep. 2022, doi:10.1016/j.nexus.2022.100124.

[18] M. Pramanik et al., "Automation of soil moisture sensor-based basin irrigation system," *Smart Agricultural Technology*, vol. 2, p. 100032, Dec. 2022, doi: 10.1016/j.atech.2021.100032.

[19] P. Pratiwi et al., "Managing and Reforesting Degraded Post-Mining Landscape in Indonesia: A Review," *Land*, vol. 10, no. 6, p. 658, Jun. 2021, doi: 10.3390/land10060658.

[20] V. Saiz-Rubio and F. Rovira-Más, "From Smart Farming towards Agriculture 5.0: A Review on Crop Data Management," *Agronomy*, vol. 10, no. 2, p. 207, Feb. 2020, doi: 10.3390/agronomy10020207.

[21] I. E. Setiawan, Z. Zhang, G. Corder, and K. Matsubae, "Evaluation of Environmental and Economic Benefits of Land Reclamation in the Indonesian Coal Mining Industry," *Resources*, vol. 10, no. 6, p. 60,

Jun. 2021, doi: 10.3390/resources10060060.

[22] I. Srilikhitha, M. M. Saikumar, N. Rajan, M. L. Neha, and M. Ganesan, "Automatic irrigation system using soil moisture sensor and temperature sensor with microcontroller AT89S52," *2017 International Conference on Signal Processing and Communication (ICSPC)*, pp. 186–190, Jul. 2017, doi: 10.1109/cspc.2017.8305835.

[23] Y. Sun, J. Zuo, M. Karakus, and J. Wen, "A Novel Method for Predicting Movement and Damage of Overburden Caused by Shallow Coal Mining," *Rock Mechanics and Rock Engineering*, vol. 53, no. 4, pp. 1545–1563, Oct. 2019, doi: 10.1007/s00603-019-01988-1.

[24] M. Tayebi-Khorami, M. Edraki, G. Corder, and A. Golev, "Re-thinking mining waste through an integrative," *Minerals*, vol. 9(5), no. 2019, p. 286, 2019.

[25] J. Wang, F. Zhao, J. Yang, and X. Li, "Mining Site Reclamation Planning Based on Land Suitability Analysis and Ecosystem Services Evaluation: A Case Study in Liaoning Province, China," *Sustainability*, vol. 9, no. 6, p. 890, May 2017, doi:10.3390/su9060890.

[26] A. S. Worlanyo and L. Jiangfeng, "Evaluating the environmental and economic impact of mining for post-mined land restoration and land-use: A review," *Journal of Environmental Management*, vol. 279, p. 111623, Feb. 2021, doi: 10.1016/j.jenvman.2020.111623.

[27] C. Wu, Y. Bi, W. Zhu, and C. Xue, "Optimizing water use strategies in arid coal mining areas: the synergistic effects of layered soil profiles and arbuscular mycorrhizal fungi on plant growth and water use efficiency," *Environmental and Experimental Botany*, vol. 221, p. 105722, May 2024, doi: 10.1016/j.envexpbot.2024.105722.

[28] A. Mishra, Y. I. Alzoubi, and N. Gavrilovic, "Quality attributes of software architecture in IoT-based agricultural systems," *Smart Agricultural Technology*, vol. 8, p. 100523, Aug. 2024, doi:10.1016/j.atech.2024.100523.

[29] B. Et-taibi et al., "Enhancing water management in smart agriculture: A cloud and IoT-Based smart irrigation system," *Results in Engineering*, vol. 22, p. 102283, Jun. 2024, doi:10.1016/j.rineng.2024.102283.

[30] M. Benzaouia, B. Hajji, A. Mellit, and A. Rabhi, "Fuzzy-IoT smart irrigation system for precision scheduling and monitoring," *Computers and Electronics in Agriculture*, vol. 215, p. 108407, Dec. 2023, doi:10.1016/j.compag.2023.108407.

[31] G. Custódio and R. C. Prati, "Comparing modern and traditional modeling methods for predicting soil moisture in IoT-based irrigation systems," *Smart Agricultural Technology*, vol. 7, p. 100397, Mar. 2024, doi: 10.1016/j.atech.2024.100397.

[32] A. R. Pilevar, H. R. Matinfar, A. Sohrabi, and F. Sarmadian, "Integrated fuzzy, AHP and GIS techniques for land suitability assessment in semi-arid regions for wheat and maize farming," *Ecological Indicators*, vol. 110, p. 105887, Mar. 2020, doi:10.1016/j.ecolind.2019.105887.