2021 年度 試験研究助成 一覧

＜インドネシア＞

No	大学名 University	研究テーマ Project Title	研究者 Researcher
1	インドネシア大学 UNIVERSTIAS INDONESIA	Development of Small-Scale Eddy Current Separator for Handling of Electronic Waste with Minimum Beneficiation Pre-Processes in Indonesia (ｲﾝﾄﾞﾈｼｱにおける粉砕工程を最小化した電子廃棄物用小型渦電流式選別機の開発)	Dr. Eng. Radon Dhelika, B.Eng., M.Eng.
2		Ammonia Synthesis by Plasma Electrolysis Technology (ﾌﾟﾗｽﾞﾏ電解法によるｱﾝﾓﾆｱ合成)	Prof. Dr. Ir. Nelson Saksono, M.T.
1	バンドン工科大学 INSTITUT TEKNOLOGI BANDUNG	Analysis of Polystyrene Biodegradation by Gut Microbiota Tenebrio Molitor Larvae through Metagenomic Approach (腸内細菌ﾃﾈﾌﾞﾘｵﾓﾘﾀｰのﾒﾀｹﾞﾉﾑｱﾌﾟﾛｰﾁによるﾎﾟﾘｽﾁﾚﾝの生分解解析)	Dr. Sony Suhandono, M.Sc.
2		Hybrid ZnO/Porous Industrial Mill Scalederived α-Fe2O3 for Efficient and Sustainable Photoelectrochemical Hydrogen Production (高効率・ｻｽﾃﾅﾌﾞﾙな光電気化学水素製造のためのﾊｲﾌﾞﾘｯﾄﾞ酸化亜鉛/多孔質 α-Fe203 材料)	Dr. Eng Muhammad Iqbal, S.T., M.T.
1	ボゴール農業大学 INSTITUT PERTANIAN BOGOR	Identifying priority conservation landscapes for biodiversity and disaster mitigation in Java through characterizing spatial structure of forest landscapes (森林景観の空間構造を特徴付けることによる、ジャワ島における生物多様性や災害軽減のための優先的な保全景観の特定)	Dr. Yudi Setiawan
2		Estimating the carrying capacity of the pollution load in Citarum River,West Java, Indonesia (ｲﾝﾄﾞﾈｼｱのﾁﾀﾗﾑ川における許容環境負荷の推定)	Prita Ayu Permatasari, SP
3		Development of a web-based data visualization system (Case Study: Data Management of ERC IPB Activities in the field of natural resources and environmental management) (Web ベースのデータ管理システムの開発：天然資源や環境管理分野における IPB の活動のデータ管理システムのｹｰｽｽﾀﾃﾞｨ)	Citra Martia Safitri, S.Hum.

＜マレーシア＞

No	大学名 University	研究テーマ Project Title	研究者 Researcher
1	サラワク大学 UNIVERSITI MALAYSIA SARAWAK	Numerical Simulation of Drying Process within a Novel Rotary Drying Machine for Palm Oil Sludge (ﾊﾟｰﾑ残渣の新規ﾛｰﾀﾘｰ乾燥機における乾燥ﾌﾟﾛｾｽの数値ｼﾐｭﾚｰｼｮﾝ)	Ahmad Adzlan Fadzli Bin Khairi
2		Effects of Absorbed Vibration Energy on the Musculoskeletal Response of the Hand-Arm-Shoulder System of a Power Tool User (吸収振動ｴﾈﾙｷﾞｰが電動工具使用者の手腕肩の筋骨格反応へ与える影響)	Abang Mohamad Aizuddin bin
3		Modelling, Simulation and Analysis of Crude Palm Oil Production System (粗ﾊﾟｰﾑ油製造装置のﾓﾃﾞﾘﾝｸﾞ・ｼﾐｭﾚｰｼｮﾝ・解析)	Magdalene Andrew Munot
4		Design of Slow Speed Permanent Magnet Synchronous Generator for the Application of Hydrokinetic Turbine (水力ﾀｰﾋﾞﾝ用の低速永久磁石式同期発電機の設計)	Ngu Sze Song
5		Copula-based modelling to predict energy consumption of metal removal process based on parameters dependence structures (金属加工機械のｴﾈﾙｷﾞｰ消費を予測するｺﾋﾟｭﾗ関数ﾍﾞｰｽのﾓﾃﾞﾘﾝｸﾞ)	Dr. Shirley Johnathan Tanjong
6		Simulation-Based Power Estimation of Low Power SHA-256 Cryptographic Hash Function Design Techniques (低電力 SHA-256 型暗号化ﾊｯｼｭ関数の設計技術のｼﾐｭﾚｰｼｮﾝによる電力推定)	Ts. Shamsjah binti Suhaili

FINAL REPORT

OSAKA GAS FOUNDATION OF INTERNATIONAL CULTURAL EXCHANGE

Year 2021/2022

Development of small-scale eddy current separator for handling of electronic waste with minimum beneficiation pre-processes in Indonesia

Principal Investigator:

Dr. Eng. Radon Dhelika

Department of Mechanical Engineering

Faculty of Engineering

UNIVERSITAS INDONESIA

DEPOK

2022

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1. Proposal Summary

Electronic waste or e-waste has become a pressing environmental problem at global scale. In Indonesia, the volume of the e-waste generated is growing at an alarming rate of 14.91% annually (Santoso et al., 2019).

To accelerate the implementation of a sustainable e-waste management, the government could promote regulations as well as infrastructure for e-waste processing plant. Especially for the latter, many analysts had predicted that the cost barrier could hinder the implementation in developing countries.

The equipment needed for a complete chain of recycling processes of e-waste is extensive. Generally, the steps required are removal of hazardous parts, beneficiation and separation by eddy current separator (Kaya, 2016; Smith et al., 2019). Beneficiation is the step in which the e-waste is reduced in size and liberated (metal fraction from non-metal fraction) by ways of shredding, crushing, etc. Beneficiation is inseparable since its quality will determine the separation rate by the eddy current separator.

However, being very lengthy in process, beneficiation also happens to be the most cost extensive step. Considering for implementation in the context of Indonesia, in this research we propose a novel approach of e-waste recycling processes by minimizing the beneficiation steps at the cost of a more difficult separation. This approach would potentially reduce the cost factor of the equipment significantly. However, minimum beneficiation of the e-waste would pose a problem: the resulting metal scrap will be randomly sized and shaped. The challenge is on how to adjust the Lorentz force in the eddy current separation to deflect the metal scrap for an improved separation rate.

Therefore, the objective of this research is to develop a small-scale eddy-current separator that can efficiently handle electronic waste with minimum beneficiation. To achieve the objective, force optimization and characterization must be conducted as the basis. This can be achieved by performing experiments for measuring the Lorentz force as well as simulations to validate the obtained data. Subsequently, based on the acquired understanding of optimization factors, the prototype will be developed and its performance, especially the separation rate will be evaluated.

It is anticipated that the results and outputs of this project will contribute by providing insights into a possible low-cost option for handling processes of metal scrap with minimum beneficiation pre-processes.

2. Research Description

The proposed system and the big picture of this research is shown in Figure 1. As depicted in the picture, the proposed system sports a simplified steps in the whole process chain whose main benefit is in cost-cutting.

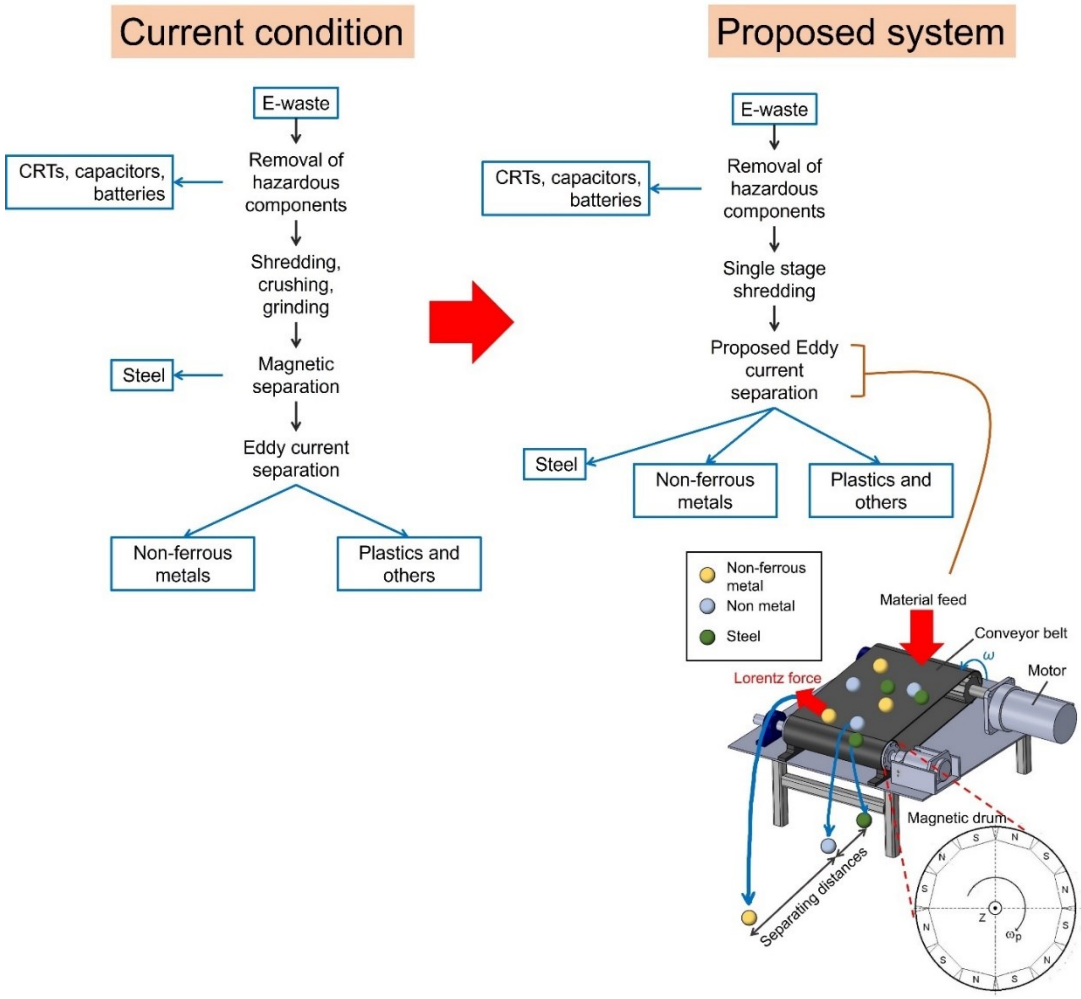

Figure 1 Graphical abstract of the proposed system

3. Methodology

In this proposed research, the activities could be divided into two separate branches that can be executed in parallel as shown in Figure 2.

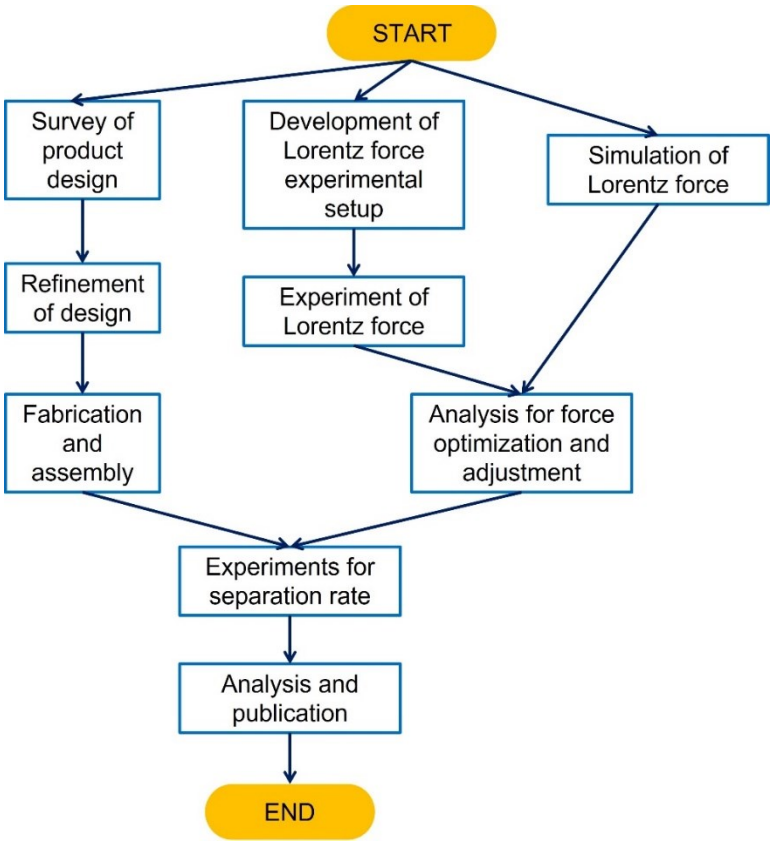

Figure 2 Flow chart of the research method

Force optimization is of the most important aspect to consider because the developed separator must be able to separate three categories of object precisely as specified in the previous section. The Lorentz force is a function of many factors and the most intricate is the conductivity of the materials. Some materials, such as copper and aluminum, have relatively small difference in the conductivity values which could lead to cases of wrong separation (Smith et al., 2019). To complicate matters even further, in the separation of actual e-waste scraps with random shapes, the magnitude of the Lorentz force will also be distorted dramatically. The proposed method for force optimization is shown in the right-hand branch of the flow chart, consisting of experimental and simulation activities.

4. Results and Discussions

4.1 Development of small scall prototype

The design process had been commenced off by listing the design requirements, i.e.

- The material has to withstand heat and corrosion due to environmental conditions, such as humid air
- The material has to withstand load from the magnets
- The prototype has to sport a speed controller which allows for a flexible setting of the linear speed of the conveyor belt which is determined by the application

- The prototype has to be able to separate three different categories of materials, namely ferrous magnetic materials, non-ferrous magnetic materials, and non metals.
- The prototype has to contain a splitter which allows for a flexible setting for the separation.

The developed design is shown in Figure 3.

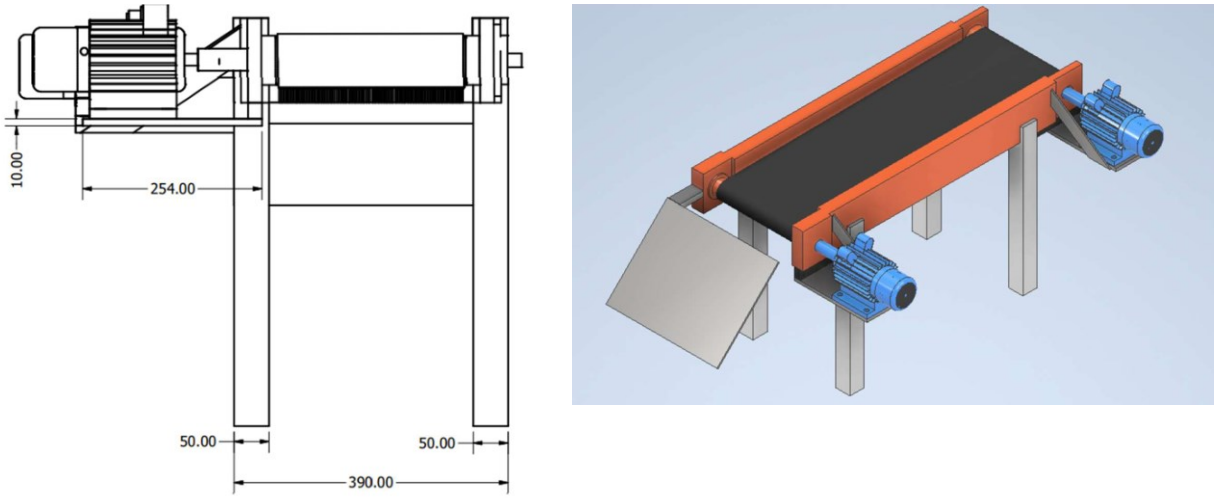

Figure 3 (a) The drawing, and (b) the CAD with an isometric view of the designed prototype

The design was then fabricated and the result is as shown in Figure 4.

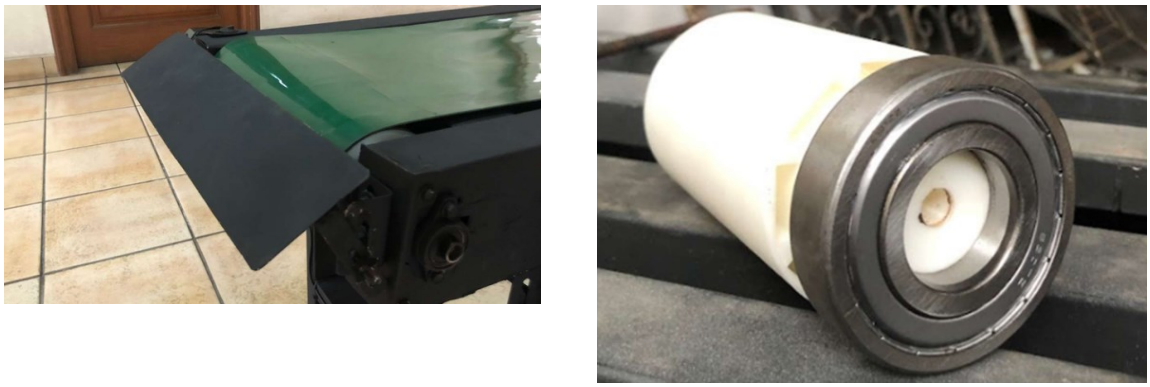

Figure 4 (a) The top view of the prototype, (b) three bins that function to collect three different categories of materials, (c) the splitter that can be adjusted for fine tuning during the process of separation, and (b) the 3D-printed drum which contains eight pieces of permanent magnets

The prototype was then tested with four different samples, i.e. PCB board (non metal), aluminum, copper, and iron. The purpose of the testing was to evaluate whether the prototype is working as intended and to evaluate the separation performance. Aluminum and copper were chosen to represent non-ferrous magnetic materials and they are supposed to deflect with different distances due to the differences in materials properties. The used samples are shown in Figure 5. The samples were all made into a plate-like shape with the same size. The iron samples, however, were prepared from iron sand which were formed by the aid of plastic wrap; therefore the sizing varies.

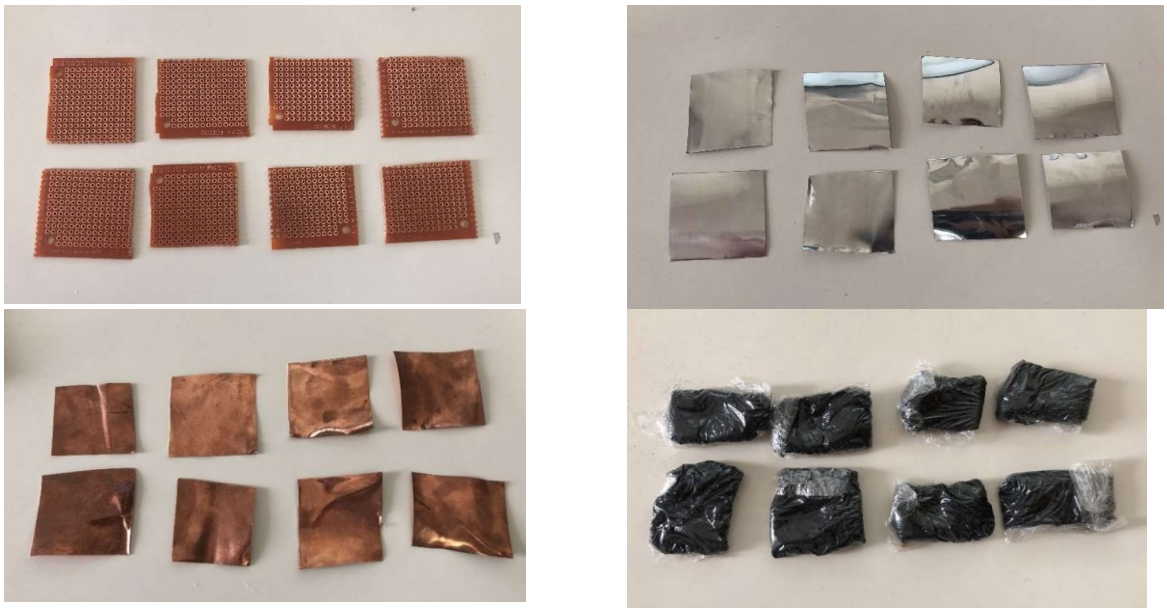

Figure 5 (a) PCB board, (b) aluminum, (c) copper, and (d) iron samples

Subsequently, each sample was placed at the running conveyor belt and where the sample went into was monitored. If the sample went into the correct bin as intended, then it was considered as a successful separation. For each sample, the experiment was

conducted three times and the average was calculated. The result is shown in Table 1.

Table 1 Separation rate for various materials

Samples/materials	Separation rate
Aluminum	100%
Copper	100%
Iron	100%
PCB board	100%

Table 1 shows a good result and the prototype seems to be promising. We then conducted the next evaluation in which multiple samples of various materials were thrown at the beginning of the conveyor belt. The separation rate for this case, however, is not as good as the former experiments. The average separation rate obtained for this case was maximum 75%, due to several cases of wrong separation, i.e. material went into a different bin than originally intended. This was mainly due to the excessive vibration on the belt. The motion of the belt was not smooth enough due to several factors, such as misalignment of the motor's shaft, etc.

4.2 Development of shape-recognition algorithm

It has been widely understood that the separation rate could drop significantly if the feed scrap metals come in various random shapes (Smith et al., 2019), which is commonly the case in the actual e-waste processing sites. The use of vision-based shape classification has been advocated by many researchers to solve the problems concerning the shape factor of the scrap metals. Besides its simplicity for integration which makes it relatively low cost, the machine vision is also robust due to its ability to utilize many powerful methods such as the Artificial Intelligence. However, most researchers (e.g. Chen et al., 2021, Wang et al., 2019) developed the vision system without incorporating it into the eddy current separator; they proposed a separate actuator for the separator using air-based jet or blower.

In this research, a shape recognition algorithm was developed and subsequently tested with samples of controlled geometries as shown in Figure 6. Aluminum and copper were chosen since they are widely available in the market. They were machined to form three common shapes, namely plate-like, strip-like, and ball-like geometries.

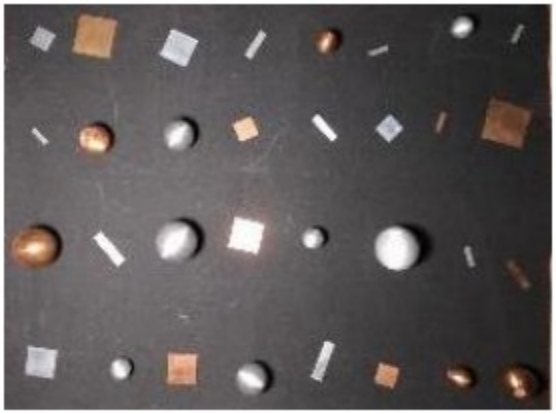

Figure 6 Samples made of aluminum and copper of various shapes

After the algorithm was developed, the testing was conducted in several stages, namely testing with a single object, testing with three objects, and testing of random objects. For the latter, the process is shown in Figure 7. During the testing, three out of four objects were correctly identified. In most cases, the plate-like and strip-like samples were identified most of the time, reaching an accuracy level of 95%. However, ball-like samples were not successfully identified and in many trials, this particular shape turns to be the most difficult to identify. Therefore, a more thorough trial is needed and further adjustment of the parameters is required.

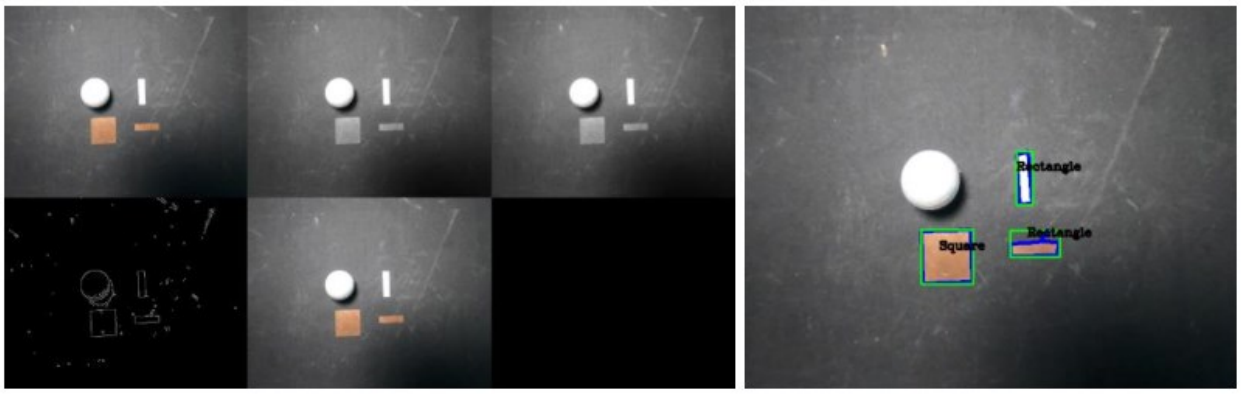

Figure 7 shape recognition algorithm in action

Furthermore, a testing of the deflection distance was also conducted to validate the effect of shapes to the generated Lorentz force, best indicated by the deflection distance. In the results, as shown in Figure 8, aluminum has a further deflection distance than copper and this has been shown for all sizes of plate-like geometry. Though not shown, this phenomenon is also true for other geometry, such as strip-like. Additionally, the ball-like geometry does not show any deflection distance (does not deflect at all). This can be explained, by first referring to Zhang et al. (1998) who states that shapes like a ball has a dominant thickness which hinders the generation of the eddy current which subsequently correlates directly to the Lorentz force. On another note, the mass of the ball samples might be too heavy to be overcome by the force.

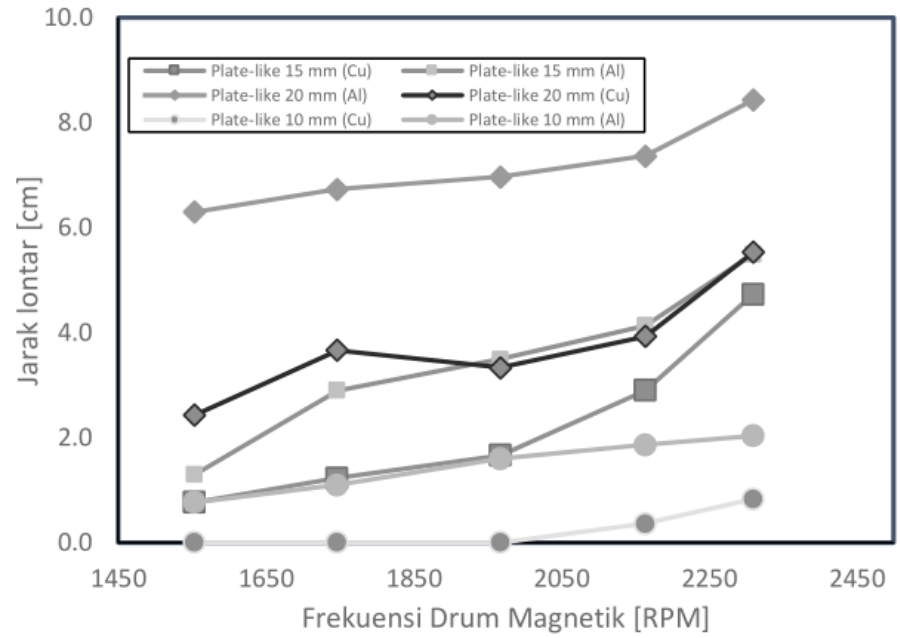

Figure 8 Deflection distances for various shapes

5. Conclusions and Future Developments

In the near future, the plan is to improve the first prototype with an aim of making sure that the machine works more smoothly such that the separation rate would improve. More testing is also necessary to fine tune and further improve the prototype for real application in the field. Additionally, with respect to the shape recognition algorithm, a fine tuning is also necessary to improve the classification rate, especially for random and multiple objects. When the two aspects have been completed, the vision system with the said algorithm would be integrated to the machine such that the separation of shapes would become a pre-processing step prior to the main eddy current separation.

Publication of the work is also under way; we have currently drafting a review paper with the title of “Design factors for eddy current separator for recovery of non-ferrous scrap metals: a mini review”.

References

Chen, S., Hu, Z., Wang, C., Pang, Q., & Hua, L. (2021). Research on the process of small sample non-ferrous metal recognition and separation based on deep learning. Waste Management, 126, 266-273.

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Smith, Y. R., Nagel, J. R., & Rajamani, R. K. (2019). Eddy current separation for

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Wang, C., Hu, Z., Pang, Q., & Hua, L. (2019). Research on the classification algorithm and operation parameters optimization of the system for separating non-ferrous metals from end-of-life vehicles based on machine vision. Waste management, 100, 10-17.
Zhang, S., Forssberg, E., Arvidson, B., & Moss, W. (1998). Aluminum recovery from electronic scrap by High-Force ® eddy-current separators (Vol. 23).

FINANCIAL REPORT

Principal Investigator : Dr. Eng. Radon Dhelika
Research Title : Development of small-scale eddy current separator for handling of electronic waste with minimum beneficiation pre-processes in Indonesia

I. BUDGET

No.	Description	Amount (Rp)
1.	Consumable Expenses	70,000,000
2.	Travel Expenses	4,000,000
3.	Publication Expenses	10,000,000
4.	Other Expenses	450,000
	Amount of Expenses	84,450,000

II. EXPENSES (100%) (including tax)

No.	Description	Amount (Rp)
1.	Consumable Expenses	75,668,246
2.	Travel Expenses	0
3.	Publication Expenses	8,787,130
4.	Other Expenses	0
	Amount of Expenses	84,455,376

1. Consumable expenses			
Description	Quantity	Cost per unit	Cost
Flir + adaptor			6,700,900
tripod monopod beike			899,900
gopro hero 8			4,890,000
Samsung microSDHC			117,500
PLAT ALUMINIUM 0,5 mm SIZE 1 m x 2 m			267,400
plat tembaga ukuran 0.5mm x 200mm x 400mm - tembaga 0,5 potongan			339,800
EDM CUT WIRE Kawat Kuningan			819,000
Grounding Rod As Tembaga 25 mm x 30 cm			435,200

Aluminium Rod Bar Shaft 25mm x 1m			257,300
Charger baterai li-on			264,000
Tas Baterai Rockbros			239,000
Belt Dressing			28,200
Pulley			240,700
Threadlock			56,300
V-Belt			216,200
1 Kaleng dyton black			25,000
1 pylox dan amplas			30,000
Jumper dan balyhold			15,000
Servis dan Baut			35,000
Solder kit dan modul controller			25,000
10 unit baut 5x50			7,000
Plat Alumunium + pemotongan			250,000
Pylox hitam dan pylox surface			43,000
Motor servo 10kg			60,000
Motor Flipsky 3500W			2,322,173
Dinolite, 3D printer, dll			39,826,663
esun 3D filament + creality ender 5 plus			9,004,000
Original Creality Ender 5 Plus Hotend Replacement Kit			456,000
Indocart Nozzle 3D Printer Creality Ender 3 3V2 5 CR6 CR10 D6-0.4mm			45,000
Conveyor PVC Belt | belt konveyor PVC | PVC Rubber belt tebal 1mm OPEN - 400 x 1 x 2500mm			503,000
Dinamo Motor Listrik Mesin Jahit Kecil Merk YKK AIWA 120 Watt			94,100
Dinamo Motor Listrik Mesin Jahit Kecil Merk YKK AIWA 120 Watt			94,100
Dimmer AC 220V 4000W Digital LCD PWM SCR Motor Speed Control Power			199,000
Magnet Neodymium 100x20x6m			2,201,000
As Besi ST41 10mm x 1200mm			50,810
Lembaran Plat Tembaga Murni ukuran 15cm x 15cm tebal 0.2mm			33,000
Seng Plat Alumunium 0.2mm (1m x 2m)			75,000
Plat Nikel Baterai Lithium ION 18650 Pure Nickel Strip Battery Uk. C			18,000
Ball Bearing 6307 ZZ 6307ZZ NTN Japan			50,300
Magnet Neodymium 100x20x6m			276,000
SOJI - Tempat Penyimpanan Makanan Kontainer Box Kulkas Akrilik - Pendek Lebar, Tinggi Kecil, Pendek Kecil			233,700
CA 11 Sikat Bulu Pembersih Sela Kasur Sofa Gagang Panjang - Random			40,700
Pasir Magnet / Pasir Hitam / Pasir Besi / Serbuk Besi 1 KG			18,200

PCB IC Isi 2 Bolong Papan Board Circuit PCB002 18 x 7 cm			17,000
Starco Timbangan Digital Presisi / Timbangan Dapur 10 KG - 10 KG			41,000
Dinamo Elektro Motor 1/4 HP			335,000
Dinamo Elektro Motor 1/4 HP			350,600
Plat Tembaga Lembaran 0.2 mm x 300mm x 300mm			95,000
DP Proses Produksi Alat			750,000
Pelunasan Produksi Alat			1,000,000
Power Supply 12 Volt			35,000
PWM			35,000
Magnet Neodimium 100x10x5mm			845,000
Motor DC 12V			312,500
Ongkos Kirim Motor DC			50,000
	SUB TOTAL (Rp)		**75,668,246**
2. Travel expenses			
Description	Quantity	Cost per unit	Cost
	SUB TOTAL (Rp)		**0**
3. Publication expenses			
Description	Quantity	Cost per unit	Cost
Enago proofreading service			2,472,338
Pembayaran APC Jurnal JAES			6,314,792
	SUB TOTAL (Rp)		**8,787,130**
4. Other expenses			
Description	Quantity	Cost per unit	Cost
	SUB TOTAL (Rp)		**0**
Total expenditures (Rp)			**84,455,376**

FINAL REPORT

OSAKA GAS FOUNDATION OF INTERNATIONAL
CULTURE EXCHANGE
YEAR 2021/2022

AMMONIA SYNTHESIS BY PLASMA ELECTROLYSIS TECHNOLOGY

Principal Investigator:

Nelson Saksono

Chemical Engineering Department
Faculty of Engineering

UNIVERSITY OF INDONESIA

DEPOK, 2022

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1. Research Descriptions

Plasma electrolysis method was found to be a potential alternative to the high temperature and pressure method for the synthesis of many chemicals (Petitpas et al., 2007; Ruan et al., 2014), such as benzene and isooctane (Rahemi et al., 2013). Additionally, the plasma electrolysis assisted nitrogen fixation method has been viewed as an attractive alternative to the Haber-Bosch process (Patil et al., 2015). In the early years of NTP nitrogen fixation, emphasis was placed on the synthesis of nitric oxide compounds instead of ammonia (Patil et al., 2015). NO_x synthesis was favored over ammonia production because it offered a thermodynamically favourable method of nitrogen fixation, requiring lower energy input (Patil et al., 2015; Wang et al., 2017).

The plasma electrolysis process is not so different with electrolysis process, but it is done with high enough voltage until the electric spark is formed producing the plasma on the electrolyzed solution. The plasma will produce reactive species on large amount, so it is able to increase the splitting of the bond on the water and able to increase the formation of hydrogen more times than the conventional electrolysis process (Mizuno et al., 2005). The main problem on the plasma electrolysis technology development is the selection of the electrode, the solution, the additional material, the additive on solution, and the reactor coolant system.

On this research, there will be a design of plasma electrolysis which include plasma generator aspect which able to produce DC voltage up to 1000 V, plasma electrolysis reactor which given a coolant system, temperature, and injector controller. The addition of methanol, and acetic acid as additive on the electrolyte solution on this research is to be predicted to increase the Ammonia production.

2. Research Objectives

The design of production system and operational process condition is an important aspect to develop the ammonia production system through plasma electrolysis process. The objectives of this research are:

1. To obtain an effective of plasma electrolysis process for ammonia production.
2. To obtain the optimum process performance to reach high ammonia production with lower energy consumption
3. To obtain the effect of methanol and Acetic acid addition on ammonia production

3. Methodology

Reactor is a system that is closed from the air outside (anaerobic) made from glass with electrode and cooling system to control temperature. Electrode used are made from tungsten with diameter of 1.2 mm and 20 cm long (cathode) alongside with stainless steel 304 with diameter of 1.6 mm and 25 cm long (anode). There is a glass around the electrode where the plasma occurs to

limit the contact to another electrode surface area when plasma occurs and as the way for air injection.

Plasma generator consists of step-up transformer and diode bridge as voltage rectifier. Current and voltage as well as electricity power throughout the process are measured using a multimeter. Ammonia gas produced will be stabilized into ammonium by adding H_2SO_4 acid, both in reactor and trap cell as shown in Fig. 1. Ammonia product in reactor and trap cell was measured using Spectrophotometer UV-Visible Nessler method while Nitrate was measured using NitraVer® 5 Nitrate Reagent and Spectrophotometer UV-Visible at wavelength 543 nm.

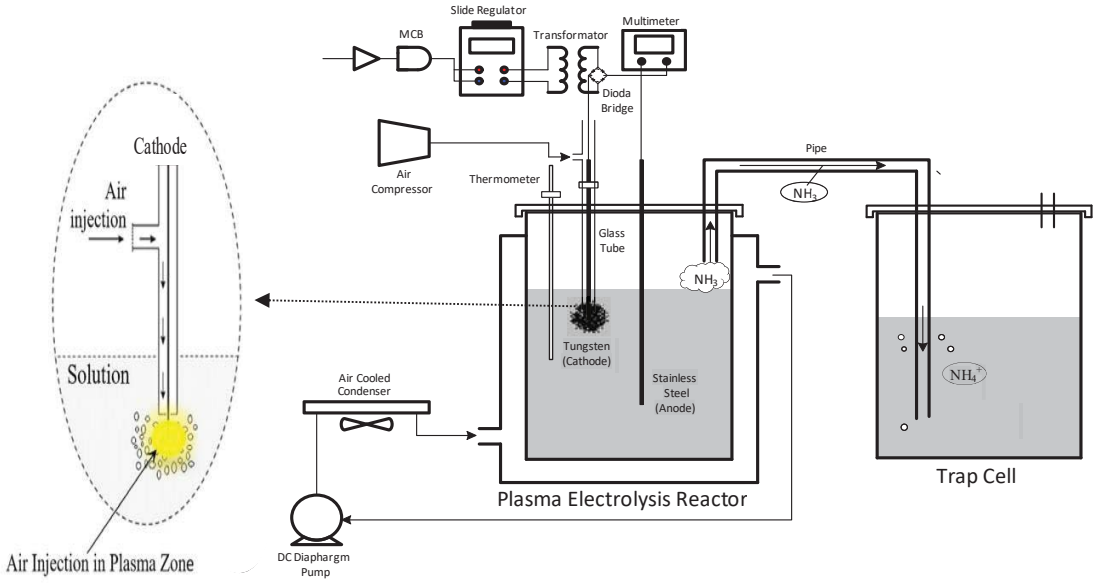

Fig. 1. Plasma electrolysis reactor and trap cell scheme with air injection in plasma zone

4. Result and Discussion

This sub-chapter will give the result of the study that has been done along with the discussion regarding the anodic and cathodic plasma effects to the ammonia produced, effect of injected gas composition to the reactor, and effect of methanol and acetate acid additive usage to the process performance. This experiment is done using 275 W with electrolyte of Na_2SO_4 0.02 M, injection gas flowrate of 0.8 lpm, and solution in the reactor and trap cell with pH of 3. Temperature during the process is maintained on 60^{o}C.

4.1 Anodic and Cathodic Plasma

In the process of electrolysis plasma, plasma can occur in anode (anodic plasma) or cathode (cathodic plasma) which has different characteristic including current, voltage, and the chemistry reaction performance.

The result of current and voltage test shows the optimal voltage and current value for cathodic plasma are 550 V and 0.5 A, while for anodic plasma are 800 V and 0.35 A. Fig. 2 shows

both operating voltage and current have reached the glow discharge zone which produced a lot of reactive species so the reaction can run effectively.

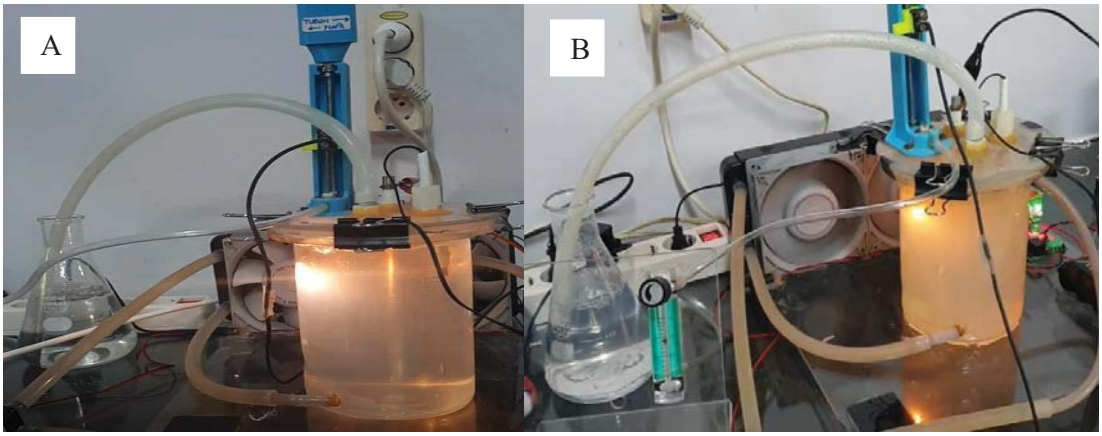

Fig. 2. (A) Cathodic plasma (550 V and 0.5 A) and (B) anodic plasma (800 V and 0.35 A) with Na_2SO_4 0.02 M electrolyte

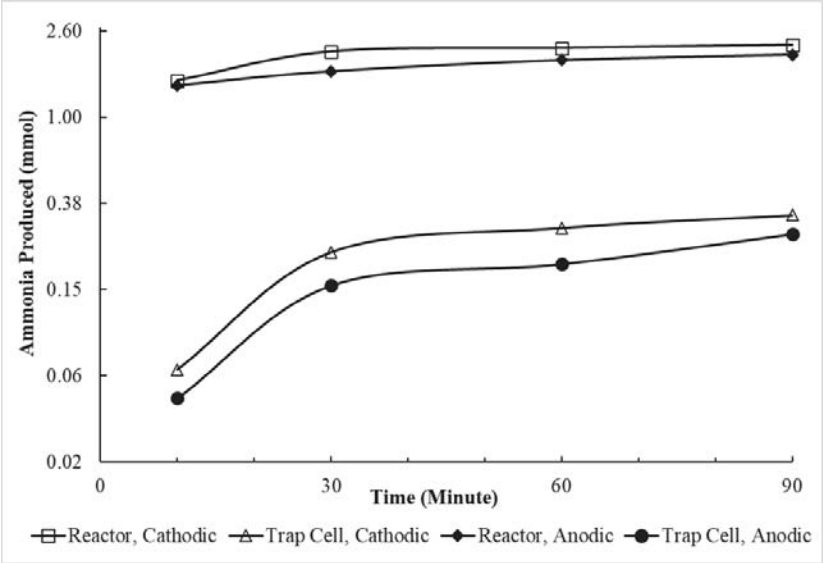

Fig. 3. Ammonia production using cathodic and anodic plasma

Fig. 3 shows ammonia production using cathodic plasma is higher than anodic plasma, both in reactor and trap cell since cathodic plasma produces higher hydrogen radical (•H) than anodic plasma (Thagard et al., 2010). •H is produced from the H_2O abstraction and •N is produced from N_2 activation by plasma. •H and •N are materials for ammonia production. The increased amount of ammonia produced by cathodic plasma reaches 11.9%.

Table 1 shows that specific energy of cathodic plasma is lower than anodic plasma to produce ammonia. As explained by Yan et al. (2009), cathodic plasma uses energy mostly to form plasma around the cathode surface. Meanwhile, anodic plasma uses energy mostly to evaporate the solution on the interphase of electrolyte solution with anodic plasma. Therefore, the energy efficiency of cathodic plasma is higher, and the energy provided for anodic plasma should be

higher to generate a stable plasma and form reactive species as the material for ammonia production.

Table 1. Effect of cathodic and anodic plasma on ammonia produced and specific energy

Type of Plasma	Ammonia Produced (mmol)		Percentage of Produced Ammonia		Specific Energy (kJ/mmol)	Current (A)	Erosion (gram)
	Reactor	Trap	Reactor	Trap cell			
Cathodic	2.23	0,34	87 %	13 %	578.60	0.5	0.2
	Total: 2.57 mmol						
Anodic	2.00	0.27	88 %	12 %	664.15	0.35	0.18
	Total: 2.27 mmol						

Table 1 shows that cathodic plasma has higher electrode erosion than anodic plasma. Even though cathodic plasma operates with lower voltage, it needs higher current to reach the same operation power as anodic plasma. Higher current leads to higher erosion. As mentioned by Chandra et al. (2014), higher current results higher temperature around metal, leading to faster ion movement around plasma and cathode so cathode is eroded faster.

4.2 Effect of Nitrogen and Air Injection

The composition of N_2 gas injected to the plasma zone affects to ammonia production. This study uses pure N_2 (100 %) and N_2 from air (79 %) as the gas injection to the reactor. Fig. 4 shows increasing amount of ammonia produced using pure N_2 injection, but the amount is not very big since producing high NH_3 not only needs N_2 in the form of •N, but also high •H.

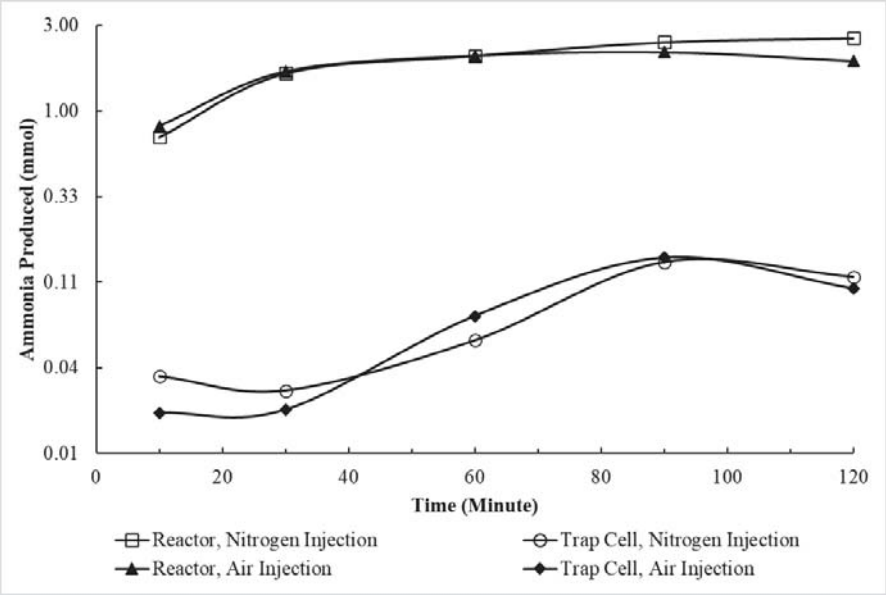

Fig. 4. Effect of gas injection type to ammonia production

Table 2 shows the amount of ammonia produced with nitrogen injection increases for 33% while the specific energy needed decreases 23%. Air injection uses plasma energy to activate O_2 producing •O which reacts with •N producing nitrate, higher than ammonia (Fig. 4). This causes ammonia produced with air injection is lower than N_2 injection.

Table 2. Effect composition of gas injection to ammonia produced and specific energy during 120 minutes process

Type of Gas Injection	Ammonia Produced (mmol)			Percentage of Produced Ammonia (%mol)		Specific Energy (kJ/mmol)
	Reactor	Trap cell	Total	Reactor	Trap cell	
Air	1.90	0,10	2	95	5	987.54
Nitrogen	2.55	0.12	2.67	96	4	741.52

Table 3. Effect composition of gas injection to nitrate produced and specific energy during 120 minutes process

Type of Gas Injection	Nitrate Produced (mmol)			Percentage of Produced Nitrate (%mol)		Specific Energy (kJ/mmol)
	Reactor	Trap cell	Total	Reactor	Trap cell	
Air	7.34	2.29	9.63	76	24	205.67
Nitrogen	6.96	2.05	9.01	77	23	219.77

Table 3 shows the nitrate production in reactor and trap is much higher than ammonia production. This is caused by the free Gibbs Energy of nitrate formation (ΔG^o_f -111.3 kJ/mmol) which is much more spontaneous than ammonia formation (ΔG^o_f -26.6 kJ/mmol) on atmospheric condition. This result shows the potential of air injection in plasma electrolysis for producing nitrate that can be used as fertilizer.

4.3 Effect of Methanol and Acetic Acid Additive Usage

This experiment uses Na_2SO_4 solution with concentration of 0.02 M, voltage and current of 550 V and 0.5 A, and plasma showed in cathode, air flowrate of 0.8 lpm, and reactor and trap with pH of 3. The concentration variation of methanol and acetate acid used are 1%, 2%, and 4% volume. The result of the experiment can be seen in Table 4.

Table 4. Effect of methanol and acetate acid additive usage variation on ammonia and nitrate production for 90 minutes reaction process

Additive	NH_3 (mmol)	NO_3 (mmol)
Non-Additive	0.62	2.81
1 % vol Methanol	2.28	7.96
2 % vol Methanol	2.35	9.32
4 % vol Methanol	2.57	10.94
4 % vol Acetic Acid	2.33	11.51

The increasing amount of methanol and acetate acid as additive increase the •H production in solution significantly. This is proved through the increased amount of hydrogen gas produced

(Yan et al., 2009). Then, •H will be reacted with •N (from the activation of N_2 by plasma) producing ammonia. Table 4 shows the usage of 4%vol of methanol can increase NH_3 production for 314.5%, while the usage of 4%vol of acetate acid increases NH_3 production for 275.8 %.

4.4 Effect flowrate of Air Injection

Variations in the flow rate of air injection were carried out at 0.8 lpm, 1 lpm, and 1.2 lpm with a concentration of 0.02 M Na_2SO_4 electrolyte solution. The initial pH of the solution in the trap cell and reactor was 3, with 1% vol of methanol as additive. The plasma used in this test is cathodic plasma due to its ability to produce more ammonia.

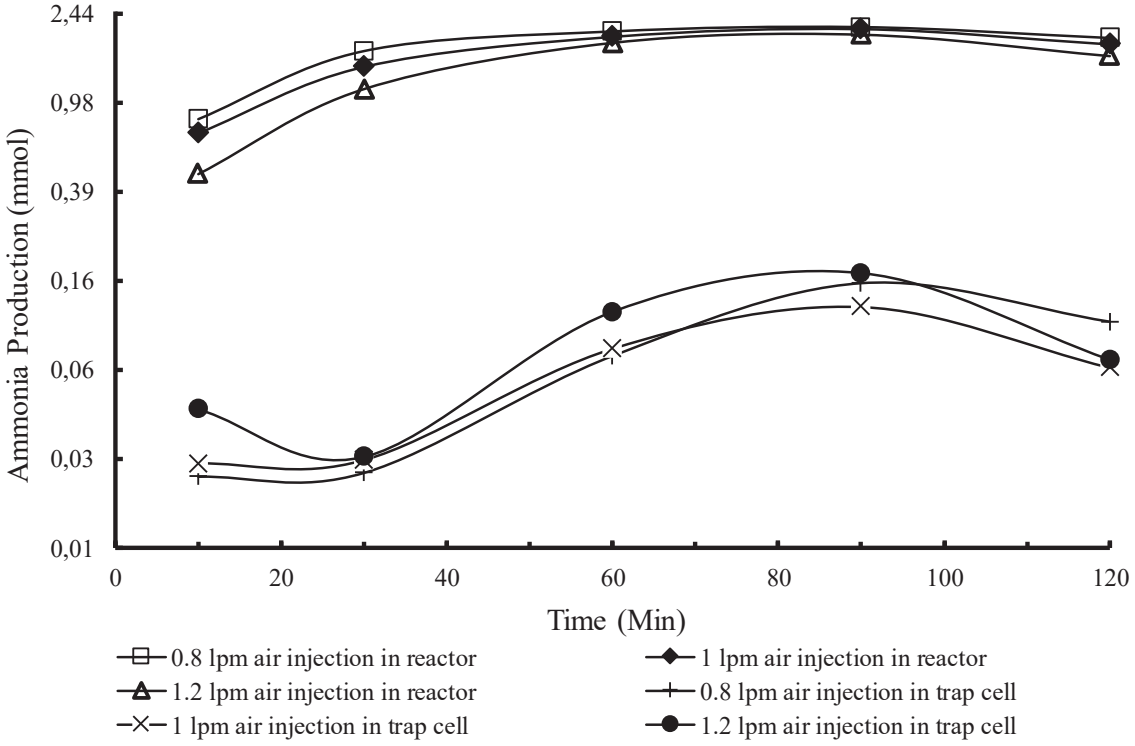

Figure 5. Effect of Air Injection Flowrate on Ammonia Production [Plasma Cathodic; Power 275 W; 0,02 M Na_2SO_4; 1% vol of Methanol]

Figure 5 shown that at a flow rate of 0.8 lpm, air injection produces the highest ammonia both in the reactor and in the trap cell. There was a slight decrease in ammonia after 90 minutes of processing. This is due to the oxidation of ammonia to nitrate by •OH. Nitrate inhibits ammonia synthesis because it takes electrons to reduce nitrate and nitrite, while electrons are also used to reduce H^+ into raw material for ammonia synthesis (Hawtof et al. (2019)).

Table 5 shown that 95% - 97% of ammonia formed in the reactor is directly captured in the electrolyte solution in the reactor with a pH of 3. Ammonia gas formed in the solution is directly converted into ammonium ions which are stable in solution at acidic pH (Clair et al. 2003).

Meanwhile, the Ammonia gas released into the gas phase in the reactor will enter the trap cell and be converted into ammonium ions due to contact with an acid solution.

Table 5. Effect of Air Injection Flowrate on Ammonia Production [Plasma Cathodic; Power 275 W; 0,02 M Na_2SO_4; 1% vol of Methanol, 120 min process]

Air flowrate Injection	Ammonia Produced (mmol)			Percentage of Produced Ammonia (%mol)		Specific Energy (kJ/mmol)
	Reactor	Trap cell	Total	Reactor	Trap cell	
0.8	1.90	0.10	2	95	5	987.54
1	1.78	0.06	1.84	97	3	1.073.94
1.2	1.58	0.07	1.65	96	4	1.201.86

Table 6. Effect of Air Injection Flowrate on Nitrate Production [Plasma Cathodic; Power 275 W; 0,02 M Na_2SO_4; 1% vol of Methanol, 120 min process]

Air flowrate Injection	Nitrate Produced (mmol)			Percentage of Produced Nitrate (%mol)		Specific Energy (kJ/mmol)
	Reactor	Trap cell	Total	Reactor	Trap cell	
0.8	7.34	2.29	9.63	76	24	205.67
1	8.51	3.38	11.90	72	28	166.43
1.2	7.76	2.73	10.49	74	26	188.76

Table 5 dan Table 6 showed that air injection of 0.8 lpm produced the highest total Ammonia of 2 mmol and the lowest total Nitrate of 9.63 mmol, while the highest total Nitrate product was achieved at a flow rate of 1 lpm, which was 11.9 mmol. The percentage of nitrate formed in trap cells is quite significant (24 – 26 %). This shows that a lot of of NO_x compound formed in the reactor were in the gas phase, in which they later got caught in the trap cell. There was a decrease in the production of ammonia and nitrate at a flow rate of 1.2 lpm because a flow rate that was too large resulted in an unstable plasma, causing formation surpression of reactive species such as •OH, •H, •O, and •N, which resulted in a decrease in ammonia and nitrate products. The optimum flow rate of air injection in the formation of Ammonia and nitrate is determined by the electrical power provided, the higher the power supplied, the higher the optimum flow rate of the air injection (Harianingsih et al, 2021).

Table 5 shows the lowest specific energy for formation of Ammonia achieved at a flow rate of 0.8 lpm which is 987.54 kJ/mmol while for the formation of Nitrate it is achieved at 1 lpm with a specific energy of 166.43 kJ/mmol (Table 6).

Table 7. Effect of Air Injection Flowrate on Cathode errosion[Plasma Cathodic; Power 275 W; 0,02 M Na_2SO_4; 1% vol of Methanol, 120 min process]

Air flowrate Injection (lpm)	Cathode Erosion (gram)	pH of electrolyte Solution	Nitrate Productionin Elektrolit (mmol)
0.8	0.21	2.8	7.34
1	0.28	2.7	8.51
1.2	0.48	2.5	7.76

Table 7 shows that the greater the flow rate, the greater the cathode erosion because increasing the air flow rate produces greater plasma which can increase erosion. In addition, the final pH of the electrolyte solution decreases during the process due to the increasing amount of nitrate formed. This causes the solution to become more acidic so that the erodibility of the tungsten cathode is greater (Li et al 2017).

4.5 Effect of Electrolyte Solution Concentration

In this experiment, Na_2SO_4 solutions with concentrations of 0.02 M and 0.04 M were used to observe the effect of electrolyte concentration on the production of ammonia and nitrate, conductivity, and erosion of the tungsteen cathode that occurred.

Table 7. Effect of electrolyte concentration on Ammonia Production and Cathode Erosion [Plasma Cathodic; Power 275 W; pH of Solution 3 ; 4% vol of Methanol]

Duration of Process	0.02 M Na_2SO_4		0.04 M Na_2SO_4	
	NH_3 in Reactor (mmol)	NH_3 in Trap cell (mmol)	NH_3 in Reactor (mmol)	NH_3 in Trap cell (mmol)
10 min	1.503	0.061	1.563	0.052
30 min	2.069	0.224	2.168	0.091
60 min	2.155	0.293	2.215	0.116
90 min	2.341	0.363	2.228	0.338
Trap/Reactor Ratio	0.155		0.148	
Ammonia Total	2.70 mmol		2.54 mmol	
Current/Voltage	0.50 A / 550 V		0.61 A / 450 V	
Spesific Energy	550 kJ/mmol		584.64 kJ/mmol	
Cathode Erosion	0.22 gr		0.36 gr	
Conductivity	1.18 mS/cm		2.01 mS/cm	

Table 7 shows that at 275 W, the voltage current at 0.02 M Na_2SO_4 is 0.5 A and 550 V, while for 0.04 M Na_2SO_4 it is 0.61 A and 450 V. Higher voltage at 0.02 M Na_2SO_4 causes higher Ammonia products about 6,3% compared to 0.04 MNa_2SO_4. Increasing the voltage has an effect on increasing the density of high-energy electrons so that it will produce more reactive species such as •H, and •N , resulting in more production of ammonia and hydrogen gas (Yan et al, 2009). The greater the electrolyte concentration, the greater the conductivity of the electrolyte solution which results in an increase in electric current. The conductivity at 0.02 M Na_2SO_4 is 1.18 mS/cm

and increases to 2.01 mS/cm at 0.02 M Na_2SO_4. This causes the current to increase from 0.50 A to 0.61 A (Table 7). The increased electric current is the cause of increased cathode erosion up to 36 %

Table 8. Effect of electrolyte concentration on Nitrate Production [Plasma Cathodic; Power 275 ; pH of Solution 3 ; 4% vol of Methanol]

Duration of Process	0.02 M Na_2SO_4		0.04 M Na_2SO_4	
	NO_3 in Reactor (mmol)	NO_3 in Trap cell (mmol)	NO_3 in Reactor (mmol)	NO_3 in Trap cell (mmol)
10 min	2.661	0.855	2.463	0.692
30 min	3.640	1.719	3.547	0.816
60 min	5.449	2.675	4.014	1.220
90 min	7.615	3.321	4.817	1.882
Current/Voltage	0.5 A / 550 V		0.61 A / 450 V	
Trap/Reactor Ratio	0.436		0.391	
Total NO_3	10.94 mmol		6.70 mmol	
Spesific Energy	135.74 kJ/mmol		221.64 kJ/mmol	

Table 8 shows a decrease in nitrate product as the concentration of Na_2SO_4 in the solution increases. The high concentration of Na_2SO_4 causes the voltage to decrease from 550 V at 0.02 M Na_2SO_4 to 450 V at 0.04 M Na_2SO_4. Liu et al (2012) found that the higher the voltage, the more reactive species •O. The •O species and •N species are very quick to form NO_x in solution that will be oxidized further by •OH to nitrate (Wang et al., 2017).

5 Conclusions

This study has succeeded to produce ammonia using plasma electrolysis reactor with nitrogen and air injection in the plasma zone and Na_2SO_4 solution. Cathodic plasma is proven to increase the ammonia production for 11.8%. Nitrogen gas injection could increase ammonia production 33% higher than air injection. Nitrogen gas and air injection in plasma electrolysis not only produce ammonia, but also proven to produce nitrate much higher than ammonia. Methanol and acetate acid usage as additive are also proven to increase ammonia production significantly.

The air injection flow rate of 0.8 lpm resulted in the highest ammonium of 2 mmol and the lowest nitrate of 9.63 mmol, while the highest nitrate product of 11.9 mmol was achieved at a flow rate of 1 lpm. The higher the flow rate of air injection, the greater the erodibility of the cathode material in which the erosion reached 0.48 gr at a flow rate of 1.2 lpm.

The increase in Na_2SO_4 concentration leads to an electrical voltage increase, which causes the products of Ammonia and Nitrate to go up. The high concentration of electrolyte Na_2SO_4 causes the conductivity and current to increase, causing cathode erosion to also increase up to 36%.

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FINANCIAL REPORT

Principal Investigator : Nelson Saksono
Research Title : Ammonia Synthesis by Plasma Electrolysis Technology

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I. BUDGET

No.	Description	Amount (Rp)
1.	Consumable Expenses	81.100.000
2.	Travel Expenses	1.000.000
3.	Publication Expenses	2.000.000
4.	Other Expenses	2.500.000
	Amount of Expenses	86.600.000

II. EXPENSES (100%) (including tax)

No.	Description	Amount (Rp)
1.	Consumable Expenses	74.600.000
2.	Travel Expenses	1.000.000
3.	Publication Expenses	1.587.100
4.	Other Expenses	7.260.000
	Amount of Expenses	84.447.100

1. Consumable Expenses

Description	Quantity	Cost per Unit (Rp)	Cost (Rp)
Na_2SO_4	6 Kg	1.500.000	9.000.000
Méthanol	30 L	120.000	3.600.000
H_2SO_4	2 L	2.500.000	5.000.000
Acetic Acid	30 L	300.000	9.000.000
Demin Water	100 LKg	20.000	2.000.000
Destilate water	300 L	10.000	3.000.000
Electrolysis reactor	3 unit	6.000.000	18.000.000
Cooling system of reactor	2 unit	2.500.000	5.000.000
Peristaltic pump	2 unit	2.000.000	4.000.000
Condenser	2 unit	1.000.000	2.000.000
Thermometer	5 pc	200.000	1.000.000
TRAFO 3KVA	2 unit	1.500.000	3.000.000
Tungsteen anode	4 pack	1.000.000	4.000.000
Cathode (stainless)	10 pc	1.000.000	4.000.000

Flow meter	2	400.000	2.000.000
		SUB TOTAL (Rp)	74.600.000
2. Travel Expenses			
Description	Quantity	Cost per Unit (Rp)	Cost (Rp)
Transport to supplier	4	250.000	1.000.000
		SUB TOTAL (Rp)	1.000.000
3. Publication Expenses			
Description	Quantity	Cost per Unit (Rp)	Cost (Rp)
Registration Fee	1	500.000	500.000
Profreading paper	1	1.087000	1.087.100
		SUB TOTAL (Rp)	1.587.100
4. Other Expenses			
Description	Quantity	Cost per Unit (Rp)	Cost (Rp)
Analysis of Ammonia	100	40.000	4.000.000
Analysis of Nitrate	80	40.000	3.200.000
Analysis of Conductivity	6	10.000	60.000
		SUB TOTAL (Rp)	7.260.000
Total Expenditures (Rp)			**84.447.100**

Research Report

Osaka Gas Foundation of International Cultural Exchange

(OGFICE)

ANALYSIS OF POLYSTYRENE BIODEGRADATION BY GUT MICROBIOTA *Tenebrio molitor* LARVAE THROUGH METAGENOMIC APPROACH

Principal Investigator:
Sony Suhandono, Ph.D

Academic Unit

Research Division	:	Genetics and Molecular Biotechnology
Faculty/School	:	School of Life Science and Technology

INSTITUT TEKNOLOGI BANDUNG

November 2022

I. IDENTITY PAGE

1	Title	:	Analysis of Polystyrene Biodegradation by Gut Microbiota *Tenebrio molitor* Larvae Through Metagenomic Approach
2	Relevance of Topic	:	Global environmental problems
3	Research Period	:	November 2021 – November 2022
4.1	Principal Investigator		
	a. Full Name	:	Sony Suhandono
	b. Academic Rank	:	Associate Professor
	c. NIP	:	19610930 198903 1002
	d. Current Position	:	Academic staff and member research group of Genetics and Molecular Biotechnology (KK GBM)
	e. Academic Unit	:	School of Life Science and Technology ITB
	f. Office Address Phone/Fax/email	:	Jalan Ganesa 10, Phone 62 22 2511575, Fax 62 22 253 4107
	g. Home Address Phone/email	:	Komp. Sariwangi Indah V no. 4A Bandung 082115119917 / sony@sith.itb.ac.id

4.2 Members of the Team:

No	Name and Academic Rank	Field of Expertise	Institution	Allocation of Time	
				Hrs/week	Months
1	N/A				

4.3 Research Assistants/Students (mention names when available):

No	Name	Departement and NIM	Alocation of Time	
			Hrs/week	Months
1.	Tati Kristianti	SITH	30	120
2.	Afandi	SITH / 30619006	30	120

5. Approved budget : Rp. 85.000.000,-

Approved by,
Head of Academic Unit

Dr. Endah Sulistyawati
NIP. 196911191995122001

Bandung, 30 November 2021
Principal Investigator

Sony Suhandono, Ph.D
NIP 196109301989031002

I. EXECUTIVE SUMMARY

1	**TITLE OF RESEARCH**	:	Analysis of Polystyrene Biodegradation by Gut Microbiota *Tenebrio molitor* Larvae Through Metagenomic Approach
2	**HEAD OF RESEARCH TEAM**	:	Sony Suhandono, Ph.D
3	**TEAM MEMBERS**	:	1. Tati Kristianti
			2. Afandi
4	**OFFICIAL ADDRESS**	:	Jl. Ganesha No. 10 Bandung
5	**EXTENDED ABSTRACT**	:	

Polystyrene (PS) is a type of petroleum-derived plastic that has been used for various commercial, packaging, and building purposes, and has grown to become one of the most common household items in the world. Polystyrene is very stable and very difficult to degrade in the environment after disposal. As a result, polystyrene waste has accumulated in the environment, causing environmental pollution, human health problems, and disturbances to the ecosystem. Although several studies have reported that PS can be biodegradable by mixed or isolate microbial cultures from various sources such as soil, garbage, and sewage sludge, the reported biodegradation efficiency of PS is low. Many studies have reported that *Tenebrio molitor* larvae can chew and eat a PS foam (Styrofoam) as a single meal, and Styrofoam efficiently degraded in the gut of the larvae in the retention time of less than 24 hours. The ability of *T. molitor* larvae to digest polystyrene is related to the activity of microbiota gut, which help the larvae in the digestive process. The gut microbiota community of *T. molitor* larvae has open new way to find a more efficient mechanism of PS degradation by microorganisms. However biodegradation mechanism of PS by bacteria from gut microbiota of *T. molitor* has not well-known. The use of shotgun metagenomic sequencing makes it possible to explore microbial taxonomy and microbial genes from environmental samples without microbial isolation and culture. This technique is increasingly being applied to explore a wide variety of pollutant microbial degradation pathways, which are completely uncharacterized. The hypothesis of this study is that there is a consortium of bacteria capable of degrading PS in the intestinal microbiota of *T. molitor* larvae. The objectives of this study were (1) to determine the structure of the microbiota community associated with plastic degradation from the gut of *T. molitor* larvae, (2) to determine the enzyme genes involved in the decomposition of PS from the big data of the NGS shotgun metagenome. (3) predicting the metabolic pathway for the breakdown of PS by the intestinal microbiota of *T. molitor* larvae. In this study *T. molitor* larvae were obtained from a local animal feed store. Fifty 11th instar larvae were put in a polypropylene food box with a volume of 1.5 L and then fasted for 48 hours. After being fasted, the larvae of the treatment group were fed Styrofoam, while the larvae of the control group were fed rice bran. Every 4 days the average weight of the larvae was calculated, the body weight change and the death of the larvae, and the excrement of the larvae were collected. After 28 days the intestines of *T. molitor* larvae were dissected and metagenomic DNA was isolated using the Qiagen DNeasy PowerSoil Kit. The metagenomic DNA was then sent to Novogen Singapore for Shotgun Metagenomics analysis using the Ilumina Novaseq 6000. Frass was analyzed by Fourier-transform infrared spectroscopy (FTIR) and Gas chromatography–mass spectrometry (GC-MS)

methods. The results of the study revealed that within 28 days, the consumption rate of Styrofoam by *T. molitor* larvae was 984.6 ± 21.2 mg 50 larva-1 day-1. Total intestinal bacteria fed Styrofoam are 4.12 x 10^5 cfu/ml lower than larvae fed rice bran which amounted to 1.1 x 10^6 cfu/ml. The results of metagenomic shotgun analysis revealed that there were four dominating bacterial phyla, Actinobacteria, Bacterioidetes, Firmicutes, Proteobacteria. The abundance of bacteria from the phylum Tenericutes was higher in the larvae group fed with rice bran compared to the Styrofoam group. Bacilli, Clostridia, Erysipelotrichia, Tissierellia, Negativicutes, and Actinomycetia as the dominant bacteria at the class level in the Styrofoam and bran larvae groups. The FTIR spectrum of larvae excrement shows the formation of new functional groups compared to the spectrum of intact Styrofoam. The results of the GC-MS analysis of the manure of the larvae fed Styrofoam can identify 16 compounds contained in the frass of the larvae..

6 **LIST OF RESEARCH OUTPUT** : - Metagenomic data
- Biodegradation pathway prediction

II. TECHNICAL REPORT

1. INTRODUCTION

PS is a petroleum-based aromatic polymer plastic made from styrene (vinyl benzene) monomer. Since PS was first commercially produced in 1931, it has been used for a variety of commercial, packaging, and building purposes, and has grown to become one of the most common household goods in the world. PS used for packaged food includes 'general purpose PS' (GPPS) such as disposable cutlery and plates; 'high - impact PS' (HIPS) such as disposable yogurt containers and cold drink cups; and expanded PS (EPS) foam used as meat trays, coolers, and cups. PS is very popular because of its light weight and insulating properties. The use of polystyrene as a packaging material has led to an increasing amount of polystyrene waste into the environment. In 2012, approximately 32.7 million tons of PS were produced globally. This figure is concerning, given the lack of PS waste management. Currently there is no household scale PS collection service. The increase in PS waste is also a cause for concern due to the hazardous nature of PS products (Farrelly and Shaw 2017; Kik, Bukowska and Sicińska 2020) . Most of the materials used to make plastics, such as polystyrene and propylene, are produced from fossil hydrocarbons. None of the plastics derived from fossil hydrocarbons are biodegradable. The natural decomposition of plastic polymers involving environmental factors such as light, heat, humidity, chemical conditions takes up to 600 years. As a result, plastic waste will accumulate, rather than decompose, in landfills or the natural environment. It is estimated that 32% of plastic waste has polluted the environment and disrupted the ecosystem.

Poor management of plastic waste will cause several critical human-made environmental problems (Lestari and Trihadiningrum 2019; Hidayat, Kiranamahsa, and Zamal 2019; Geyer, Jambeck, and Law 2017; Jambeck et al. 2015) .

One method of decomposing solid plastic waste more quickly is the use of insect activity. Some insect larvae are known to be able to chew and eat Styrofoam as a single food, such as *Zophobas atratus* and *Tenebrio molitor* , as well as *Plodia interpunctella larvae* which are able to chew and digest polyethylene plastic films (Y. Yang, Wang, and Xia 2020) . *T. molitor* larvae are highly suitable for plastic degradation due to their voracious appetite for solid waste, and resistance to adverse environmental conditions and rapid weight gain. *T. molitor* larvae are omnivores capable of digesting foods that are not found in their natural environment, such as polyethylene, polystyrene and cellulose waste (Przemieniecki et al. 2020) .

Styrofoam can be efficiently degraded in intestinal larvae of *T. molitor* in a retention time of less than 24 hours. Larvae can survive for one month on one Styrofoam meal. *T. molitor* fed rice bran and Styrofoam was able to complete all stages of the life cycle (larvae, pupae, beetles, eggs) (SS Yang et al. 2018) . The ability of *T. molitor* larvae to digest plastic is related to the digestive activity of intestinal microorganisms, which help the larvae in the digestive process. Symbiotic microorganisms have been found widely in the intestines, body cavities, or cells of various insects. Microorganisms in the gut of insects can benefit their hosts by helping to digest food, detoxify harmful molecules and provide essential nutrients (Urbanek, Mirończuk, et al. 2020; Kwong and Moran 2016) .

Intestinal microorganisms enter the intestine through food, some are commensal or parasitic microorganisms, some of which may benefit their host. Various polysaccharide-degrading bacteria were identified from the gut of herbivorous insects, which produce enzymes that degrade indigestible plant components (eg cellulose, xylan). Based on this, it can be assumed that enzymes from intestinal microorganisms play an important role in the degradation of plastic compounds by *T. molitor* larvae (Urbanek, Rybak, et al. 2020; Krishnan et al. 2014) .

Recent years have seen an increasing number of plastic-degrading microorganisms isolated and identified from the gut of *T. molitor* larvae, but the enzymes responsible or associated degradation pathways are rarely identified for polystyrene plastic (Hou and Majumder 2021) .

Metagenomics, the direct analysis of DNA from environmental samples, is a powerful tool to access the genetic and metabolic diversity encoded in environmental microbes without cultivation bias. This technique is increasingly being applied to explore various degradation pathways of microbial pollutants, which are largely or completely uncharacterized (George, Bouhajja, and Agathos 2011) .

1.1 Research Objectives

This research will conduct "shotgun metagenomics sequencing" on the intestinal microbiota of larvae that have been fed Styrofoam, as well as bioinformatics analysis of metagenomic data to identify polystyrene decomposing enzymes. The research objective is. (1) Evaluating the diversity and structure of the intestinal microbial community of *T. molitor larvae* fed plastic feed. (2) Evaluating the diversity of microbial enzymes associated with the degradation of gut microbial plastics of *T. molitor larvae.* (3). Predicting the metabolic pathways of plastic decomposition by gut microbiome enzymes.

2. METHODOLOGY

2. 1. Larvae *T. molitor* and treatment of larvae

T. molitor larvae used came from a local feed store in Bandung. The larvae are fed rice bran as the main feed and reared until they become imago. Larvae and imago were identified as *Tenebrio molitor Linnaeus* 1758 based on their morphology and color (Calmont and Soldati 2008) . The identified *T. molitor* was grown in polypropylene plastic boxes with a volume of 1.5 liters filled with rice bran to produce 11th instar larvae.

The experiment was carried out in 2 groups with 3 replicates, each treatment using 50 specimens of 11th instar larvae (same length in the range of 12-13 mm). Maintenance was carried out in propylene plastic boxes with a volume of 1.5 liters and stored in a room with a dark period of 24 hours with a temperature of 24.13 ± 0.01 °C and a humidity of 57.48 ± 0.09 %. Each treatment is as follows:

- PS: larvae are fed Styrofoam.

- C: (control) larvae were fed with rice bran ad libitum.

Giving Styrofoam to experimental animals was carried out for 28 days. The weight of *T. molitor larvae* and Styrofoam were weighed every 4 days from day 1 to day 28 of the experiment. Each observation of larval excrement was collected, and the frass samples were stored in a refrigerator at -20°C. Before and after treatment, the intestines of the larvae were dissected from each group to measure the total number of bacteria.

2. 2 . Metagenome DNA isolation and metagenome sequencing

The intestines were dissected from 10 individuals in each group and metagenome DNA was isolated. Metagenome DNA isolation was carried out using a metagenomic DNA isolation kit from Qiagen, namely the DNeasy PowerSoil kit, the isolation procedure followed the work instructions from the isolation kit manufacturer. Species diversity and gut microbiota plastic degrading enzymes were obtained from “shotgun metagenome sequencing” using Novogen Singapore service, the available NGS platform for shotgun metagenomes is Illumina Novaseq 6000.

2. 3. Depolymerization of PS foam

The functional groups of PS polymer residues extracted from larvae excrement were characterized by Fourier transform infrared spectroscopy (FTIR) (Thermo Scientific Nicolet iS FTIR Spectrometer, Pittsburgh, PA, USA), at a wavelength between 4000 to 500 cm^{-1}. The spectra of larvae excrement were then compared with the spectra of intact Styrofoam.
Chromatographic analysis was performed with an Agilent Technologies 7890B GC instrument (Waldbronn, Germany) equipped with a mass detector (Agilent Technologies 5977A). The injection volume was 1 L. The process temperature used was initial temperature 40°C for 1 minute, then heated to 300°C.

2.4 Species Diversity Analysis Data

Fastqc is used to process "raw data" from the "Illumina sequencing" platform to obtain "clean data" that will be used for further analysis. “Clean data” was then analyzed using Kraken2 to obtain bacterial species data. The processing results obtained are tsv files which are then visualized using the online Pavian metagenomic data explorer on the site https://fbreitwieser.shinyapps.io/pavian/_w_da717fd0/# .

3. Results and discussion

3.1 Styrofoam eating activity

Identification of the morphology of the base of the elytra, the shape of the pronotum, the morphology of the underside of the head and the stigma on the lateral parts of the larva according to the guidelines provided by Calmont and Soldati (2008) , the morphological identification results of *T. molitor* can be seen in Figure S1. Observations on the life cycle of *T. molitor* showed that larvae fed rice bran reached the 15th instar before entering the pupal stage (Table S1). All larval stages have a brown color except for the 1st instar which is white

(Figure S2). The change from the larval instar to the next instar is marked by the change of the larva's skin (Park et al. 2014) . The selection of 11th instar larvae as research material was based on a preliminary test where at this stage isolation of the larvae's gut (midgut, hind gut and foregut) was easier to do without the need for the help of a binocular microscope and during treatment with 11th instar larvae no changes were found in the shape of the larvae into pupae.

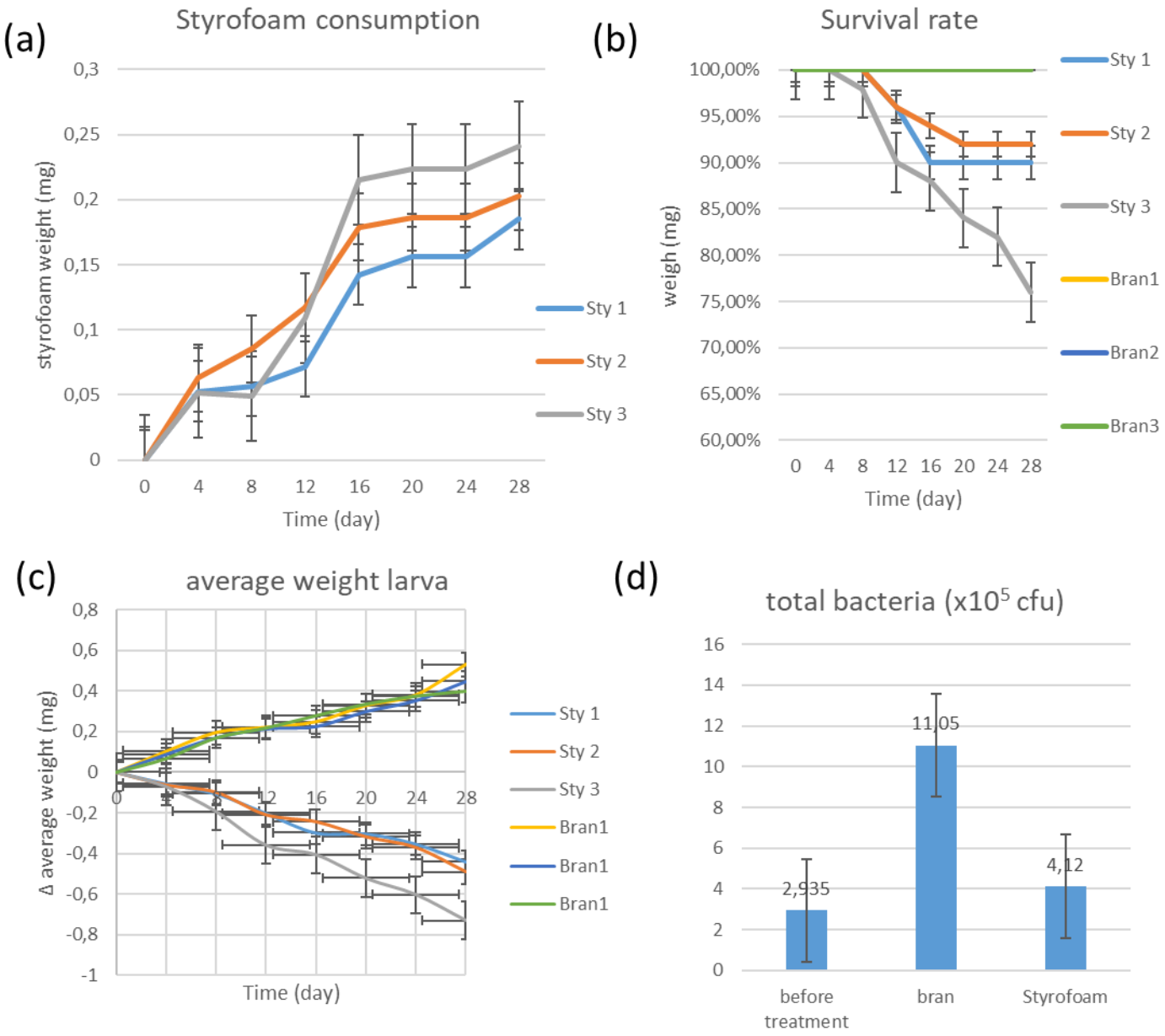

Figure 1. (a) Consumption of Styrofoam by larvae in 28 days. (b) Survival rate of *T. molitor larvae* fed Styrofoam and rice bran during treatment. (c) The delta average weight of each larva by feeding Styrofoam and rice bran. (d) The number of larval gut bacteria before and after feeding rice bran and Styrofoam.

T. molitor larvae were able to consume Styrofoam in increasing amounts with increasing observation time (Figure 1a). The average consumption of Styrofoam during the experiment was 0.66 ± 0.01 gr larvae $^{-1}$ day $^{-1}$. The larval mandibles in the mouthparts allow this species to chew plastic so that the larvae can swallow the plastic. According to Y. Yang et al. (2015) The physicochemical "treatment" of plastic (by chewing, swallowing, mixing with gut contents, etc.) together with the activity of enzymes secreted by the larvae is also important for the successful rapid degradation of PS.

Even though Styrofoam consumption increased, Styrofoam feeding also increased larval mortality, this was indicated by a decrease in the "survival rate" after day 8 (Figure 1b) and the survival rate value showed a decreasing trend until the end of the observation. This is different from the rice bran feed group, the survival rate is consistent at 100% from the beginning to the end of the observation. The increase in Styrofoam consumption was not followed by an increase in larval weight (Figure 1c). In contrast to the rice bran group which showed an average weight gain of larvae starting from day 1 to day 28. The weight gain of the larvae in the rice bran group was supported by proximate data (Table 1) which showed that rice bran contained nutrients in the form of carbohydrates, proteins, and fat. According to Lu et al. (2021) the presence of a nitrogen source and an appropriate C/N ratio in feed can facilitate the formation of larval protein, larval development and the bioconversion process.

The type of feed also affects the number of intestinal bacteria that can be cultured, based on the results of the total plate count (TPC) of intestinal bacteria (Figure 1d) showing that after treatment the bacteria of the two treatment groups experienced an increase from the initial number of bacteria, which was 2.9×10^5 CFU per gut, but for the Styrofoam feed group the number of bacteria was less, namely 4.1×10^5 CFU per gut compared to the number of bacteria in the rice bran group which reached 1.1×10^6 CFU per gut.

Table 1. Rice Bran Proximate Test Results

Parameter	Unit	Result
Water	%	5,03
Ash	%	17,11
Proteins (N x 6.25)	%	5,31
Fat	%	3,36
Carbohydrate	%	69,19

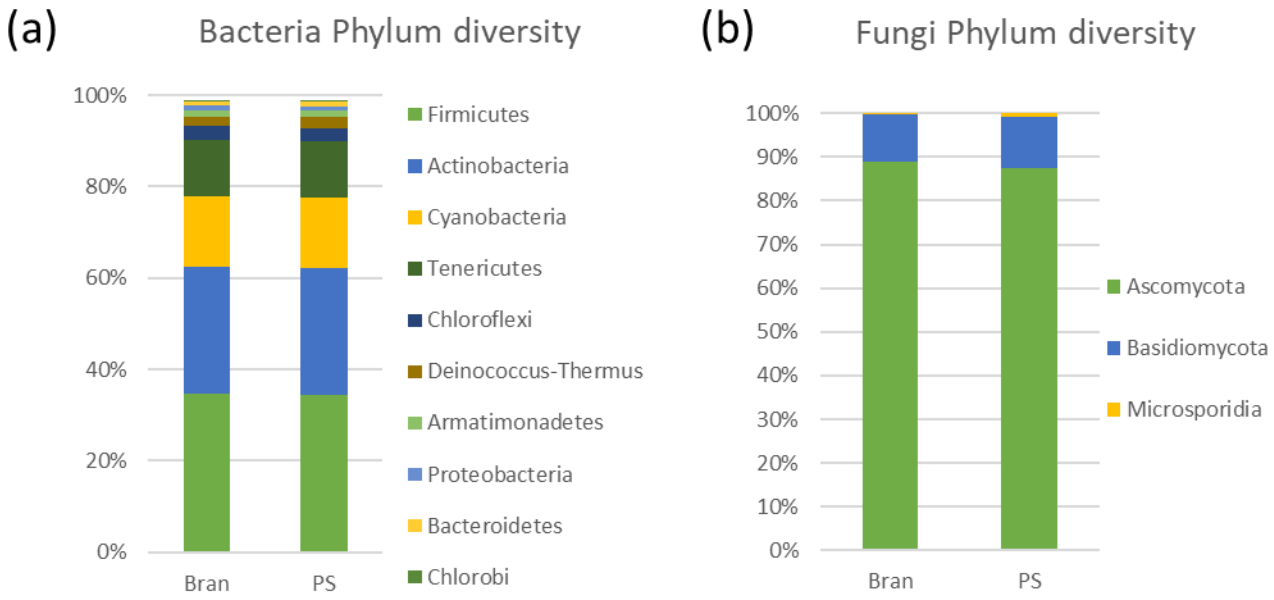

Figure 2. The abundance of bacteria and fungi at the phylum level. (a). Bacterial abundance (b) Fungal abundance.

Analysis of bacterial abundance at the phylum level showed Firmicutes, Actinobacteria, Cyanobacteria, and Tenericutes as the dominant bacteria found in the larvae intestine of the rice bran and polystyrene feed groups. However, the results of the analysis showed that the abundance of Actinobacteria and Cyanobacteria was higher in the polystyrene group larvae with a difference of 1% from the bran group larvae. While the abundance of fungi was found in the phylum Microsporidia in the polystyrene group while in the rice bran group there was no Microsporidia. The abundance of microbes at the phylum level is shown in Figure 2.

Analysis of bacterial abundance at the class level showed Bacilli, Clostridia, Erysipelotrichia, Tissierellia, Negativicutes, and Actinomycetia as the dominant bacteria at the class level in the Styrofoam and bran larvae groups. The abundance of fungi at the class level showed Sordariomycetes and Schizosaccharomycetes as the dominant fungi in the Styrofoam and bran group larvae. The abundance of microbes at the class level is shown in Figure 3.

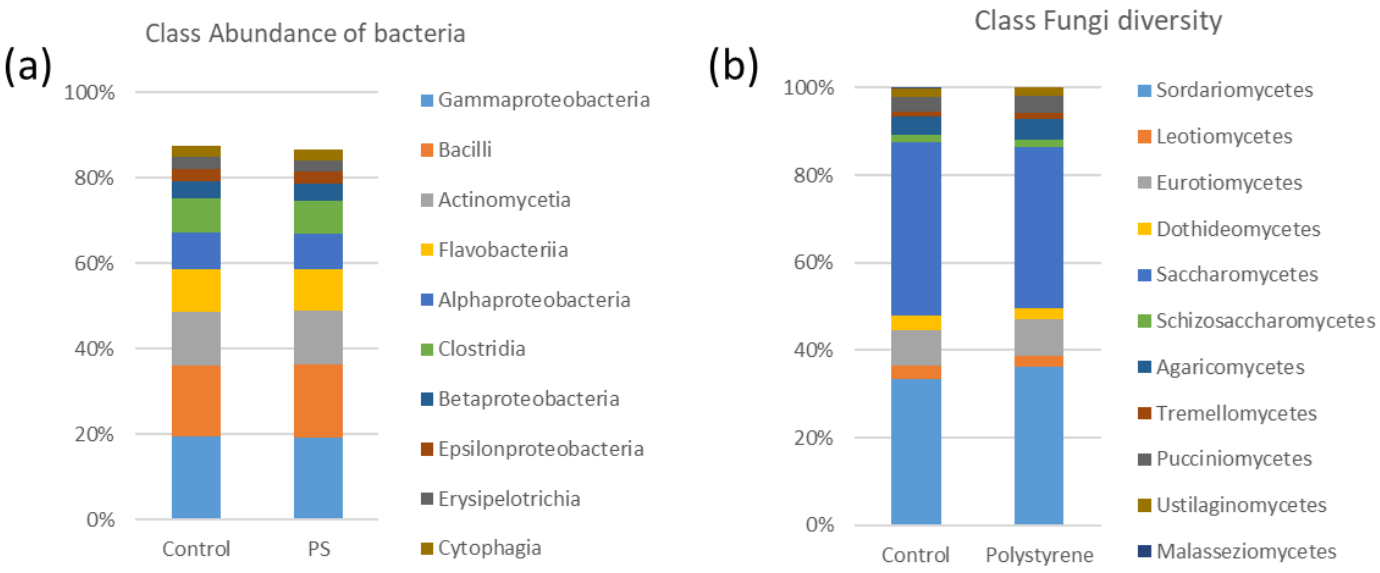

Figure 3. Class level microbial abundance (a) bacterial abundance (b) fungal abundance

The results of the species diversity analysis showed that there were no dominant bacterial groups in the Styrofoam feed group (Fig. 4). The heatmap results indicated the dominant species *Halarcobacter bivalviorum* in both groups, but the results of a literature search did not show that these species were involved in the decomposition of polystyrene.

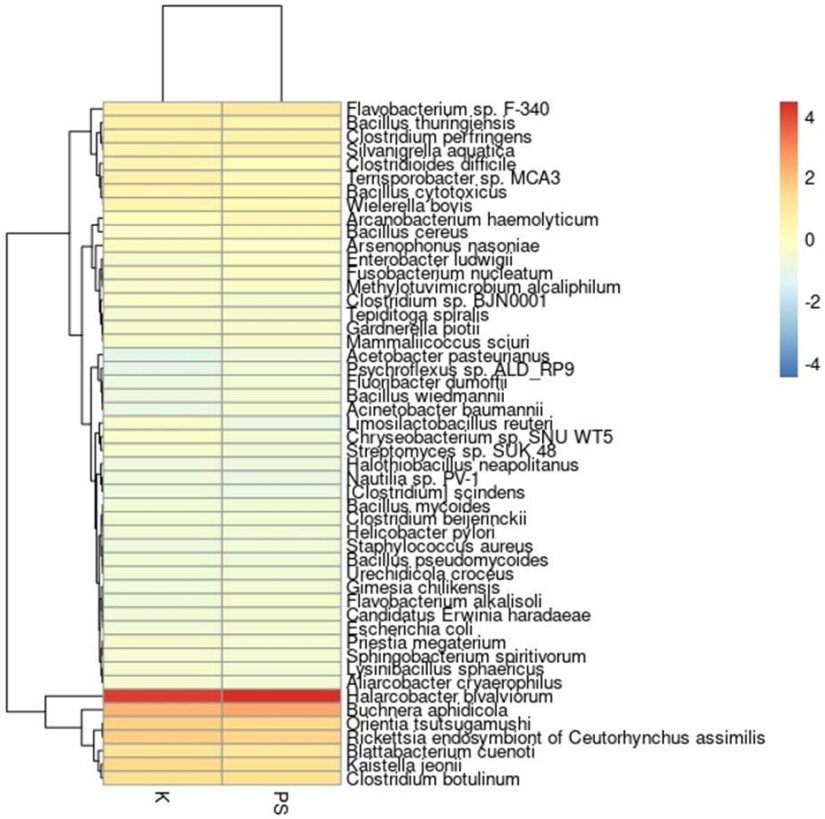

Figure 4. Results of heat map analysis of species diversity between rice bran and Styrofoam feed groups

FTIR was used to detect changes in digested PS functional groups in the gut of *T. molitor* larvae . The peak intensity at 625-970 cm $^{-1}$ (ring-bending) was strong in intact Styrofoam, weaker intensity was found in larval excrement powder samples and much weaker in methanol-extracted larval excrement (Figure 5). The FTIR spectrum of the larvae excrement powder did not produce any new clusters, we suspect that the tested excrement powder had not been completely digested in the *T. molitor* larvae gut. The FTIR spectrum of methanol extracted larvae excrement shows the formation of new groups as indicated by the emergence of peaks associated with CO stretching at wavelengths (1000-1200 cm $^{-1}$) and alcohol groups (R-OH stretch), at wavelengths 3000-3500 cm $^{-1}$.

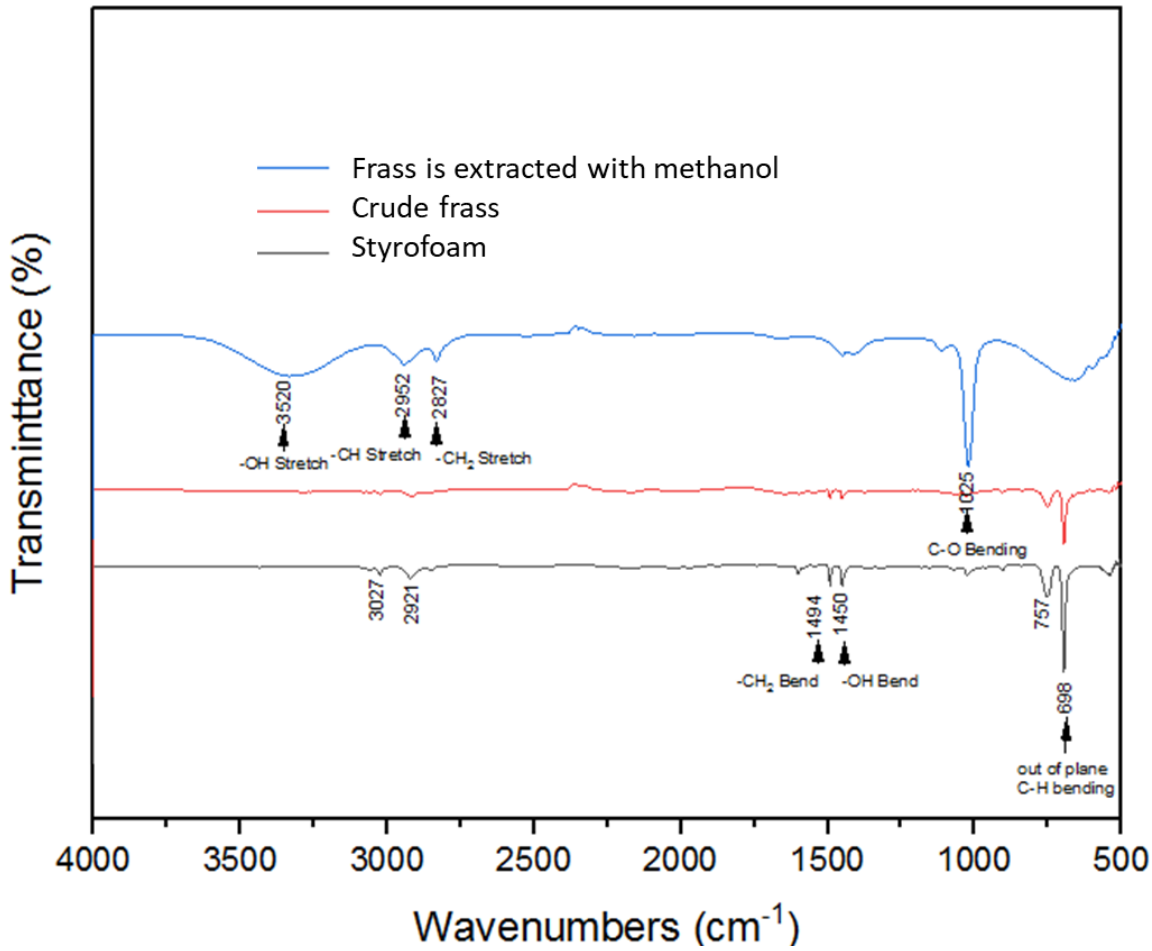

Figure 5. FTIR spectrum of intact Styrofoam with methanol-extracted larvae excrement powder and larvae excrement

The GC-MS results identified 15 compounds with a molecular weight of 230-472 (Table 2). Two fatty acid compounds were identified, namely Pentadecanoic acid and Heptadecanoic acid, and one type of alcohol, namely Ethanol, 2-(dodecyloxy), one type of phenol Phenol,

2,4,6-tris(1-phenylethyl) and one type of alkane, namely eicosane. In addition, several compounds containing one or more cyclic hydrocarbons were found, such as 7,9-Di-tert-butyl-1-oxaspiro(4,5)deca-6,9-diene-2,8-dione; 1H-1,3-Benzimidazole, 2-tricyclo[3.3.1.1(3,7)]dec-1; Imidazo[1,2-a]pyridine, 2-(1-adamantyl);1,2,4-Oxadiazole, 5-(3-methoxyphenyl)-3-phenyl; Bis(2-ethylhexyl) phthalate; 2-Methyl-7-phenylindole; Phenol, 2,4,6-tris(1-phenylethyl); alpha.-Tocopheryl acetate

Table 2. List of compounds identified from frass

Compound Name	Molecular Formula	Molecular Weight
Ethanol, 2-(dodecyloxy)-	$C_{14}H_{30}O_2$	230
7,9-Di-tert-butyl-1-oxaspiro (4,5)deca-6,9-diene-2,8-dione	$C_{17}H_{24}O_3$	279
Pentadecanoic acid, 14-methyl-, methyl ester	$C_{17}H_{34}O$	256
1H-1,3-Benzimidazole, 2-tricyclo[3.3.1.1(3,7)]dec-1-yl-	$C_{17}H_{20}N_2$	252
Imidazo[1,2-a]pyridine, 2-(1-adamantyl)-	$C_{18}H_{22}N_2$	266
1,2,4-Oxadiazole, 5-(3-methoxyphenyl)-3-phenyl-	$C_{15}H_{12}N_2O_2$	252
Heptadecanoic acid, 14-methyl-, methyl ester	$C_{18}H_{36}O_2$	284
Eicosane	$C_{20}H_{42}$	282
Bis(2-ethylhexyl) phthalate	$C_{24}H_{38}O_4$	390
2-Methyl-7-phenylindole	$C_{15}H_{13}N$	207
Glycerol tricaprylate	$C_{27}H_{50}O_6$	470
Phenol, 2,4,6-tris(1-phenylethyl)-	$C_{30}H_{30}O$	406
Silicic acid, diethyl bis(trimethylsilyl) ester	$C_{10}H_{28}O_4Si_3$	296
2-(Decanoyloxy)propane-1,3-diyl dioctanoate	$C_{29}H_{54}O_6$	498
alpha.-Tocopheryl acetate	$C_{31}H_{52}O_3$	472

4. RESEARCH PROBLEM

Processing gene functional data from metagenomic shotgun data is experiencing problems because it requires a server with large enough memory storage. We are working on renting a dedicated server for functional gene data processing. Currently data processing is underway on the server we have rented.

5. CONCLUSIONS AND FUTURE RESEARCH PLANS

Based on the results of the study, it can be concluded that the diversity of the gut bacterial phylum *T. molitor* that has been fed Styrofoam and rice bran, the dominant ones are Actinobacteria, Bacterioidetes, Firmicutes, Proteobacteria.

Data regarding the functional genes of the Styrofoam feed group is still in the identification process, considering that this data is very important to find enzymes that play a role in the decomposition of PS, and prediction metabolic pathway of biodegradation PS. The next research plan is to complete functional gene analysis.

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OGFICE Self Evaluation Report

(*filled out and submit with final report*)

Title of research	Analysis of Polystyrene Biodegradation by Gut Microbiota *Tenebrio molitor* Larvae Through Metagenomic Approach
Topic	Global environmental problems
Researchers	Sony Suhandono, Ph.D
Unit	School of Life Science and Technology
Significance of research	Obtain information on microbial species and enzymes that can accelerate the biodegradation process of polystyrene plastic, and predict the metabolic pathways of polystyrene decomposition
Brief summary of research (results)	Diversity of the gut bacterial phylum T. molitor that has been fed Styrofoam and rice bran, the dominant ones are Actinobacteria, Bacterioidetes, Firmicutes, Proteobacteria
Output of research	- Metagenomic data - Biodegradation pathway prediction - Draft publication
Self- evaluation	Originality: The use of the shotgun metagenomic method in observing the diversity of intestinal microbial enzymes in digesting polystyrene and predicting the metabolic pathways of polystyrene decomposition
	Impacts on Indonesian society: Obtain information on local isolates of microbial species capable of decomposing polystyrene plastic
	Involvement of students in research: One Ph.D student can complete the first phase of his dissertation research.

Research Report

Osaka Gas Foundation of International Cultural Exchange

(OGFICE)

Research Title

Hybrid ZnO/Porous Industrial Mill Scale-derived α-Fe2O3 for Efficient and Sustainable Photoelectrochemical Hydrogen Production

Principal Investigator:

Dr. Eng. Muhammad Iqbal, S.T., M.T.

Academic Unit

Research Division	:	Advanced Functional Materials
Faculty/School	:	Faculty of Industrial Technology

INSTITUT TEKNOLOGI BANDUNG

November 2022

I. IDENTITY PAGE

1. Title : Hybrid ZnO/Porous Industrial Mill Scale-derived α-Fe_2O_3 for Efficient and Sustainable Photoelectrochemical Hydrogen Production
2. Topic : Global environmental problems
3. Research Period : November 2021 – November 2022

4.1. Principal Investigator :

a. Full Name : Dr. Eng. Muhammad Iqbal, S.T., M.T.
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4.2 Members of the Team:

No	Name and Academic Rank	Field of Expertise	Institution	Allocation of Time	
				Hrs/week	Months
1	Prof. Brian Yuliarto, Ph.D (Professor)	Nanomaterials	FTI	10	10
2	Dr. Eng. Deni Shidqi Khaerudini (Senior Researcher)	Energy materials	BRIN	5	10

4.3 Research Assistants/Students (mention names when available):

No	Name	Departement and NIM	Alocation of Time	
			Hrs/week	Months
1.	Nick Wisely, S.Si.	Engineering Physics (23320306)	20	10

5. Approved budget : Rp 84,594,000

Bandung, 30 November 2022

Dean of Faculty of Industrial Technology

Digitally signed by Prof. Brian Yuliarto, ST,M.Eng.,Ph.D.
Location: Bandung

Prof. Brian Yuliarto, S.T., M.Eng., Ph.D
NIP. 197507272006041005

Principal Investigator

Dr. Eng. Muhammad Iqbal, S.T., M.T.
NIP. 120110008

I. EXECUTIVE SUMMARY

1. **TITLE OF RESEARCH** : Hybrid ZnO/Porous Industrial Mill Scale-derived α-Fe_2O_3 for Efficient and Sustainable Photoelectrochemical Hydrogen Production
2. **HEAD OF RESEARCH TEAM** : Dr. Eng. Muhammad Iqbal, S.T., M.T.
3. **TEAM MEMBERS** : Prof. Brian Yuliarto, Ph.D
   Dr. Eng. Deni Shidqi Khaerudini
   Nick Wisely, S.Si.
4. **OFFICIAL ADDRESS** : TP Rachmat Building, Ganesha 10, Bandung 40132

5. **EXTENDED ABSTRACT** :

As a clean and renewable resource, hydrogen is a perfect candidate to supply the energy demand of the world. In particular, photoelectrochemical (PEC) water-splitting technology provides an effective way to produce hydrogen in a sustainable manner with high efficiency and minimal environmental pollution. The key element in PEC technology is the photoactive materials. Amongst the metal oxide semiconductors, zinc oxide (ZnO) is considered one of the promising candidates for PEC. In this project, the ZnO was combined with hematite, specifically α-Fe_2O_3, as a heterojunction that led to the hydrogenation with a low bandgap and the ability to stimulate the photoresponse of electrons and holes. To promote the sustainable production of photoactive materials, the α-Fe_2O_3 has been derived from an industrial mill scale. The industrial mill scale is a mixed iron oxide-based by-product from the steel industry. In this project, the mill scale has been converted to α-Fe_2O_3 through the dissolution of the mill scale in oxalic acid to produce intermediate iron oxalate. After the subsequent calcination process, the intermediate product is converted into rod-like α-Fe_2O_3 particles. The diffraction pattern on the converted mill scale shows that α-Fe_2O_3 has been successfully formed. Electron microscopy imaging shows that the particle size reduced with an average length of 5 um and diameter of 1 um. The photoanode film consisting of ZnO and α-Fe_2O_3 film layer was prepared on an FTO substrate through the spin coating and electrophoretic deposition (EPD), respectively. The photoresponse test of the prepared photoanode has been carried out using the amperometric i-t technique under the visible light lamp source. The electrolyte employed in the photoresponse test was 0.1 M Na_2SO_4 aqueous solution. Upon the cycle of illuminated and dark conditions, the photoanode shows a good response to the illumination of visible light by delivering photocurrent 5 times higher than dark current.

6. **LIST OF RESEARCH OUTPUT**

(1) Nick Wisely, Muhammad Iqbal, Gerald Ensang Timuda, Brian Yuliarto, Deni Shidqi Khaerudini, A Scientometric Review of Photoanode Material in Photoelectrochemical Water Splitting for Hydrogen Production Application, Frontiers of Chemical Science and Engineering, *submitted*.

(2) Nick Wisely, Muhammad Iqbal, Gerald Ensang Timuda, Brian Yuliarto, Deni Shidqi Khaerudini, Physical and Chemical Conversion of Industrial Mill Scale to Rod-Like Hematite towards Highly Efficient Water Splitting Photoanode, *draft*.
Manuscript draft will be submitted to ACS Sustainable Chemistry & Engineering / International Journal of Hydrogen Energy / Energy & Fuels

II. TECHNICAL REPORT

The project has been carried out with the methodology that can be seen in Figure 1. At the first step of the project, the synthesis route is designed and materials that will be involved thorough the project is prepared. Further, the synthesis process is carried out to convert the mill scale into hematite. To investigate the properties of produced samples, several characterization techniques, including X-ray diffraction (XRD), scanning electron microscopy (SEM), and energy dispersive spectroscopy (EDS), were carried out. The subsequent photoresponse testing has been conducted to observe the photocurrent generated by the fabricated samples. The data resulted from the characterization and testing then collected and analyzed.

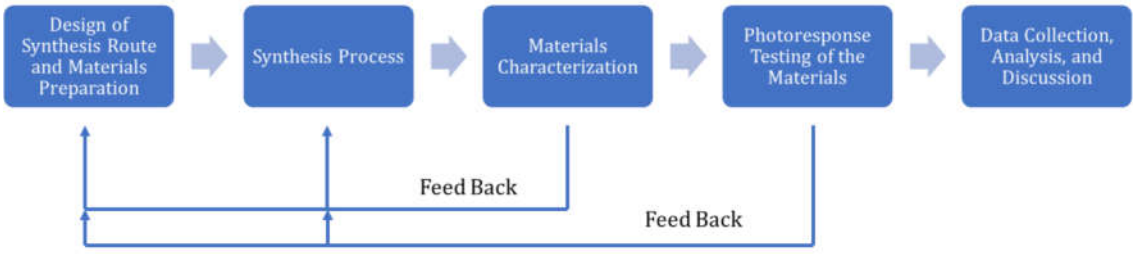

Figure 1. Block diagram of the research project.

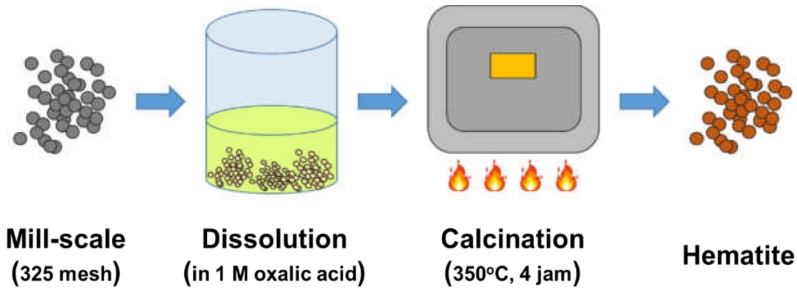

Figure 2. Schematic illustration of the two steps conversion process from mill scale to hematite.

The conversion process is conducted through two steps (Figure 2), *i.e.* the formation of intermediate product namely iron oxalate and the conversion of iron oxalate into hematite. The presence of oxalic acid played an important role to leach out the undesired elements from the mill scale and to form the iron oxalate (Figure 3a). The conversion from iron oxalate has been carried out through calcination process at 350°C for 4 hours. The resulted product was hematite with rod-like morphology as can be seen from microscopic images depicted in Figure 3b.

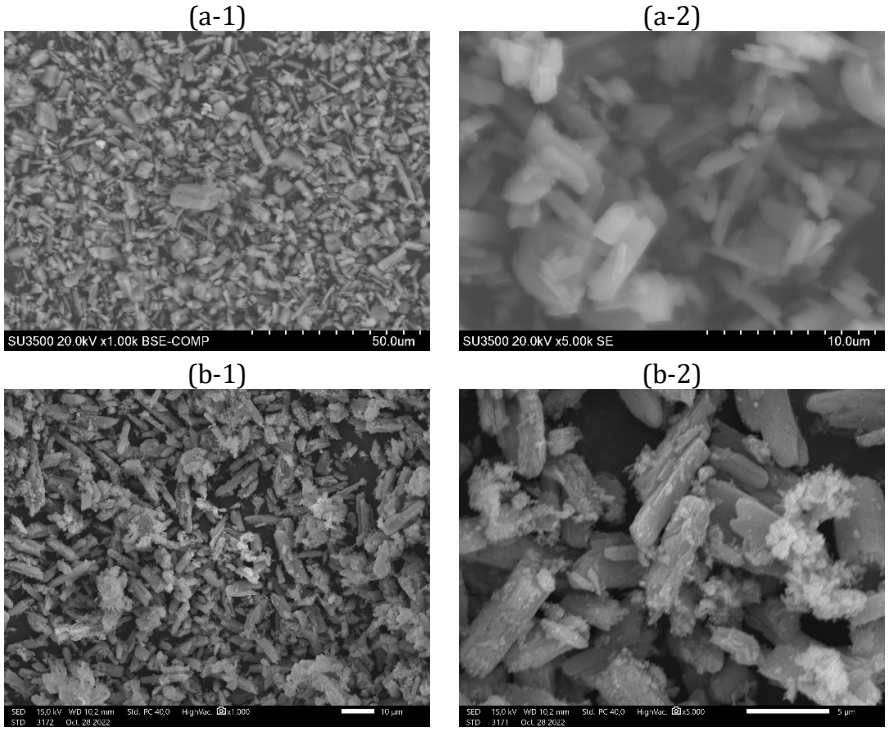

Figure 3. Morphology of (a) iron oxalate and (b) hematite observed by scanning electron microscope (SEM) at a low and high magnification.

The respective formation of iron oxalate and hematite were investigated using X-ray diffraction (XRD) technique. Figure 4 shows the diffraction pattern of iron oxalate hematite that resulted from the first and second step of the conversion process, respectively. From the diffraction pattern, it could be clearly seen that the distinctive peak positions between iron oxalate and hematite. Both diffraction patterns have been confirmed with the JCPDS database.

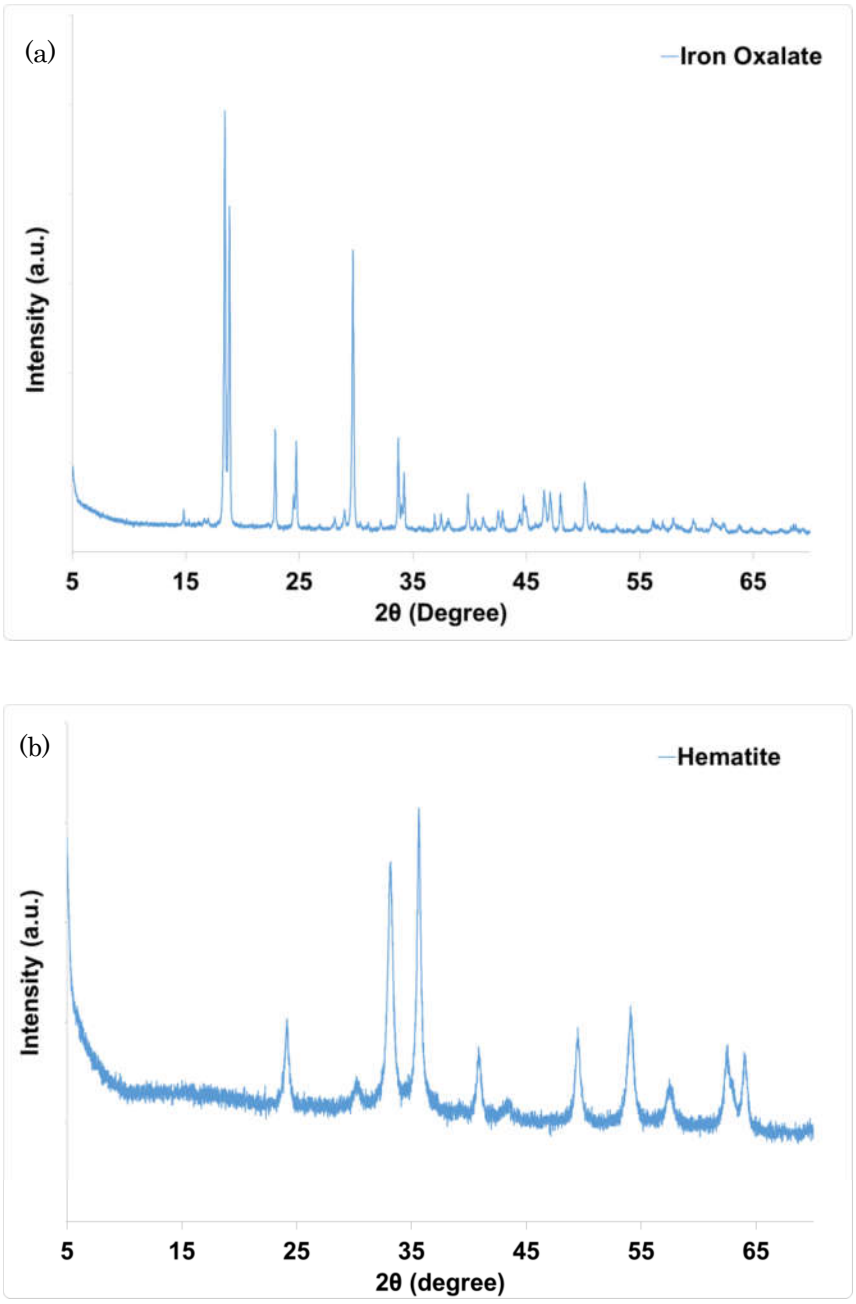

Figure 4. Diffraction pattern resulted from (a) iron oxalate and (b) hematite samples.

After the confirmation of hematite formation, the hematite then deposited on the FTO substrate to form a photoanode. The ZnO layer was deposited onto the FTO substrate prior the hematite deposition. The ZnO layer was deposited through spin coating method (Figure 5a). Further, the hematite is deposited on the ZnO/FTO using electrophoretic deposition (EPD) method (Figure 5b). The electrophoretic potential was varied as 1, 5, 10, 20, and 40 V for 1 minutes. The resulted photoanode is depicted in Figure 6.

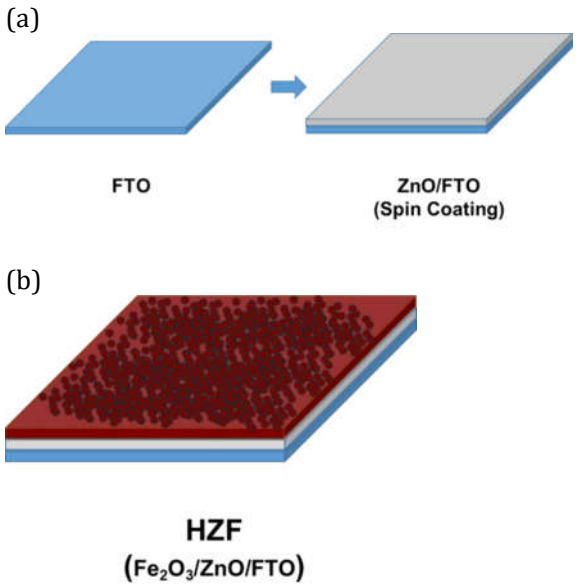

Figure 5. The schematic illustration of (a) ZnO deposition onto the FTO substrate using spin coating and (b) hematite deposition on the ZnO/FTO using epelctrophoretic deposition method.

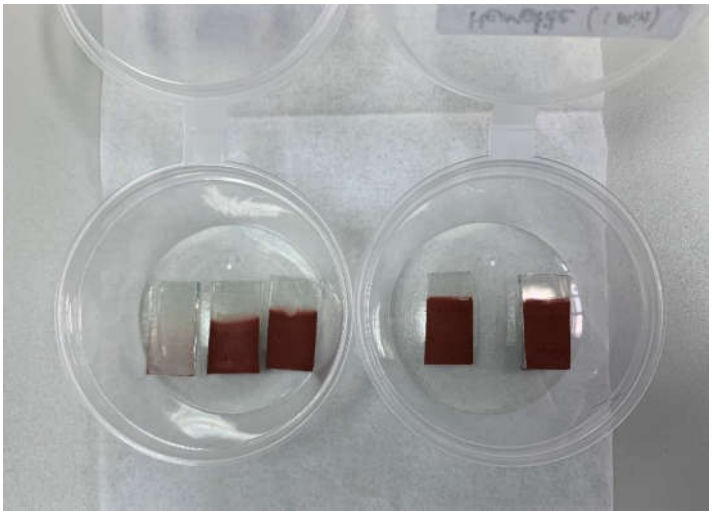

Figure 6. Photograph of the photoanode samples prepared at a various of electrophoretic potential (from left ro the right): 1, 5, 10, 20, and 40 V at the same deposition time for 1 minute.

The photoresponse test of the prepared photoanode has been carried out using the amperometric i-t technique under the visible light lamp source. The electrolyte employed in the photoresponse test was 0.1 M Na_2SO_4 aqueous solution. Upon the cycle of illuminated and dark conditions, the photoanode shows a good response to the illumination of visible light by delivering photocurrent 5 times higher than dark current (Figure 7).

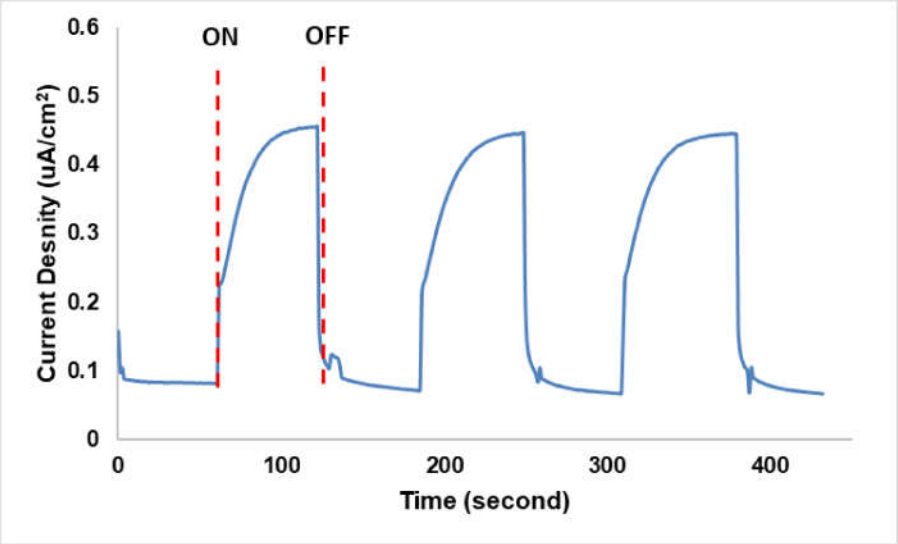

Figure 7. Photoresponse of Hematite/ZnO/FTO photoanode.

OGFICE Self Evaluation Report

(*filled out and submit with final report*)

Title of research	Hybrid ZnO/Porous Industrial Mill Scale-derived α-Fe_2O_3 for Efficient and Sustainable Photoelectrochemical Hydrogen Production
Topic	Global environmental problems
Researchers	Dr. Eng. Muhammad Iqbal, S.T., M.T. Prof. Brian Yuliarto, Ph.D Dr. Eng. Deni Shidqi Khaerudini Nick Wisely, S.Si.
Unit	Faculty of Industrial Technology
Significance of research	The utilization of industrial wasre from steel industry into functional materials that can be utilized as photoanode in photoelectrochemical water splitting to produce hydrogen
Brief summary of research (results)	In this project, the mill scale has been converted to α-Fe_2O_3 through dissolution of the mill scale in oxalic acid to produce initermediate iron oxalate. After subsequent calcination process, the intermediate converted into rod-like α-Fe_2O_3 particles. Diffraction pattern on the converted mill scale shows that α-Fe_2O_3 has been successfully formed. Electron microscopy imaging shows that the partilcle size reduced with an average length of 5 um and diameter of 1 um. The photoanode film consisted of ZnO and Fe_2O_3 film layer was prepared on FTO substrate through spin coating and electrophoretic deposition (EPD), respectively. The photoresponse test of the prepared phothoanode has been carried out using amperometric i-t technique under the visible light lamp source. The electrolyte employed in the photoresponse test was 0.1 M Na_2SO_4 aqueous solution. Upon the cycle of illmuninated and dark condition, the photoanode shows good response to the illumination of visible light by delivering photocurrent 5 times higher than dark current.
Output of research	1. Nick Wisely, Muhammad Iqbal, Gerald Ensang Timuda, Brian Yuliarto, Deni Shidqi Khaerudini, A Scientometric Review of Photoanode Material in Photoelectrochemical Water Splitting for Hydrogen Production Application, *Frontiers of Chemical Science and Engineering*, submitted. 2. Nick Wisely, Muhammad Iqbal, Gerald Ensang Timuda, Brian Yuliarto, Deni Shidqi Khaerudini, Physical and Chemical Conversion of Industrial Mill Scale to Rod-Like Hematite towards Highly Efficient Water Splitting Photoanode, draft. Manuscript draft will be submitted to *ACS Sustainable Chemistry & Engineering / International Journal of Hydrogen Energy / Energy & Fuels*
Self- evaluation	Originality: Thermal and oxalic acid conversion of mill scale into rod-like hematite

	Impacts on Indonesian society: • Steel industry in Indonesia has an alternative to recycle their secondary materials, such as mill scale, by converting it into more value-added materials, *i.e.* hematite through a facile and sustainable way. • The photoelectrochemical water splitting process using the photoanode based on industrial mill scale-derived hematite could assist Indonesian society to develop the hydrogen production technology for a various of needs.
	Involvement of students in research: A master student involved in this research and completed his master thesis through the research project

The Osaka Gas Foundation of International Cultural Exchange (OGFICE)

Research Grant FY 2021/2022

Final Report

Identifying priority conservation landscapes for biodiversity and disaster mitigation in Java through characterizing spatial structure of forest landscapes

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Submitted to:

Center for Environmental Research

Bogor Agricultural University

for

The Osaka Gas Foundation of International Cultural Exchange (OGFICE)

December 2022

General Information

Title : Identifying priority conservation landscapes for biodiversity and disaster mitigation in Java through characterizing spatial structure of forest landscapes

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Bogor, 11 December 2022

Center for Environmental Research,
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TABLE OF CONTENT

I. Introduction

1.1. Background

Indonesia in the last few decades has experienced the loss of forest areas, especially in Java Island, and has an impact on biodiversity levels and accelerates climate change (Margono et al. 2014; Alisjahbana and Busch 2017). It has been proven that Indonesia has had a dark history of the extinction of the Javan tiger, the last seen numbering three individuals being in Meru Betiri National Park in 1979 (Tilson and Seal 1987). This is one of the effects of human activities that come into contact with areas of high biodiversity so that the forest landscape is damaged and cannot support the life of this biodiversity (Boomgaard 2010). Conservation efforts have long been carried out to save biodiversity, one of which is through government policies that establish national parks as nature conservation areas. Through the inauguration of the national park, the biodiversity of the island of Java with a rare status such as the Javan rhinoceros in Ujung Kulon National Park (UKNP) can be conserved naturally and controlled from human activities. In addition, forest areas are also designated in urban areas in an effort to control the quality of the urban environment (Article 29 of Law No. 26 of 2007). As is the case in the Jabodetabek Megacity area, which is a city that has the largest concentration level of urban communities in Indonesia, thus requiring the existence of an urban forest area to fulfill the needs of urban communities (Firman et al. 2011; Prasasti et al. 2015; Dwyer et al. 1992). Meanwhile, in coastal areas, the designation of protected areas for mangrove forests has a major impact on the economy, coastal conservation, and the mitigation of natural disasters such as tsunamis and climate change (Murdiyarso et al. 2015; Burbridge and Koesoebiono 1982).

Over time, and followed by population growth, regional development, and volcanic activity, the carrying capacity of the forest landscape on the island of Java has become alarming. For example, rapidly increasing population growth and increasing urban sprawl development in big cities in Indonesia have an effect on the availability of vegetated land (including urban forests and urban mangrove areas) (Robbany et al. 2019). In addition, recent reports reveal that UKNT is constrained by the potential for long-term natural disasters that can threaten the existence of rhinos, such as tsunamis due to the convergence of tectonic plates (Løvholt et al. 2014) and volcanic eruptions (Giachetti et

al. 2012). To overcome imminent obstacles and direct more effective conservation actions, a comprehensive study of the forest landscape on the island of Java is needed. As a follow-up, research on the Javan rhinoceros was carried out to identify and model the carrying capacity of UKNT for the survival of the species, taking into account environmental factors such as soil, vegetation, and parasites in rhino puddles. While in urban areas, mapping of urban sprawl, urban forest, and mangrove areas was carried out to determine the dynamics of development and the influence of population growth.

1.2. Objective

The forest landscape in Java is increasingly worrying. However, every effort has been made in various locations, for example in national parks whose areas have been degraded and are immediately rehabilitated. Meanwhile, urban forest landscapes can be found in various urban forest parks at Jabodetabek Megacity. This is one of the derivative products of forest landscape conservation for the preservation of biological resources in primary forests and environmental quality in urban areas. However, all of that requires further in-depth study, in examining several related environmental factors.

Moreover, Ujung Kulon National Park (UKNT) has a high level of biodiversity and home to Javan rhino, one of the largest endangered mammals. It is known that the species is vulnerable to extinction due to several environmental hazards such as inundation, tsunami, and parasites. Concerning the importance of site selection and further extent of Javan rhino's conservational action, wallow site study is considered neccesary. This research was conducted by focusing on the condition of the Javan rhinoceros wallow, including soil and water properties, vegetation characteristics and the parasites diversity in order to determine the environmental factors contribution for their selection. Also, we included remote sensing parameters and then modelled all factors spatially. From the results of this study, it is expected to provide information and recommendations regarding the Javan rhino's suitable habitat from wallow site perspective.

II. Methodology

2.1. Research location and time

The research location focuses on the island of Java by taking two study topics, namely the conservation of the Javan rhinoceros in Ujung Kulon National Park (Banten Province), and for urban sprawl studies in several metropolitan cities on the island of Java. Data collection for the first study was carried out between December 25, 2021 - January 04, 2022, and for the second study it was carried out in July - August 2022.

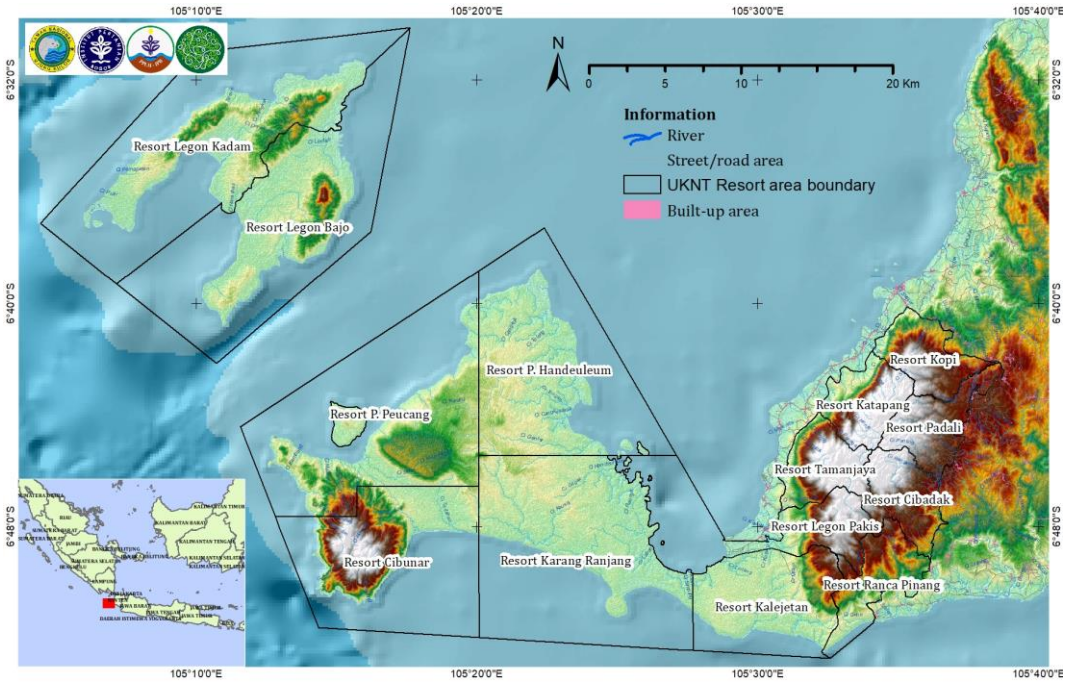

Figure 1. Area of interest (AOI) for researcch collection

2.2. Data and data collection

In the first study, environmental factors were measured, such as soil characteristics (pH, eH, EC, total and base exchange, cation exchange capacity, texture), water (water table, pH, eH, EC, salinity), vegetation conditions (vegetation analysis). and canopy cover analysis), and parasite diversity. Measurement of environmental factors was carried out in active, former, and river ponds where the rhino wallows were selected. Then the soil samples and parasites will be analyzed further in the soil testing laboratory (Department of Soil Science and Land Resources, IPB) and the parasite laboratory (Faculty of Veterinary Medicine, IPB). The results of the laboratory determination (soil and parasites) were then used as habitat modeling material at the Environmental Spatial

Planning Laboratory (Department of Forest Resources Conservation and Ecotourism of IPB) to obtain a suitable area estimate for the location of the Javan rhino wallow. The process is carried out using a manual geographic information system and cloud computing that combines soil and water spatial maps, parasite distribution, Sentinel-2 imagery, and topographic maps. Meanwhile, urban sprawl research (including mangroves and urban forests) was conducted by taking vegetation data, urban sprawl data, and training sample points for further modeling using remote sensing

2.3. Data analysis

2.3.1. Conservation: Rhino wallow suitability

Data analysis was carried out by statistically connecting three main parameters, namely soil characteristics, vegetation and parasite diversity. EDA was conducted using several descriptive approaches. The difference between each environmental factor was assessed using Linear Mixed Effect Models with Restricted Maximum Likelihood (LME-ReML). Furthermore, linear and non-linear based multivariate methods were used as a companion to LME-ReML. Principal Component Analysis/PCA was chosen as a multivariate method with linear projections. In addition, autoencoder projections based on artificial neural networks/ANN or multilayer perceptron/MLP function as non-linear projections. The two methods are then compared to find a precise statistical understanding that reflects most of the natural relationships.

2.3.2. Land use land cover with high heterogeneity

This analysis is carried out by mapping land cover in the area and also identifying forest damage due to deforestation or natural disasters that threaten the habitat of the Javan Rhino. This identification involves various image data such as Sentinel (SAR and MSI types) and Landsat (4-9) and is analyzed through the Google Earth Engine (GEE) platform. This analysis was performed using several index algorithms and classification algorithms (random forest: RF). The results of this analysis will be presented in a spatio-temporal manner and associated with the selection of rhinoceros puddles. To test the accuracy of the results, it is continued by conducting an accuracy test using Overall Accuracy (OA) and Kappa Statistics (KS) which refers to the following figure.

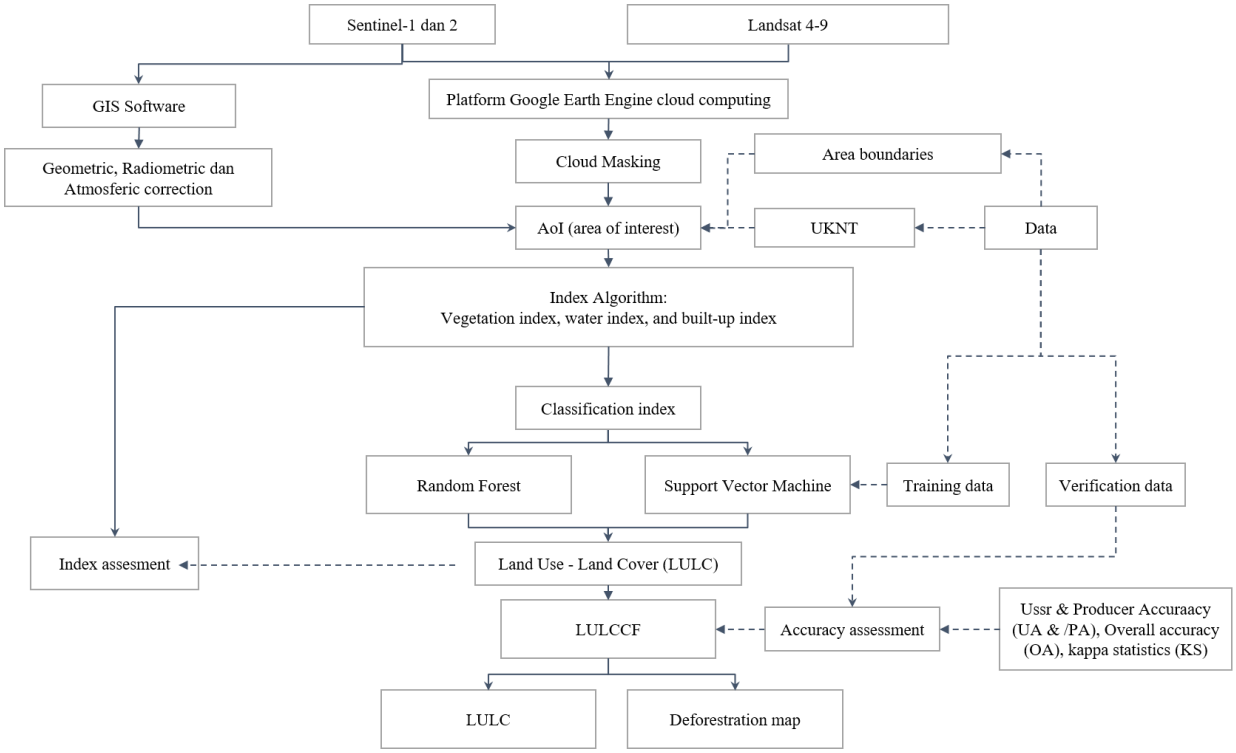

Figure 2. Flowchart of land cover identification

2.3.3. Impacts analysis of tsunami disaster

Data analysis in this study was divided into two stages, namely land cover classification and detection of mangrove damage due to the tsunami disaster. Land cover classification analysis is carried out first to separate land cover in the form of mangroves from other land covers. And then carried out analysis of mangrove damage detection with several indices. The stages of data analysis are presented in the following flowchart..

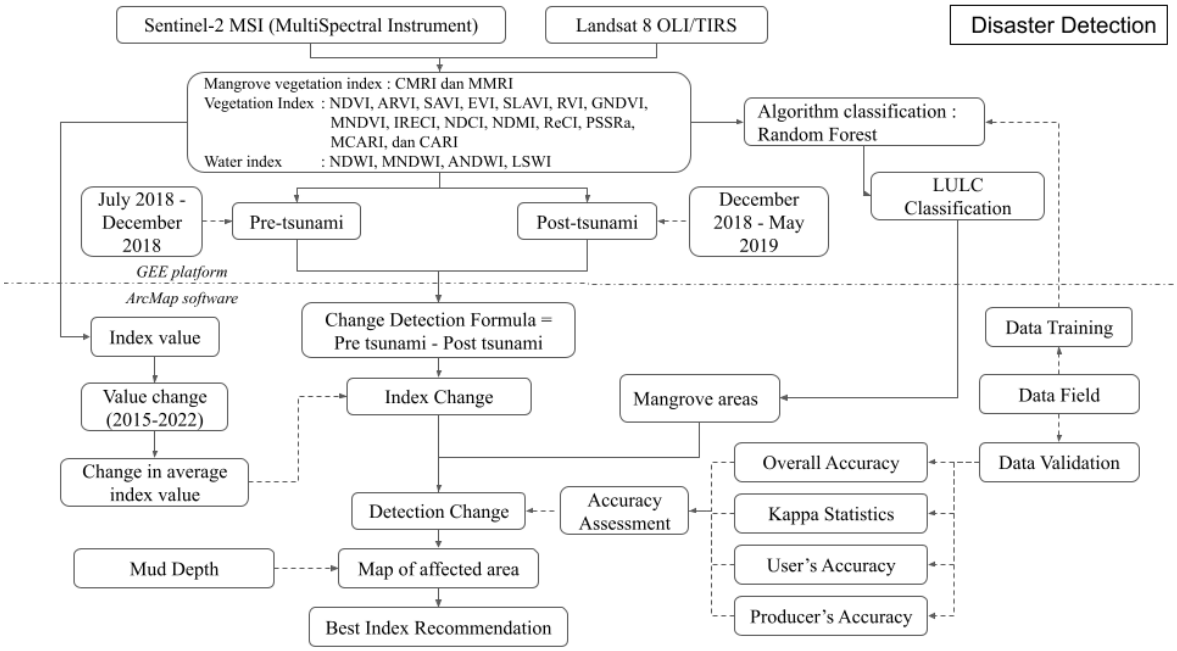

Figure 3. Detection models

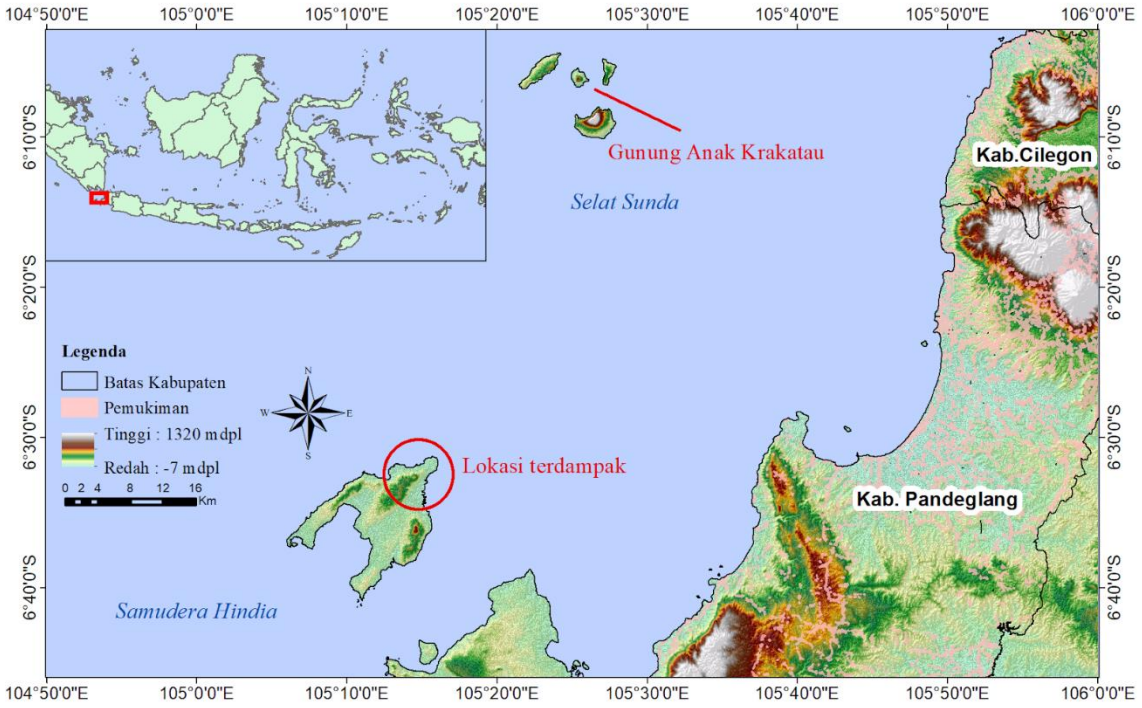

Figure 4. Map of the area affected by the tsunami disaster

Land cover classification was carried out by involving 210 training data taken through high-resolution imagery in Google Earth pro software. The training data is taken by representing land cover classes, namely water, forest, and mangroves. Classification analysis uses a random forest (RF) algorithm and through a cloud computing-based GEE

geospatial platform to simplify the classification process without having to download image data.

The characterization of the affected area is carried out using an index algorithm so that it becomes the basis for determining the threshold value in the affected area. There were 21 indices involved and divided into mangrove type classes (Table 1), vegetation (Table 2), and water (Table 3). The mangrove-type index algorithm is used by considering that the study area is located in a mangrove area so that it is considered to be easier in analyzing post-tsunami changes. In addition, the same as the vegetation index is involved taking into account the vegetation cover of the study area. Meanwhile, the water index is used by considering the effect of water on the mangrove ecosystem.

Table 1. Mangroves Indices

Indeks	Formula	Inventor	References
(CMRI) Combined Mangrove Recognition Index	NDVI - NDWI	Gupta et al. 2018	Maung dan Sasaki 2021, Xia et al. 2022
(MMRI) Modular Mangrove Recognition Index	(MNDWI - NDVI) / (MNDWI + NDVI)	Diniz et al. 2019	Sahadevan et al. 2021

Table 2. Vegetation index

Indeks	Formula (Sentinel-2)	Inventor	References
NDVI	(B8 – B4) / (NIR + B4)	Rouse jr et al. 1974	Baloloy et al. 2021
ARVI (Atmospherically Resistant Vegetation Index)	(B8 - (B4 - (1 * (B4 - Blue)))) / (B8 + (B4 - (1 * (B4 – B2))))	Kaufman dan Tanre 1992	Rahmawati et al. 2022, Nurdiansah dan Dharmawan 2021
SAVI	((B8 – B4) / (B8 + B4 +0.5)) * (1.0+0.5)	Huete 1988	Vidhya et al. 2014
EVI (Enhanced Vegetation Index)	((B8 – B4) / ((B8 + 6) * (B4 - 7.5) * (B2 + 1))) * 2.5	Huete et al. 2002	Berlanga-Robles dan Ruiz-Luna 2020
MNDVI	(B6 – B5) / (B6 + B5)	Jurgens 1997	-
GNDVI (Green normalized difference vegetation index)	(B8 – B3) / (B8 + B3)	Gitelson et al. 1996	Zhen et al. 2021, Rahmawati et al. 2022
RVI (Ratio vegetation index)	(B8 / B4)	Jordan 1969	Xu et al. 2022
SLAVI (Specific Leaf Area Vegetation Index)	(B8) / (B4 + B12)	Lymburner et al. 2000	Ali et al. 2019

Indeks	Formula (Sentinel-2)	Inventor	References
NDMI (Normalized Difference Moisture Index)	(B8 – B11) / (B8 + B11)	Wilson dan Sader 2002	Aljahdali et al. 2021
NDRE (Normalized Difference Red-Edge)	(B8 – B5) / (B8 + B5)	Gitelson dan Merzlyakb 1994	Behera et al. 2021
NDCI (Normalized Difference Chlorophyll Index)	(B4 - B5) / (B4 + S5)	Caballero et al. 2020	Dutta et al. 2022
ReCI (Red Edge Chlorophyll Index)	(B8/B5) − 1	Gitelson et al. 2005	Behera et al. 2021
IRECI (Inverted Red Edge Chlorophyll Index)	(B8 – B4) / (B5 + B6)	Frampton et al. 2013	Behera et al. 2021
PSSRa (Pigment-Specific Simple Ratio Index)	B8/B4	Blackburn 1998	Behera et al. 2021
MCARI (Modified Chlorophyll Absorption Ratio Index)	((B5 – B4) - 0.2 × (B5 – B3)) × (B5/B4)	Daughtry et al. 2000	Behera et al. 2021, Baloloy et al. 2021, Ali et al. 2019
Chlorophyll Absorption in Reflectance Index (CARI)	((B5 – B4) – 0.2 (B5 – B3))(B5/B4)	Kim (1994)	Arshad et al. 2020

Table 3. Water Indices

Indeks	Formula (Sentinel-2)	Inventor	References
NDWI (Land Surface Water Index)	(B3 - B8) / (B3 + B8)	McFEETERS 1996	Baloloy et al. 2021
MNDWI (Modified Normalized Difference Water Index)	(B3 – B12) / (B3 + B12)	Xu 2006	Wang et al. 2018, Rahmawati et al. 2022,
ANDWI (Augmented Normalized Difference Water Index)	(B2 + B3 + B4 – B8 – B11 – B12) / (B2 + B3 + B4 + B8 + B11 + B12)	Rad et al. 2021	Wandani et al. 2021
LSWI (Land Surface Water Index)	(B8 - B12) / (B8 + B12)	Xiao et al. 2002	Sannigrahi et al. 2020

Previous research, detection of affected areas by using a comparison of the results of land cover analysis. In this study, we tested a new approach using index value comparisons. To generate a new index showing the affected area, we perform calculations and use pre and post index data (F1). The two same index data are calculated using the algebra map tools on ArcMap. The results of the analysis are then carried out to determine the threshold value which indicates the affected area. In

addition, statistical analysis was also involved, namely the paired T-test to prove a significant difference after the tsunami disaster (F2). This is done to strengthen the assumption of determining the threshold value which will be used as a recommendation for the analytical approach. The process of statistical analysis for these 21 indices was carried out in the R Studio software.

$$Index_{Affected\ areas} = Index_{pre} - Index_{post} \text{.....F1}$$

$$t = \frac{X_D - \mu_0}{S_D/\sqrt{n}} \text{.....F2}$$

2.3.4. Accuracy Assessment

Accuracy assessment was carried out using User's Accuracy (UA), Producer's Accuracy (PA), Overall Accuracy (OA), and Kappa Statistics (KS). [19] Fitzgerald and Lees (1994) explained that the assessment of the accuracy of the classification results can be expressed in terms of the percentage of overall accuracy and is calculated from the number of diagonal elements of the matrix of errors, confusion, or misclassification resulting from the application of classifiers. This analysis is needed in evaluating the process of making spatial information before it is disseminated and consumed by many people ([20] Foody 2001). For this reason, this study involves an accuracy assessment that evaluates the results of detection of mangrove damage and is presented in equations 1-4. This process uses validation data which is divided into two types, namely areas that have not changed and mangrove areas that have been damaged. The distribution of the validation data samples is distributed in three areas, namely the top, middle, and lower as shown in Figure 2. In addition, the results of calculating the OA value are divided into six interpretation classes (Table 4).

$$OA = \frac{1}{N}\sum_{i=1}^{r} X_{ii} \times 100\% \text{ .....F3}$$

$$KS = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r} X_{ii}\,(X_{i+} \times X_{+i})}{N^2 \sum_{i=1}^{r} X_{ii}\,(X_{i+} \times X_{+i})} \text{ .....F4}$$

Tabel 4. Kappa intepretation

Kappa value	Description
<0.00	Poor
0.00 – 0.20	Slight

0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.80	Substantial
0.81 – 1.00	Almost perfect

III.Description of Research Site

Ujung Kulon National Park (TNUK) is a representative of the remaining and largest lowland tropical rainforest ecosystem in western Java, to be precise at the western tip of Java Island and is included in Pandeglang Regency in Banten Province with an area of 120,551 ha (Mujiono 2010). There are two routes for accessibility to reach the Ujung Kulon area, namely the land route and the sea route. Land routes can be reached by using public transportation, such as buses to Jakarta or Kalideres–Labuan or Jakarta or Kp.Rambutan–Serang–Labuan with a distance of 120 km and the time taken for 4-5 hours, then the journey continues by using mini public transportation bus or elf heading Labuan- Sumur-Tamanjaya with a distance of 2-3 km and the time taken is 2-3 hours. Meanwhile, if traveling to the Ujung Kulon area by sea, use a chartered boat (longboat or slowboat) which is usually rented out in Labuan or Carita, Sumur, and Tamanjaya (TNUK 2009).

The Natural Potential of Ujung Kulon National Park consists of five vegetation, namely: Coastal Forest, Mangrove Forest, Freshwater Swamp Forest, Lowland Rain Forest and Grasslands. Regional Flora Potentials The Ujung Kulon National Park area has three types of ecosystems, namely marine ecosystems, terrestrial ecosystems and coastal ecosystems. The complete vegetation in this National Park contains a very high diversity of germplasm as well as useful and rare plant species. The diversity of flora that belongs to Ujung Kulon National Park is 700 species of flora, of which 57 species are rare species, such as Merbau (Intsia bijuga), Palahlar (Dipterocarpus haseltii), Bungur (Lagerstroemia speciosa), Cerlang (Pterospermum diversifolium), Kihujan (Engelhardia serrata), and various types of orchids (Windadri 2009). Fauna Potential The Ujung Kulon National Park area is representative of the remaining and largest lowland tropical rainforest ecosystem in West Java. Various types of fauna or wild animals in this area are quite high, both endemic and endangered species. The animals found in the Ujung Kulon National Park area consist of 35 species of mammals, 5 species of primates, 59 species of reptiles, 22 species of

amphibians, 240 species of birds, 72 species of insects, 142 species of fish and 33 species of coral reefs. Among all these types of animals there are several wild animals that are rare, namely the Javan Rhino (Rhinoceros sondaicus), Javan gibbon (Hylobates moloch), surili (Presbytiscomata), bull (Bos javanicus), langur (Trachypithecus auratus), leopard (Panthera pardus)), Forest Cat (Prionailurus bengalensis), Giant Clam (Tridacna gigas), Deer (Rusa timorensis), and Forest Dog (Cuon alpinus) (Muryadi 2013). Ujung Kulon National Park is an ideal habitat for the survival of the Javan rhinoceros (Rhinoceros sondaicus).

The Javan rhinoceros is the rarest of the five rhino species in the world, so it is categorized as endangered or threatened in the Red List Data Book issued by the International Union for Conservation of Nature and Natural Resources (IUCN) in 1978, so the Javan rhinoceros get the highest priority to be saved from extinction. The spread of the Javan rhinoceros in the world is limited, in Indonesia alone the Javan rhinoceros is only found in Ujung Kulon National Park with a relatively small population, which is around 56-69 individuals. However, the numbers in this population are still in doubt, because the methods used in calculating the population cannot describe the entire population of the Javan rhinoceros. The existence of the Javan rhinoceros tends to be concentrated in the Ujung Kulon Peninsula region (Santosa et al. 2010). Accessibility There are two routes to reach the Ujung Kulon area, namely the land route and the sea route.

IV. Results and Discussion

4.1. The suitability of the Javan rhino wallow

There are 18 rhino puddles that have been observed between December 25, 2021 - January 04, 2022 and are divided into two different observation stations. Field identification produces three main data, namely vegetation, soil and parasites. There are differences in soil characteristics, vegetation, and parasites in some rhinoceros puddles with different conditions. For example, in puddles 16-18 which have seawater intervention, it affects the intensity of the Javan rhino's wallowing needs.

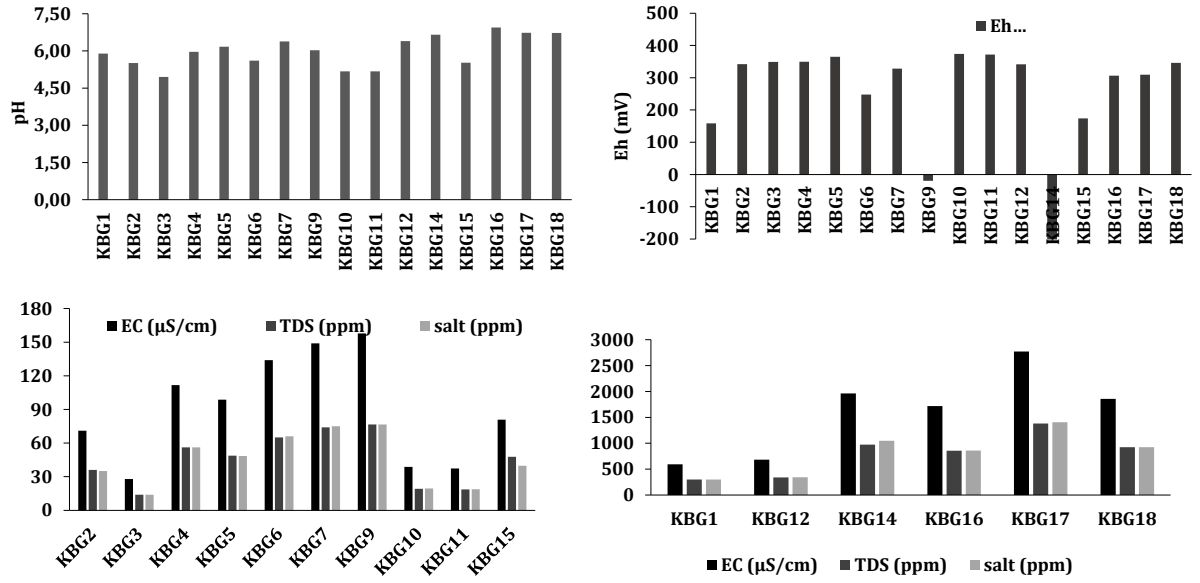

Figure 5. Soil characteristics

4.2. Land Use and Land Cover in UKNP

4.2.1. Classification Result

The GEE classification results in nine land use classes: water body, primary forest, mixed forest, bamboo forest, mangrove forest, bare land, built-up area, crop area, and swamp forest (Figure 6). The classification results reveal that the water body is the LULC class with the largest area of about 45.44% and the built-up area is the lowest LULC class with an area of 144.45 ha or about 0.13% (Table 4). Within the UKNT area, the water body is located northwest to south of this national park. This area includes parts of the river to marine conservation areas. In addition, the second largest LULC class is mixed forest area which covers about 19.53% or about 25,616.28 ha of the total area of UKNT.

It is known from a field survey conducted at one of the UKNT resorts that mixed forest consists of large trees mixed with overlapping plants such as honje and tepus (Figure 6: E). These clumps of plants cover the entire forest floor very tightly in this area, making it difficult for humans to reach them. According to Purwaningsih and Atikah (2018), the gaps formed by several fallen trees naturally provide opportunities for seeds to germinate. In addition, this mixed forest is a food corridor for UKNT's main animal, the Javan rhino. This makes the LULC class very important in supporting the habitat of the endangered Javan rhino.

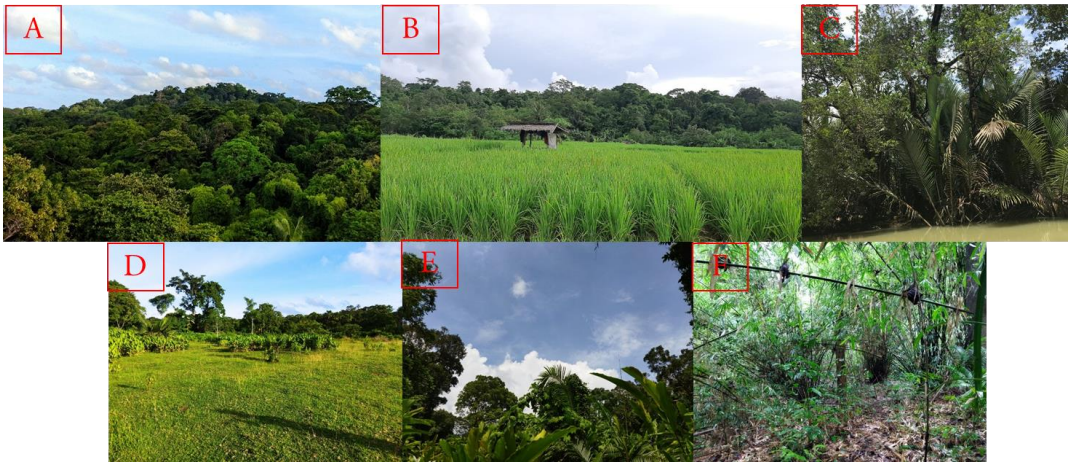

Figure 6. Primary forest (a), crop area (b), mangrove forest (c), bare land (d), mixed forest (e), bamboo forest (f).

The forest area in UKNT is the last remaining habitat for the Javan rhino on the island of Java. In addition to mixed forest, GEE has identified four other forest classes, namely primary forest (19.53%), bamboo forest (5.39%), mangrove forest (1.69%), and swamp forest (0.78%) (table 5). In some forest classes, this also has a vital role in habitat conservation efforts in UKNT. It is known that the Javan rhino wallowing activity was also recorded in this type of forest. Primary forest is a forest that is quite widely spread in the UKNT area. This type of forest consists of large trees, and the forest floor is overgrown with rare invasive plants. According to Hariyadi et al. (2012) and Febriana et al. (2019) that the rare plant (Arenga obtusifolia) distributed in the UKNT forest is one of the problems that threaten the habitat of the Javan rhino. In Santosa et al. (2013), the land overgrown by rare plants was converted into rhizome plantation land as a feeding corridor for herbivores in this national park.

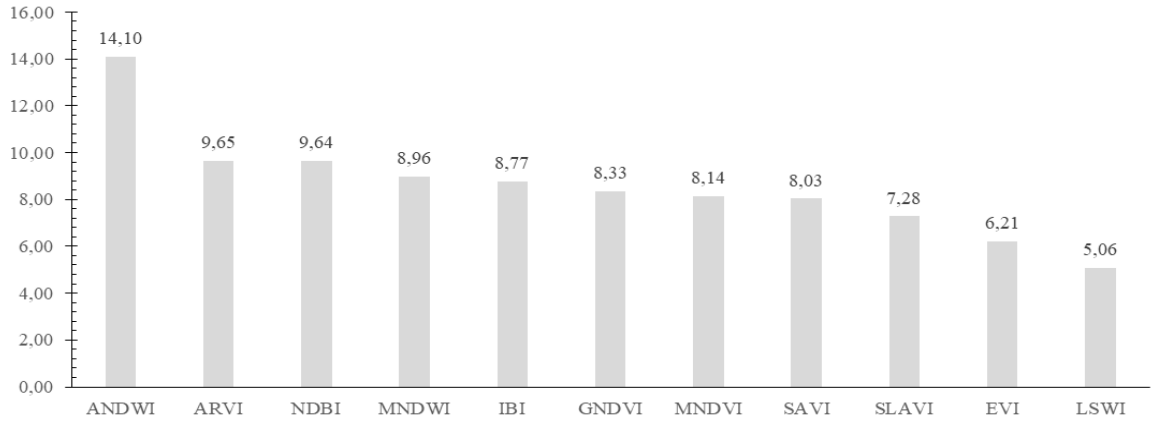

Figure 7. Important variables in the classification process using 11 indices

Table 5. Comparison of LULC area of classification and improvement

No.	Land use	Area	
		Hectares (ha)	Percentage (%)
1	Water body	49.971,27	44,63
2	Primary forest	21.868,41	19,53
3	Mixed forest	25.616,28	22,88
4	Bamboo forest	6.039,32	5,39
5	Mangroves forest	1.897,88	1,69
6	Bare land	595,66	0,53
7	Built-up area	144,45	0,13
8	Crop area	1.938,02	1,73
9	Swamp forest	871,88	0,78
10	Schrub	3.029,40	2,71
	Total	111.972,57	100

Ujung Kulon NP has an essential role in the surrounding community, which is a buffer zone. Agriculture, plantations, and tourism are one of the uses of the area by the surrounding community. The RF algorithm detected the presence of agricultural areas within the UKNT area with an area of about 1,938.02 ha (Table 5). This agricultural expansion should not occur in conservation forest areas, given the importance of maintaining the ecosystem function of the national park. This is in accordance with the research of Wandani et al. (2022), which explains that

1,556.82 ha of community-owned farms are located in eight (8) resorts in UKNT. This is due to the increasing number of residents in the administrative villages surrounding the national park, thus triggering continued dependence on UKNT resources. The same thing happened to Meru Betiri National Park because the uncertainty of the community's income around the national park triggered illegal forest destruction (Harada et al. 2015). Davergne (1994) also describes the results of a World Bank investigation of deforestation, whose leading causes are land clearing for agriculture, commercial logging, firewood collection, and animal husbandry. Previously, in Dwiyahreni et al. (2021A) explained that access and community activities that were too intense contributed to a 10.5% decrease in forest area in the UKNT-protected area for the period 2012 - 2017. et al. 2021B).

4.2.2. LULC classification based on resort division

According to the Regulation of the Directorate General of KSDAE-KLHK, Ujung Kulon National Park, in the area's management, is divided into several resorts. This national park has 14 resorts as a processing unit with the smallest area. The LULC classification covers all resorts in UKNT and provides an overview of the land cover dynamics at each resort. Li et al. (2017) explained that spatial information regarding changes in LULC is one indicator that can assess the effect of human interaction with the environment. Therefore, any differences in the composition of LULC in each resort are indirectly influenced by the landscape as well as the dynamics or accessibility of the surrounding population (Davergne 1994; Carr 2009; Carr et al. 2005).

Each resort has six resorts, namely Legon Bajo, Peucang Island, Legon Pakis, Cibunar, Karang Ranjang, and Handeleum Island, which are dominated by bodies of water (Figure 9). Meanwhile, the other six resorts, namely Kalejetan Resort, Ketapang, Ranca Pinang, Cibadak, Padali, and Taman Jaya, are dominated by primary forest and the remaining two resorts are mixed forest (Figure 9). The difference in the dominance of the LULC class between these resorts occurs because five of the 14 resorts do not have water areas. These five

resorts are located in the mountainous area of Mount Honje and are directly adjacent to community-owned land. These five resorts also get a strong influence from community activities around the national park's boundaries. In addition, two other resorts influence human activities in the vicinity. This influence can be seen from the expansion of agricultural land that occurred at Legon Pakis Resort (260.62 ha), Tamanjaya Resort (168.59 ha), Ketapang Resort (182.77 ha), Kopi Resort (77.97 ha), Padali Resort (115.84 ha), Resort Cibadak (205.34 ha), Resort Ranca Pinang (143.25 ha). Therefore, the expansion of community-owned agriculture within the UKNT resort area should not occur. Given the essential function of the area to be protected from forest destruction activities. In addition, several big cats make this area a habitat, so it is considered very prone to conflict with farmers on agricultural land in the UKNT forest area (Gunawan et al. 2017).

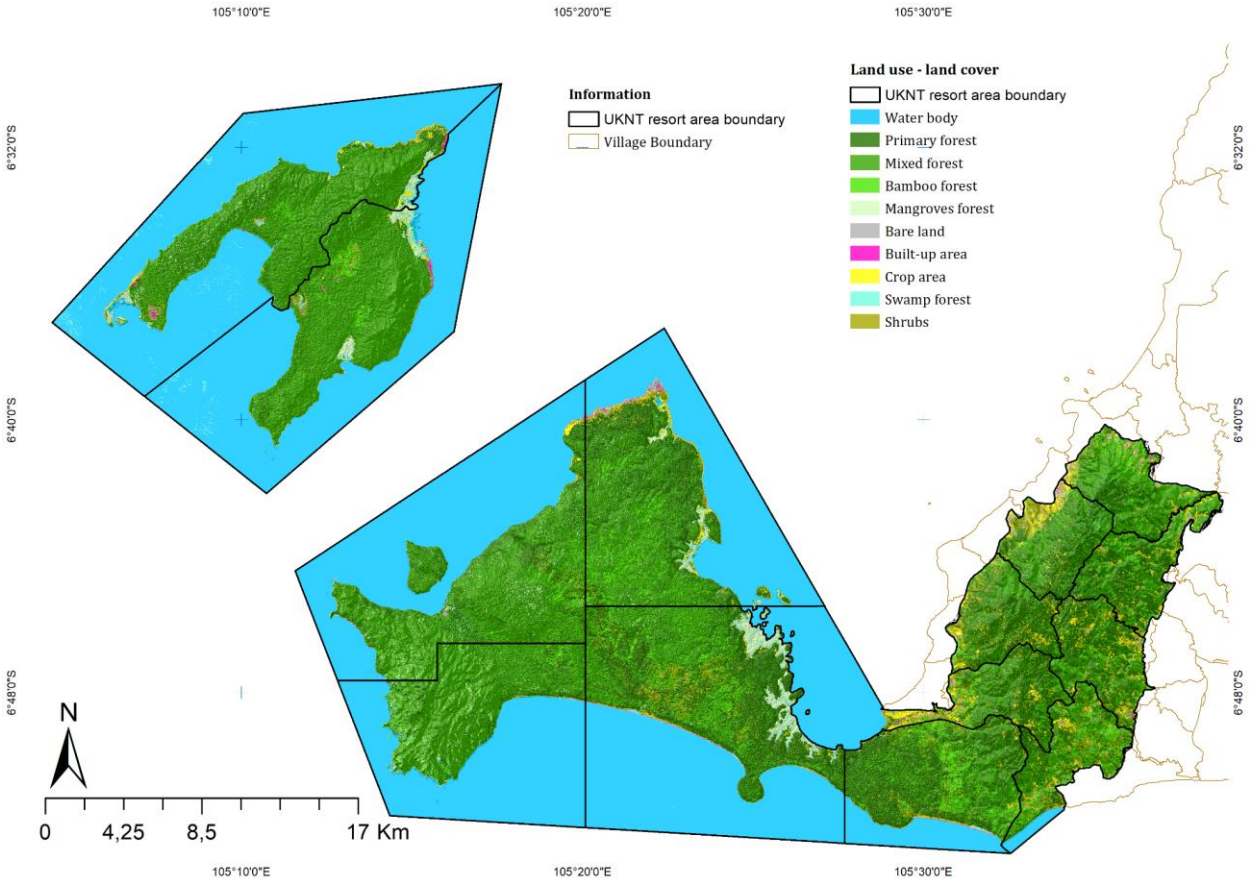

Figure 8. LULC classification results

The other LULC classes have distribution in each resort, although they have a slightly smaller composition. Open land, for example, only has about 0.53% of the total area and is more widely distributed in Resorts Ranca Pinang (84.13 ha), Kopi (83.32 ha), Ketapang (73.67 ha). This open land class is characterized by the presence of an artificial grazing area created by UKNT to assist in monitoring herds of banteng (Bos javanicus). This can be seen in Figure 6, part D, which depicts one of the pastures in the P. Handeleum Resort. In addition, open land is associated with shrubs scattered in Resort H. Handeuleum and is a former area affected by the tsunami in 2018. It was previously known that this area was prone to tsunami activity that damaged stretches of coastal forest (Widiyanto and Hsiao, 2020; Widiyanto et al., 2020). Borrero et al. (2020) explained that, the impact of tsunami activity as high as 10 meters hit the coastal forest as far as 400 meters into the interior of the UKNT coastal forest area.

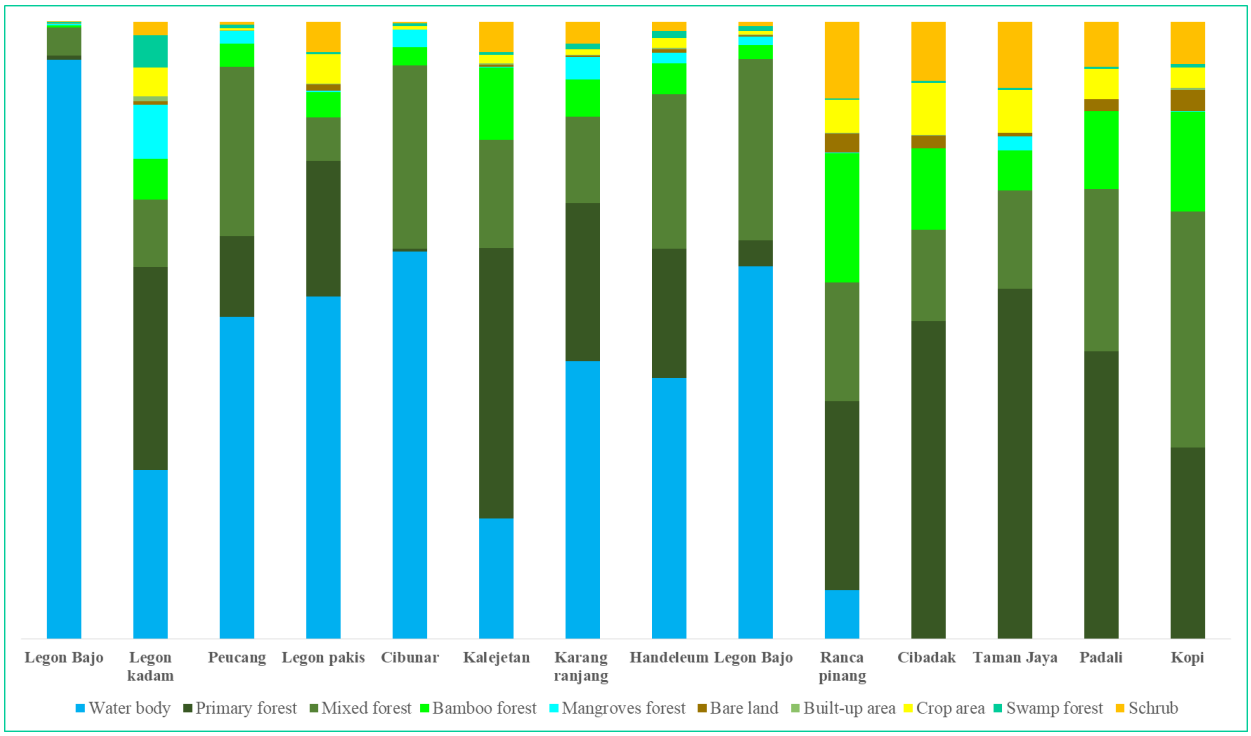

Figure 9. LULC based on UKNT's resorts

Meanwhile, another study revealed that UKNT, within 60 km of the tsunami epicenter, destroyed coastal forests along the coast of Panaitan Island and as far

as 200 meters inland (Muhari et al., 2019). In addition, it is essential to note that the impact of the damage caused by this tsunami is threatening the habitat and existence of endangered animals in the world, namely R. sondaicus (Setiawan et al. 2017). The field survey conducted by the author shows that this area is an expanse of heath forest and overgrown with shrubs and shows natural forest succession activities. This is different from the built-up area, which is the smallest LULC class and has an area of about 0.13% of the total area. The area spread throughout the resort ranging from 3 - 29 ha. This LULC class is known to have a distribution in the Legon Pakis Resort area of around 7.32 ha. It is connected to access roads belonging to rural communities along the west coast of Ujung Jaya Village, Pandeglang Regency.

Spatial information on the distribution of LULC at each resort is beneficial for managing national parks in strategic conservation plans at the resort level (Galicia and García-Romero 2007). The roles and functions of knowing the LULC information include information on the distribution of vacant land for banteng grazing land, primary forest integrity as a habitat for herbivores and big cats, mixed forest expanses for feed corridors, mangrove forests and swamps for conservation of aquatic animals, built-up land and agriculture for mitigation. Wildlife conflicts, and so on. In addition, the resort-level LULC class information provides an overview of the changes in LULC in this national park. By extracting spatial information, it can also provide an overview of deforestation activities in UKNT in each particular period and changes due to being affected by other natural disasters. In its development, UKNT has experienced various natural disasters, such as forest fires which are thought to be caused by the existence of a peat dome on Panaitan Island and the impact of the tsunami waves along the coast of Handeleum Island.

4.2.3. Classification Result Accuracy

The LULC classification generally provides spatial information that should require further testing for accuracy. This is used to test the accuracy of the classification

results to provide spatial information that can be used reliably by users. This accuracy was tested using the Overall Accuracy (OA) and Kappa Statistics (KS) formulas and obtained values of 80.08% and 0.78, respectively. A total of 231 field validation data were tested in this accuracy assessment to get the Substantial class (according to Table 3). Meanwhile, according to Scepan (1999), the best accuracy value can be seen from the OA value, which reaches 85%, so the OA value generated from the study does not reach the limit value. This is due to the discrepancy between the classification results and the validation data, which is 46 data. This proves that further studies are needed regarding this method to produce the best accuracy value (including being able to exceed 85%) in classifying LULC with high heterogeneity. In addition, an evaluation of index involvement needs to be carried out, considering the different capabilities of each index and assessing its contribution to the classification process through variable importance analysis (Figure 7).

4.2.4. Classification Problems: Index Assessment and Classification Process

Based on the classification results, seven (7) resorts should not have agricultural land but are classified as having agricultural land. This is a misclassification that occurred, so this spatial information needs improvement. This is defined because agriculture is easy to identify in the area division in UKNT, while the other LULC classes cannot be identified directly. Almost all LULCs have distribution in all resorts. However, some classes of LULC should not have distribution in any of the resorts. For example, agriculture and mangrove forests are LULC classes that are not spread throughout the resort.

Meanwhile, swamp forests and built-up land require further investigation by verifying the classification results and comparing them in the field. This is due to the construction of offices or supporting operational facilities for conservation and tourism activities at every resort in UKNT. Therefore, the built-up land class is found in all resorts in UKNT. In the case of mangroves, this study found 1,897.88 ha, whereas in previous studies, the area of mangroves in this national park was 547.34

ha (Asy'Ari et al., 2022. This is considered necessary for an evaluation of the LULC classification process. In the same case, the classification process should be carried out at each resort by considering the representation of the LULC class to reduce the influence of the LULC class, which should not be in its area.

The combination of index algorithms in this analysis provides an overview of one of the causes of misclassification. We have included several indices considered to have a significant contribution opportunity, evident in Figure 7. 11 indices were involved in classifying 9 LULC classes and were assessed to be highly heterogeneous. Figure 7 has proven the contribution of these 11 indices in assisting the RF classification algorithm in classifying 9 LULC classes in UKNT. Starting from the ANDWI index is the highest index, with a contribution of 14.10%, the LSWI index has the lowest contribution value of 5.06%. In addition to the index, insufficient training data is also considered to influence the classification process. This is a challenge for research on LULC classification in large-scale primary forest areas due to difficult access to LULC classes that will be used as training data.

Every surface of the earth, specifically the LULC class, has a threshold value when viewed from the point of view of the characteristics of the index algorithm (Aprilianti et al. 2021). There are several indices involved that have the same characteristics between more than one LULC class. This occurs in the LULC class between shrubs and agriculture and between built-up and open land. In some resort locations, a LULC class should not exist. For example, the agricultural LULC class at Resort Karang Ranjang, P. Handeleum, P. Peucang, Cibunar, Legon Kadam, and Legon Bajo. The six (6) resorts should not have the distribution of agricultural land because community access is difficult and far from community villages. This also occurs in the LULC class of built-up land identified along the north to the west coast of Resort P. Handeleum. The entire class spread on the former tsunami's coast in several heath forest locations. This causes the classification algorithm to experience errors in interpreting the earth's surface and provides inappropriate spatial information. This is caused by the high heterogeneity in the

forest landscape, so the classification algorithm experiences confusion in the decision-making process (Ghimire et al., 2010).

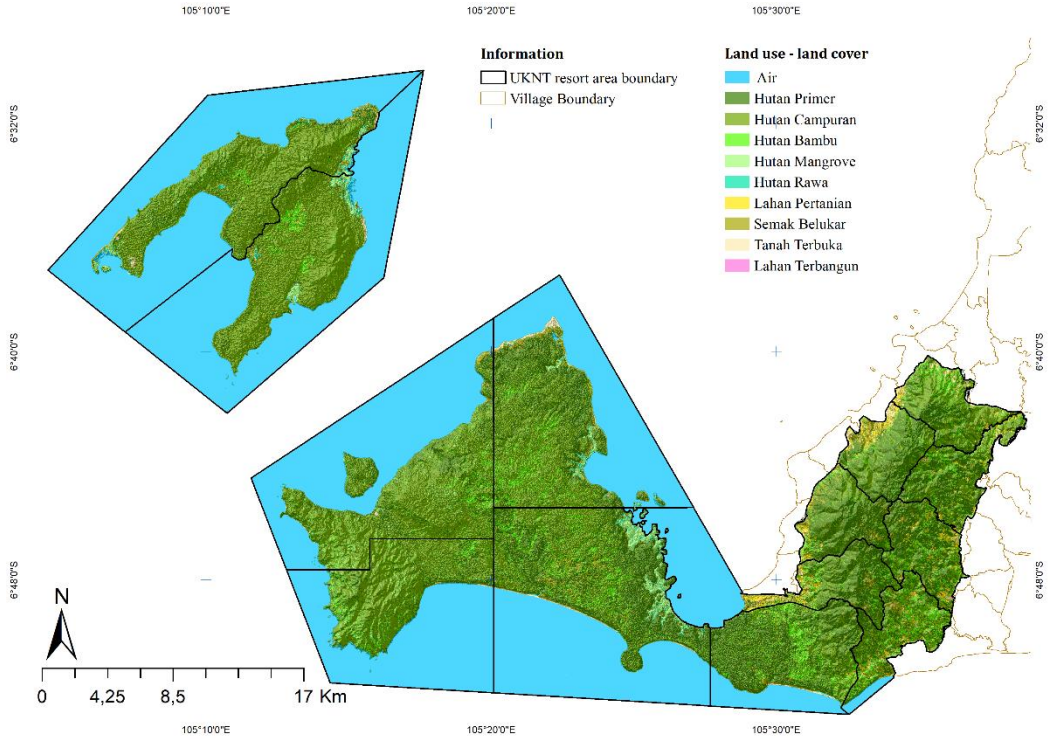

Figure 10. Spatial distribution of improved LULC

Table 6. LULC class area

LULC Class	Area (ha)	Percentage (%)
Water body	494,64	44,74
Primary forest	218,04	19,72
Mixed forest	257,61	23,30
Bamboo forest	57,68	5,22
Mangroves forest	18,34	1,66
Bare land	7,13	0,64
Built-up area	0,11	0,01
Crop area	7,22	0,65
Swamp forest	4,43	0,40
Schrub	40,42	3,66
Total	1105,61	100,00

The heterogeneity of the forest landscape in UKNT affects the indexes' involvement in the classification process. This is identified at the time of selecting which indices to include. The level of landscape heterogeneity influences the classification process (Qu et al. 2021), so researchers must be careful in classifying.

Ghimire et al. (2010) also revealed that this is a challenge in the LULC classification process due to the high intra-class variability and heterogeneous landscape artifacts. The index's ability to assess the earth's surface or distinguish each earth's surface based on its pixel value is one of the most critical reasons before starting the classification process. Therefore, this error requires further investigation into the cause of this misclassification to prove confidence in the resulting accuracy. This was also carried out to test the ability of the RF classification algorithm to classify in high heterogeneity landscapes, which previously had better capabilities than the Support Vector Machine algorithm (SVM; Pal 2005; Gislason et al. 2006; Belgiu and Dragut, 2016).

To ensure the suitability of the classification results, the improvement of the RF classification results is carried out in the ArcMap software. Improvements to the LULC class take precedence over the LULC class which should not have distribution across multiple locations. There are four classes of LULC whose distribution is improved, namely swamp forest, water bodies, agricultural land and built-up land. The results of the spatial and extensive LULC improvements are presented in Figure 6 and Table 6. Although spatially there is no visible change, the change in land area value is very important in the LULC classification. Spatial information from the results of this improvement can then be used in further research to make policy decisions.

4.3. Forest cover distrubace in Ujung Kulon NP

The threat of forest destruction has haunted or even occurred for Ujung Kulon NT, with various dynamics of different land use. There are two threats that have occurred in this national park, namely threats from human activities and natural disasters. In 2018 there was a tsunami due to volcanic activity from Mount Anak Krakatau which had damaged coastal forests in the west. In addition, the threat of deforestation due to human activities in the Mount Honje area such as agriculture, plantations, to grazing has been in the forest area of the national park. This can be seen clearly in the following image the results of the identification of forest land cover changes in Ujung Kulon NT.

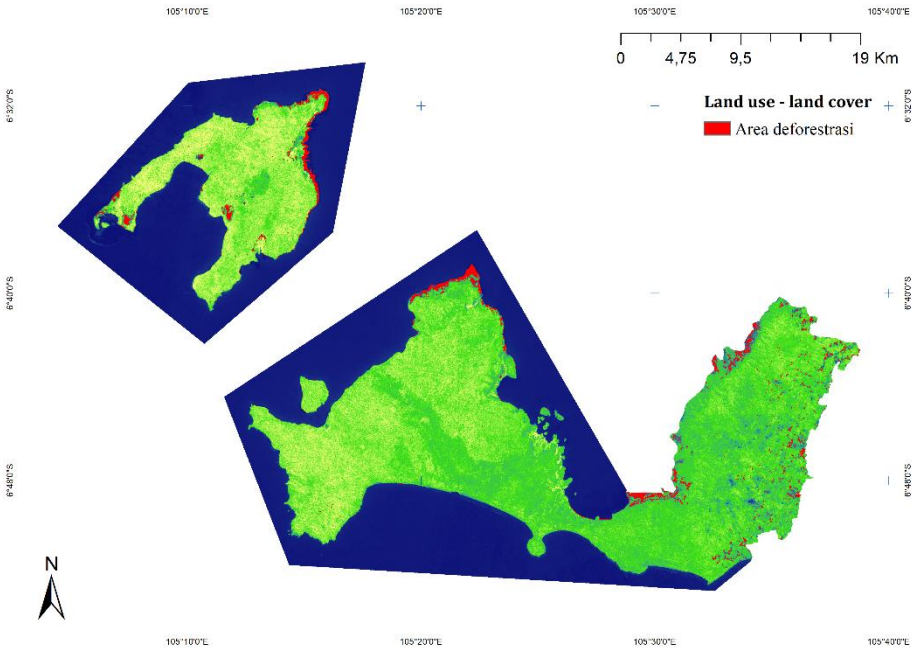

Figure 11. Forest damage in UKNT

4.4. Impact of Tsunami at Ujung Kulon NP

Development of a land cover change detection model, especially for mangrove landscapes that are on the boundary in Ujung Kulon NP. Testing this detection model involves 21 indices consisting of the type of vegetation index, water index, and mangrove index. This development model was made to streamline the process of detecting the impact of disasters that existed in previous studies, which still used differences in land cover and used a classification method. In this model, only two index data are used, namely, the pre-tsunami and post-tsunami indexes. These two data are calculated to obtain data on significant changes in index values and indicate areas affected by the disaster. Testing the significance of the detection model was carried out using a statistical approach using a paired t-test. This test is able to show the index value of those that have experienced significant changes and show areas of change. Model development and test results for the 21 indices are presented in the following two figures.

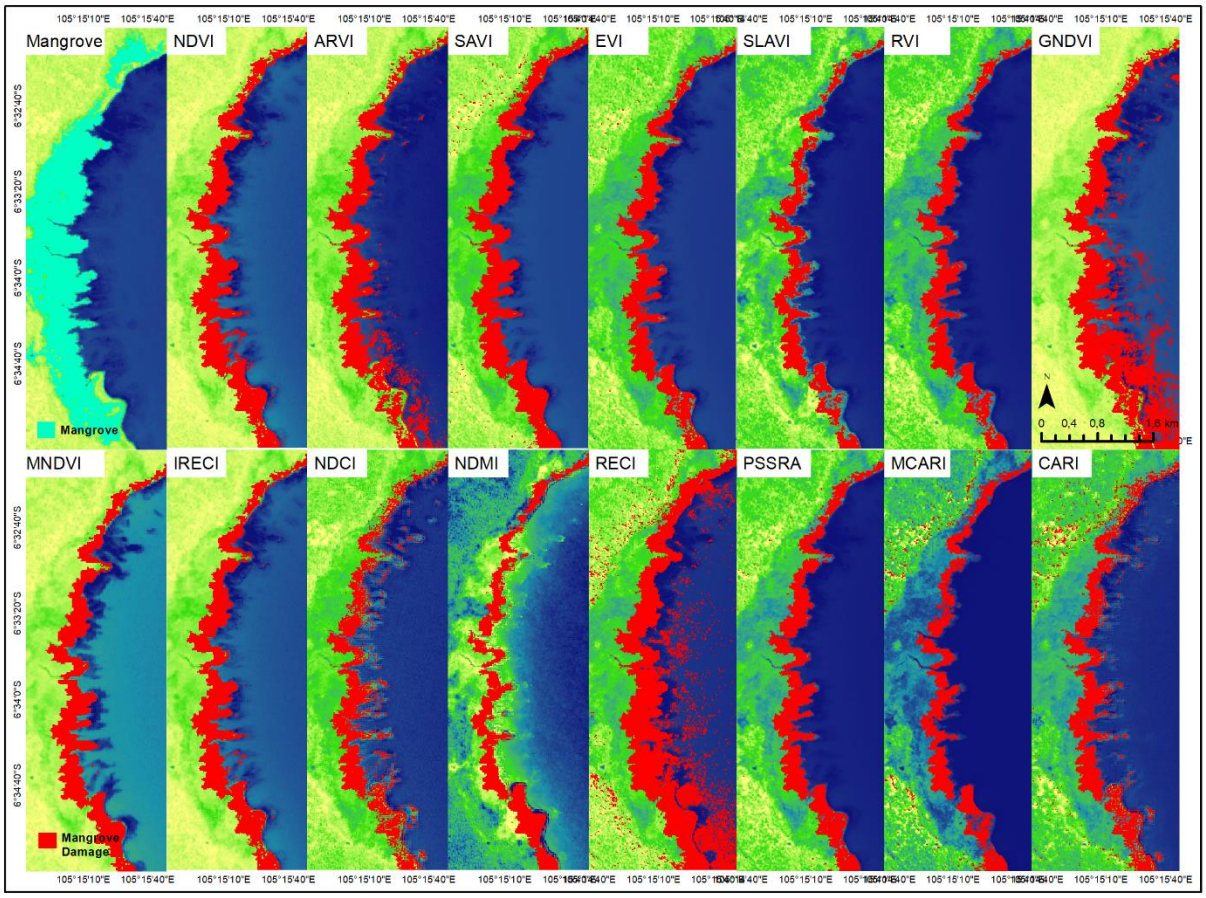

Figure 12. Testing on several indexes

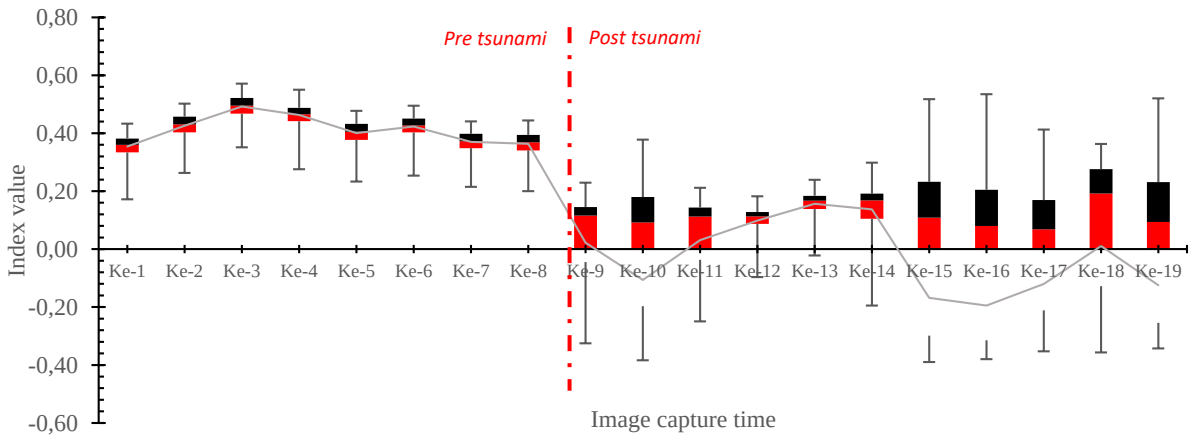

Figure 13. Index value characteristics: pre-tsunami and post-tsunami

V. Conclusion and Recommendation

This study succeeded in mapping LULC in Ujung Kulon National Park (UKNT), which has a high level of heterogeneity. This is used to support the conservation of the

Javan rhino at UKNT. The compactness of 11 indexes through the random forest algorithm produces 10 LULC classes and shows that water bodies have the most significant percentage of the area and the least amount of built-up land. In this case, the high level of heterogeneity causes disruption of the LULC classification process so that the accuracy values only reach 80.08% (OA) and 0.78 (KS). This condition creates a classification error that requires classification correction before the spatial information dissemination of the LULC data is carried out. Therefore, the combination of the index, training data, classification algorithm (RF), and determination of the classification area is considered to need further evaluation to solve the confusion in research on this topic. It is hoped that this research will become a reference material for further research and consideration for UKNT managers.

These 10 LULC classes show the distribution of areas experiencing deforestation. Deforestation occurs naturally as a result of natural disasters and there is also the result of land conversion into agriculture, plantations, and community settlements around the forest. Natural disaster areas are detected using a model based on 21 test indices to produce appropriate index recommendations. This natural disaster was caused by a tsunami that occurred in 2018 from the direction of Mount Krakatau.

Testing this detection model is still in the model development stage, involving statistical tests. This model is expected to be a recommendation model for detecting the impact of the tsunami natural disaster on mangrove forest areas for local governments, especially for national park managers.

Acknowledgments

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Final Report

Estimating the Carrying Cappacity of the Pollution Load in Citarum River, West Java, Indonesia

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Executive Summary

River is one of the most important natural resources in the world. In developing countries, population growth has a positive impact on increasing built-up land, especially settlements and industry. Built-up areas also increase the risk of erosion entering water bodies and producing sedimentation. The high use of agricultural fertilizers has an impact on the flow of nutrients to water bodies which are at risk of increasing eutrophication. If not managed properly, water quality will decrease and the development of algae and water hyacinth will increase. This condition will make river ecosystem services not optimal. Citarum is the third biggest river in Java Island. In 2018, no less than 20,000 tons of waste and 340,000 tons of wastewater, mostly from 2,000 textile factories, are disposed directly into the once clear and pristine waterways of the Citarum River every day. In 2018, the government launched a revitalization program for the Citarum River, named Citarum Harum. To see the performance of the program, it is necessary to monitor water quality and calculate pollution load capacity frequently.

Water quality and pollution load capacity in the Citarum Hilir River show a significant increase in 2022. This can be seen from the decrease in several water quality parameters such as BOD, COD, and TSS at the study site. The "Citarum Harum" revitalization program initiated by the central government in 2018 is estimated to be one of the factors that has made the water quality in Citarum Hilir increase. The military involvement in river revitalization makes the river cleaning process more effective. This program also changed the mindset of the community to participate in protecting the environment and avoiding throwing garbage in the river.

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I. Introduction

1.1. Background

River is one of the most important natural resources in the world. Rivers are able to provide various types of ecosystem services for the community, both as water providers, food, habitat, water quality regulators, air temperature reducers, recreational service providers and research sites (Khan et al., 2019). These various ecosystem services show that rivers are able to support human life from environmental, social and economic aspects. Therefore, environmental degradation in river ecosystems can bring harm to humans and the surrounding environment. Hydrological disasters, infectious diseases, loss of biodiversity, and loss of recreational sites are some of the impacts of not being managed properly by rivers. There are several factors that can encourage the degradation of inland freshwater ecosystems (Chen et al., 2017).

In developing countries, population growth has a positive impact on increasing built-up land, especially settlements and industry (Sejati et al., 2018). Pollutants produced from industrial and household activities can flow into water bodies such as rivers, lakes, and the sea. Built-up areas also increase the risk of erosion entering water bodies and producing sedimentation (Spalevic et al., 2020). In addition, the high demand for food makes agricultural land also increase. The high use of agricultural fertilizers has an impact on the flow of nutrients to water bodies which are at risk of increasing eutrophication. If not managed properly, water quality will decrease and the development of algae and water hyacinth will increase (Spears et al., 2022). This condition will make river ecosystem services not optimal.

One of the most polluted river in Indonesia is Citarum River. Citarum is the third biggest river in Java Island. The river is about 270 km long flowing across an area 6614 km2 from Situ Cisanti, Bandung in the upstream to the downstream at Bekasi (Zakia et al., 2019). In 2018, no less than 20,000 tons of waste and 340,000 tons of wastewater, mostly from 2,000 textile factories, are disposed directly into the once clear and pristine waterways of the Citarum River every day. There are various activities, domestic and non-domestic, in the watershed and surroundings tributaries of this river (Idris et al., 2019). It is not uncommon to find large amounts of waste in the mainriver and tributaries of the Citarum. These cause Citarum become the world's most contaminated river, according to a WHO statement.

In 2018, the government launched a revitalization program for the Citarum River, named Citarum Harum. This program was created due to the bad predicate given to the river. This restoration program involves the TNI (Indonesian National Army) as the main actor through the Citarum Harum Program. Under the command of the military command of Siliwangi III, West Java, this program became a breakthrough in Indonesia where the TNI participated in carrying out environmental restoration programs. Several stakeholders claim that Citarum Harum has given tangible results in improving river water quality (Ayyasy et al., 2021). This can be seen in the disappearance of piles of garbage at several points on the Citarum River that previously existed (Idris et al., 2019). To see the performance of the program, it is necessary to monitor water quality and calculate pollution load capacity frequently.

Pollution Load Capacity (PLC) is a calculation of the maximum number of pollutants that can be accommodated by a water body. This calculation aims to keep the quality

standards and allocation of pollutants amount that can be received by water bodies from pollutant sources (Singh et al., 2020). Thus, the river water quality does not exceed the the proposed designation. In Indonesia, the results of the PLC study can be used for spatial planning and in general for the formulation of water pollution control policies (PCP). Water Pollution Load Capacity in Water Sources is determined using the QUAL2E software. QUAL2E is a program that can calculate the load carrying capacity of pollution. The QUAL2Kw program used in this study is an upgraded version of the QUAL2E program.

1.2. Objectives

The purpose of the study was to obtain information on pollutant sources, both point sources and non-point sources that enter the watershed and obtain information on the amount of pollutant load that permitted to be discharged into the river or the number of pollution load carrying capacity in the Citarum River.

II. Literature Review

2.1. Citarum River

The Citarum River is one of the strategically valuable rivers on the island of Java. Citarum is the biggest river in West Java (Hidayat et al., 2022). The river is about 270 km long flowing across an area 6614 km^2 from Situ Cisanti, Bandung in the upstream to the downstream at Muaragembong, Bekasi (Kurniawan et al., 2019). This river flows across administrative areas in West Java such as Bandung Regency, Purwakarta Regency, and Karawang Regency Citarum River is vital for the 25 million people who daily depend on it for agriculture, water, and electricity. There are three big reservoirs cascading along the river, namely Saguling Reservoir, Cirata Reservoir, and Jatiluhur Reservoir (Zakia et al., 2019). Based on its ecosystem service, the Citarum River has all the functions of ecosystem services, such as providing water and energy, regulating water systems from flooding and pollutants, supporting irrigation for agricultural activities, and having cultural functions for both recreational and research activities.

The development in the Greater Jakarta (Jabodetabek) and Greater Bandung (Bandung Raya) areas has a significant influence on land use changes in the Citarum watershed. This has an impact on the condition of the Citarum River which continues to experience pollution due to agricultural, residential and industrial activities (Idris et al., 2019). In 2018, no less than 20,000 tons of waste and 340,000 tons of wastewater, mostly from 2,000 textile factories, are disposed directly into the once clear and pristine waterways of the Citarum River every day. There are various activities, domestic and non-domestic, in the watershed and surroundings tributaries of this river. It is not uncommon to find large amounts of waste in the mainriver and tributaries of the Citarum (Zakia et al., 2019). Based on the research results, the composition of waste in the Citarum River is dominated by plastic wrap and styrofoam (Hidayat et al., 2022). This shows that in the Citarum watershed, household waste management is still very poor. This has the potential to make the Citarum River an entry point for waste to the Java Sea. These causes Citarum become the world's most contaminated river, according to a WHO statement in 2017.

The poor environmental conditions and water quality in the Citarum River have prompted the central government to make many programs to restore the river. The Citarum River restoration program was initiated in 1989 through Prokasih (Clean River Program) activities. The government also continues to run similar programs with different time periods. However, this has not succeeded in improving the condition of the Citarum River. When the Citarum was "crowned" as the dirtiest river in the world in 2017, the Indonesian president issued Presidential Regulation Number 15/2018 concerning the Acceleration of Pollution Control and Damage to the Citarum River. Unlike previous programs, this restoration program involves the TNI (Indonesian National Army) as the main actor through the Citarum Harum Program. Under the command of the military command of Siliwangi III, West Java, this program became a breakthrough in Indonesia where the TNI participated in carrying out environmental restoration programs. Previously, military involvement had also been carried out by other countries such as India and the United States in forest and river restoration efforts (Ayyasy et al., 2021).

Fridayani (2020) stated that from 2001 the government has tried to clean up the river starting from upstream to downstream with various program names. The last program that was echoed in 2013, the Citarum Clean, Healthy, Beautiful and Lestari Movement (Bestari)

missed the prestigious target. The hope, in 2019, Citarum River water can be drunk. However, until now the quality has not met the water quality standards that have been set, so it is not possible to consume. The recovery of the Citarum River itself already has a roadmap or road map that is contained in strategic interventions per location with short-term (2010-2015), medium-term (2016-2020), and long-term (2021-2025) targets.

The Citarum roadmap has identified dozens of projects that are constantly being updated to be implemented. However, related to the achievements of the program so far there has not been a comprehensive study. Beginning in 2018, the Citarum improvement scheme was re-coined. The Citarum Harum Program joins the issuance of Presidential Regulation No. 18 of 2018 concerning the Control of Citarum Watershed Pollution. The Presidential Regulation regulates the scope of duties and authorities of the agencies involved as well as the legal basis for the restoration of the Citarum River. This program is claimed to be more integrated than before with a target of seven years Citarum problems can be resolved divided into three stages namely upstream, middle and downstream.

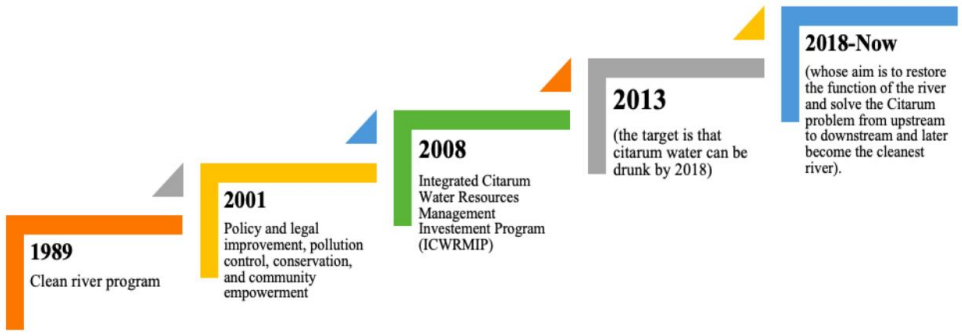


Figure 1. Roadmap of Citarum River (Fridayani, 2020)

2.2. Water Quality

The high level of population and anthropogenic activities in watershed will have a negative impact on water quality in aquatic ecosystems. River water quality is one of the indicators in SDG number 6. Land degradation has a significant impact on changes in river ecosystems in urban areas (Wei et al., 2020). Built-up land in urban areas is one of the important components that have an impact on decreasing water quality. The existence of point source and non-point source pollutant sources originating from industrial, household, and service/trade activities can have a direct or indirect impact on the urban lakes ecosystem. Total phosphorus (TP) and total nitrogen (TN), dissolved oxygen, and pH are some of the parameters commonly used to assess water quality (Sremački et al., 2020). If not managed properly, water bodies in urban areas will have a negative impact on human health (Namugize et al., 2018).

The water quality assessment method that is often used is the water quality index (WQI). This method is able to estimate the quality of the lake in general by using several selected parameters. Parameter selection is one of the important aspects in using this method. In general, water quality parameters can be grouped into several types, namely physical, chemical, and biological parameters. In detail, the grouping can be re-specified into physical components, oxygen depletion, nutrients, heavy metals, metals and minerals, and microbiology. Differences in freshwater ecosystem conditions in one location with other

locations make the selected parameters vary according to ecosystem conditions (Gradilla-Hernández et al., 2020). This method is widely used in freshwater ecosystems that have been degraded due to anthropogenic activities.

Water quality has an important role for the sustainability of a freshwater ecosystem. Poor water quality will have an impact on people's lives (Chandra et al., 2019). Determination of water class is something that is crucial to know at what level the water quality in a location is located and the use of water that can be utilized for the community. Class 1 water quality indicates the condition of water that can be used for all purposes ranging from drinking water, tourist attractions, agricultural irrigation, and livestock. Class 2 water quality can be used for tourist attractions and irrigation. Class 3 water quality can be used for water needs for livestock and agriculture. Class 4 water quality can only be used for agricultural irrigation (Effendi et al., 2018).

Water quality can be a key variable to support other environmental, social, and economic aspects of river ecosystems. Water quality can be an indicator of biodiversity in river ecosystems. Several studies have stated that the loss of river aquatic species is caused by deteriorating water quality in urban areas (DKI Jakarta Provincial Environment Agency, 2019; Sirait et al., 2018). The loss of biodiversity will have an impact on the imbalance in the limnic ecosystem. Water quality also has an important role in the economic function of river ecosystems. Poor river water quality will reduce tourism potential, especially for water sports activities. The provision of food sources in the form of fish can also decrease if water quality parameters (especially DO) deteriorate.

Several studies have observed the relationship between water quality in freshwater ecosystems and visitors' willingness to pay (Silva et al., 2022). The results reveal that the decline in the ecosystem has an impact on the decrease in WTP generated by the respondents. This shows that a decrease in the environmental quality of freshwater ecosystems can affect the economic sustainability of these ecosystems. Based on Presidential Decree 59/2017, river water quality is one of the indicators in SDG number 6 (Ensuring Availability and Management of Clean Water and Sustainable Sanitation). At the provincial level, this indicator has a target for water quality management, both in rivers, reservoirs, lakes, lakes, river mouths, beaches, including improvements to the hydrological monitoring system and water quality with indicators of improving water quality in 15 lakes and 5 river areas.

2.3. Pollution Load Capacity

According to Government Regulation No. 82 of 2001, the carrying capacity of the pollution load is the ability of water in a water source to receive input from the pollution load without causing the water to become polluted. Furthermore, the carrying capacity of the pollution load is defined as the ability of water in a water source or body of water to accept the burden of pollution without causing the water to become polluted (Minister of Environment Decree No. 110 of 2003).

The study of the calculation of the pollution load capacity (PLC) as the basis for allocating the pollution load was carried out using the key parameters of water quality in the river which included BOD. Considering that these key parameters can show a general picture of river water quality levels for various uses, the water quality standard used in this study is

the Class II water quality standard based on Government Regulation no. PP 2021 Appendix VII. This calculation uses the Qual2Kw water quality model (Version 5.1).

The Qual2Kw model also pays attention to climatological conditions and morphological characteristics as well as river systems so that this model is better for modeling water quality and can be used to determine Pollutant Load Capacity in a river (MoEF, 2010). The model, which is operated in Microsoft Excel and with the VBA (Visual Basic for Application) programming language, utilizes point source pollution data (Pelle-tier, 2005). Non-point source pollution data is less representative for this model but is still used as a consideration for drawing conclusions (Abdi, 2011). Furthermore, the data on the distribution of river water quality from the monitoring results in the field is compared with the estimated distribution of water quality data obtained from the modeling process to test whether the modeling results are similar to the monitoring data or not. If there is no similarity (the model is rejected), then adjustments are made through the calibration process repeatedly until the most similar results are obtained (the model is accepted).

III. Methodology

3.1. Data Collecting

Data collecting consists of primary data and secondary data. Primary data was obtained from field observations while secondary data was obtained from government agencies and research reports that had been carried out previously. The data needed in this study can be seen in **Table 1**.

Table 1. Research data

No	Data	Type of Data	Source
1	Water quality (BOD, COD, TSS, DO, Turbidity, pH, Temperature)	Primary	Field survey (in situ data collection)
2	Non-point source pollutant in downstream area of Citarum Watershed	Secondary	Data projection from previous study
3	Point source pollutant in downstream area of Citarum Watershed	Secondary	Ministry of Environment and Forestry
4	Land use map	Secondary	RBI map, Geospatial Information Agency
5	Topographic map	Secondary	Ministry of Environment and Forestry
6	Meteorological, climatological, and hydrological data	Secondary	Ministry of Environment and Forestry

In-situ data collection was carried out at 8 sampling points that represented the overall condition of the study location. The water quality parameters for in situ data collection can be seen in the **Table 1** while some parameters analyzed in the laboratory. Water samples at 8 sites were collected and located with a Global Positioning System (GPS) receiver. The samples were taken at a depth of 30 cm using a Van Dorn water sampler (Alpha Bottle Kit - 2.2L Horizontal, Wildco, Yulee, FL, USA), preserved in 1-L cleaned, dark-colored bottles, and then refrigerated.

3.2. Calculating Total River Pollution Load

The materials needed in this research are some data, including:
a) Potential household pollution load (data on population in each sub-watershed)
b) Potential pollution load from livestock (Number of livestock in each sub-watershed)
c) Potential pollution load from agriculture (area of agricultural land in each sub-watershed)
d) Potential pollution load from hotels and hospitals (number of hotel rooms and hospital beds in each sub-watershed)
e) Potential pollution load from fisheries (number of fish kept in cages in each sub-watershed)
f) Potential pollution load from waste (population multiplied by potential waste in each sub-watershed)
g) Potential pollution load from Small-Scale Enterprises (number of soybean and tapioca processing industries in each sub-watershed)

h) River physical and biophysical data
i) River's spatial plan
j) Water balance data
k) Water quality data consisting of: pH, dissolved oxygen, TSS, fecal coli, coliform, BOD, COD, iron, zinc, ammonia, nitrate, phosphate, mercury, manganese, sulfate, and nitrite.

The total potential pollution load in the watershed is the sum of the pollution loads from institutional sources, households, livestock, agriculture and waste, each of which is calculated per sub-district. The total potential load of water pollution is calculated by the following formula:

Total River Pollution Load = Institutional Load + Household Pollution Load + Livestock Pollution Load + Agriculture Pollution Load + Hospital Pollution Load + Hotel Pollution Load + Fishery Pollutant Load + Pollutant Load from Garbage + Pollutant Load from small scale enterprises

The detailed calculation of total river pollution load will be explained in progress report. Data of potential pollution load in each sector and administrative area will be obtained from secondary data.

3.3. Water Quality Sampling

Water quality sampling was held in certain points covering each segment of the study area, Sampling was conducted in dry season (May 2022). Water quality parameters analyzed are chemical and physical parameters. The chemical parameters analyzed were pH, DO, BOD, and COD, while the physical parameters analyzed were temperature, turbidity, and TSS. The analytical method or tool used for the analysis of each chemical and physical parameter is equipped with quality standards based on Government Regulation No. 22/2021 concerning water quality management and water pollution control and their units are shown in **Table 2**.

Table 2. Analyzed Water Parameter based on Government Regulation No 22/2021

No.	Parameters	Methods	Unit	Water Pollution Categories (*)			
				I	II	III	IV
Physical Parameters							
1.	Temperature *)	SNI 06-6989.23-2005	◦C	Dev 3	Dev 3	Dev 3	Dev 3
2.	TSS *)	SNI 06-6989.3-2004	mg/L	40	50	100	400
Chemical Parameters							
3.	pH *)	SNI 06-6989.11-2004		6.0-9.0			5.0-9.0
4.	DO	Winkler Modf	mg/L	6	4	3	1
5.	BOD *)	SNI 6989.72:2009	mg/L	2	3	6	12
6.	COD *)	SNI 6989.2:2009	mg/L	10	25	40	80

3.4. Estimating River Pollution Load Capacity and Pollutant Load Allocation

In calculating the river's PLC using Qual2kw software, several work steps were carried out, such as determining river segments and collecting river length data in each segment to the distance of each segment. The distance of each segment is calculated from the downstream of the river. Water quality data for each segment is also input into the

program. BOD is one of common used water quality parameter in PLC study (Nugraha et al., 2022). In addition to water quality data, the Qual2Kw program requires inputting climatological data such as dew point, temperature, wind speed, cloud cover, and topography and vegetation shade. River water quality data that is input into the program not only comes from point sources but also from non-point sources. The flow diagram of this analysis can be seen in **Figure 2**.

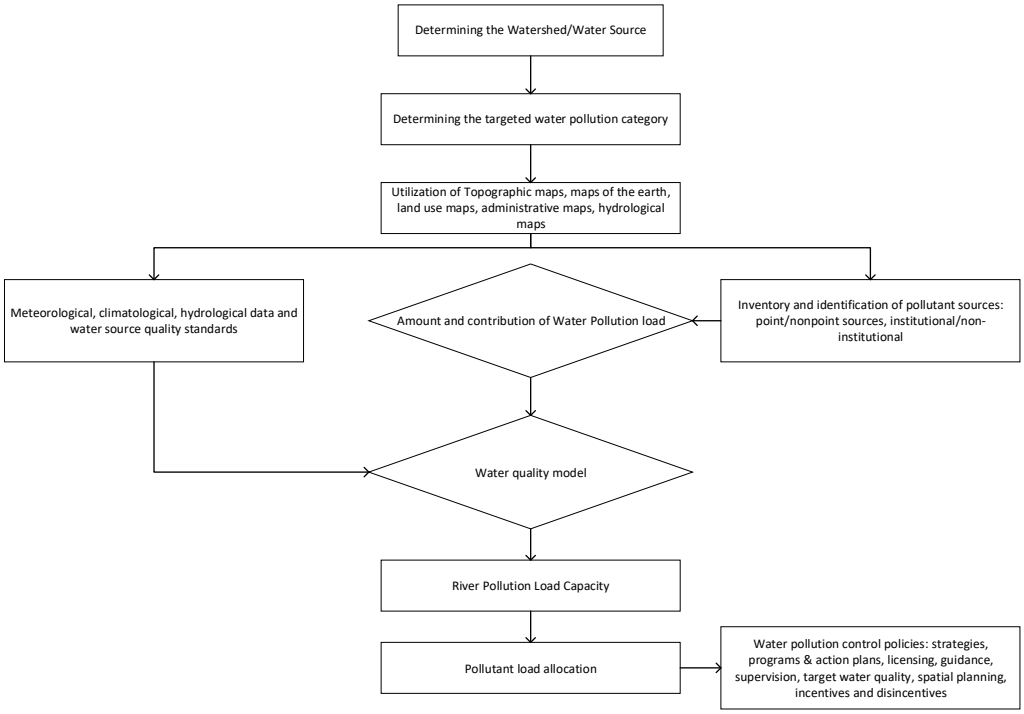


Figure 2. The Flow Diagram of River's PLC Analysis

IV. General Condition

4.1. Karawang Regency

Karawang Regency is a regency area which has an area of 1,753.27 km2 or 3.73% of the area of West Java Province. Most of the area is covered by coastal plains that lie on the northern coast. This district is located in the northern part of West Java Province which is geographically located between 107°02' - 107°40' East Longitude 5°56' - 6°34' South Latitude. The administrative boundaries of Karawang Regency are:

- North: Java Sea
- East: Subang Regency
- Southeast: Purwakarta Regency
- South: Bogor Regency and Cianjur Regency
- West: Bekasi Regency

Karawang Regency is an area with a tropical climate. The average rainfall ranges from 2 - 304 mm and the average rainy day is 7 days/month. The rainy season occurs between November and April. The highest rainfall occurs in February, while the lowest rainfall occurs in August. Karawang Regency is traversed by a river that slopes to the North towards the Citarum River and is the separator between Karawang Regency and Bekasi Regency, while the Cilamaya River is the border with Subang Regency. Regarding to rivers, there are also 3 large irrigation canals: the North Tarum Main Canal, Middle Tarum Main Canal and West Tarum Main Canal which are used for irrigating rice fields, ponds and industrial purposes.

Karawang Regency has 30 districts, consisting of 297 villages and 12 districts. The highest number of villages are in Telagasari, Jatisari, and Tempuran districts, which are 14 villages and the least are Majalaya and Ciampel sub-districts, which are 7 villages. Most of the Karawang Regency has a relatively flat plain with a variation of 0-5 meters above sea level. The bumpy and hilly area is only found in a small area with an altitude between 0-1,200 meters above sea level.

4.2. Bekasi Regency

Bekasi is a regency area which has an area of 127,388 ha. The largest district is Muaragembong District (14,009 ha) or 11% of the district's area. This regency is located at 6°10'53" - 6°30'6" South Latitude and 106°48'28" -107°27'29" East Longitude.
Bekasi Regency administrative boundaries are:

- North: Java Sea
- South: Bogor Regency
- West: North Jakarta City and Bekasi City
- East: Karawang Regency

Bekasi Regency is an area with a tropical climate. The average rainfall ranges from 8.4 - 367.18 mm with the highest rainfall and the most rainy days occurring in February. The air temperature in Bekasi Regency ranges from 28 °C -32 °C.

Hydrological conditions can be divided into 3: surface water, groundwater and shallow ground water. In Bekasi Regency there are 16 major rivers, such as Citarum River, Bekasi River, Cikarang River, Ciherang River, Belencong River, Jambe River, Sadang River, Cikedokan River, Ulu River, Cilemahabang River, Cibeet River, Cipamingkis River, Sungal Serengseng, Sepak River and Jaeran River. The width of the river ranges from 3 - 80 m.

In Bekasi Regency, there are 13 lakes spread over several sub-districts, namely: Situ Tegal Abidin, Situ Bojongmangu, Situ Bungur, Situ Ceper, Situ Cipagadungan, Situ Cipalahar, Situ Ciantra, Situ Taman, Situ Burangkeng, Situ Liang Maung, Siru Cibeureum, Situ Cilengsir and Situ Binong. The area of the lake ranges from 3 - 40 ha. The groundwater conditions in the Bekasi Regency area are mostly shallow groundwater at a depth of 5-25 m from the ground surface, while deep groundwater is generally obtained at a depth between 90-200 m (Regional Planning Agency 2007).

The Bekasi Regency area is divided into 23 districts which include 7 districts (Bahagia, Kebalen, Wanasari, Telaga Asih, Kertajaya, Jatimulya, Kertasari) and 180 villages. The topography of Bekasi Regency is divided into two parts, namely lowlands which cover part of the northern part and undulating plains in the southern part. The altitude of the location is between 6 - 115 meters and a slope of 0 - 25 meters. Meanwhile, Muara Gembong District, which is included in the area affected by the oil spill, is at an altitude of 3 meters above sea level.

4.3. Karawang and Bekasi Development

The increasing need for industry in Java Island has an impact on the development of the Bekasi and Karawang regencies. The two regencies get a spillover effect from the growth of the Jakarta, Bogor, Depok, Tangerang, and Bekasi (Jabodetabek) areas. The high demand for goods and services accompanied by limited land in the Jabedetabek area makes Bekasi and Karawang regencies the ideal locations for various industrial areas. The strategic location of the two regencies and located on the axis of big cities on the island of Java such as Jakarta-Bandung and Jakarta-Semarang has made industrial activities in these locations increasingly developed (Rustiadi et al., 2021). Moreover, Bekasi and Karawang regencies are located on the north coast of Java Island which makes it easy to access sea transportation.

The development of industry in these two regencies has a real influence on the quality of the Citarum River. Basically, Citarum River pollution does not only occur in downstream areas but also in upstream areas such as Bandung Regency, West Bandung, and Purwakarta. However, the potential for pollution is increasing in the downstream area due to industrial waste originating from the regencies of Karawang and Bekasi. Karawang Regency also has a large agricultural area so that it becomes Indonesia's granary. The potential flow of nutrients from agricultural areas also strengthens the risk of Citarum River pollution.

The growth of industrial estates in the Karawang and Bekasi areas also has an impact on urban development. The growing industry is followed by the growth of industrial areas consisting of residential areas and various public facilities to support the people in them. This has resulted in both districts experiencing significant urbanization. Therefore, the districts of Karawang and Bekasi which are included in the Citarum watershed not only

provide potential for river pollution originating from agricultural and industrial activities but also from household activities and trade services.

V. Results and Discussions

5.1. Estimated NPS Pollutant

Based on the projected non-point source pollutant data (NPS), Karawang district is the administrative area with the largest potential pollutant load in the Citarum watershed. Based on their activities, the sources of NPS pollutants are divided into several sources such as households, agriculture, industry, livestock, etc. (**Table 3**).

Table 3. Projected NPS Pollutant potential in Karawang Regency

No	Sectors	BOD		COD		TSS	
		Kg/Day	(%)	Kg/Day	(%)	Kg/Day	(%)
1	Industries	19,149.81	13.01	35,983.68	16.01	10,371.12	13.56
2	Hospitals	29.44	0.02	67.43	0.03	38.24	0.05
3	Hotels	1,633.84	1.11	2,382.43	1.06	1,193.14	1.56
4	Households	85,254.20	57.92	123,571.69	54.98	62,731.49	82.02
5	Livestocks	19,782.74	13.44	51,739.18	23.02	-	0.00
6	Agricultures	15,131.44	10.28	-	0.00	22.94	0.03
7	Fisheries	220.79	0.15	359.61	0.16	-	0.00
8	Small Scale Enterprises (SSE)	4,945.69	3.36	9,012.78	4.01	2,126.23	2.78
9	Wastes	1,045.07	0.71	1,640.73	0.73	-	0.00
	Total	**147,193.02**	**100.00**	**224,757.53**	**100.00**	**76,483.17**	**100.00**

Based on **Figure 4, 5,** and **6**, households are the sectors that produce the highest BOD, COD, and TSS with percentages of 57.92%, 54.98%, and 82.02%, respectively. The high population in Karawang Regency is one of the triggers for the high potential for pollutants originating from households.

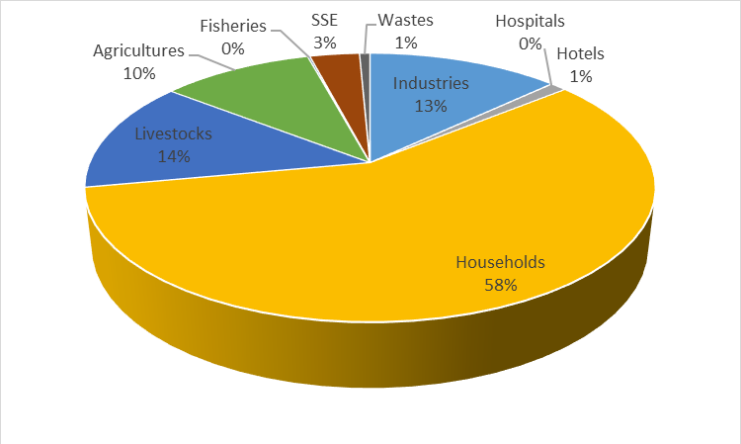


Figure 3 Estimated BOD potential in Karawang Regency

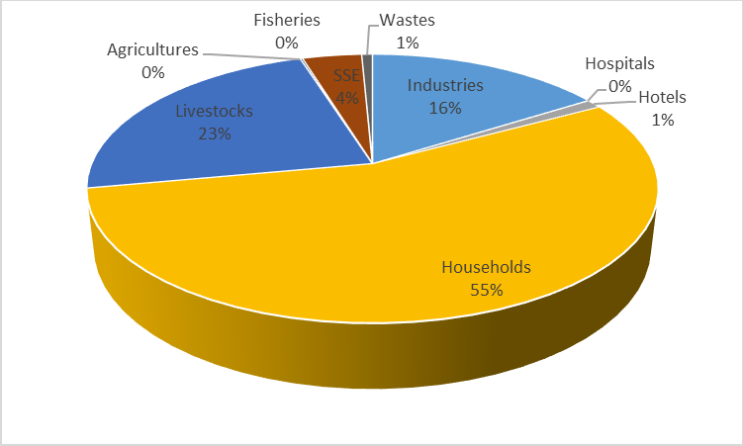


Figure 4 Estimated COD potential in Karawang Regency

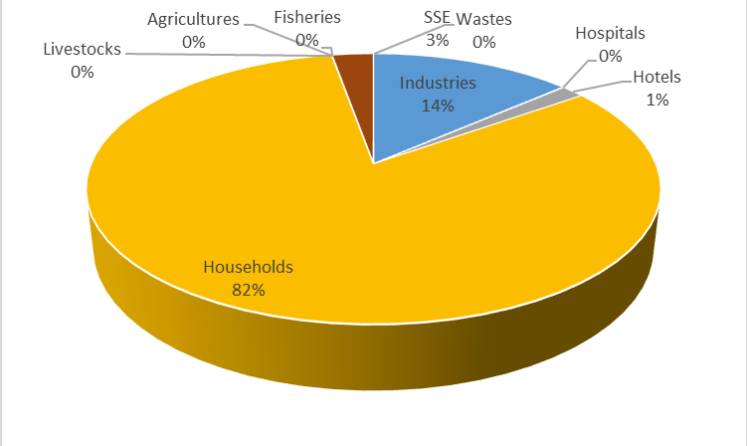


Figure 5 Estimated TSS potential in Karawang Regency

The high number of NPS pollutants in Karawang Regency is caused by several factors. Karawang Regency is an administrative area in the Citarum watershed with the second largest population after Bandung Regency. The high population in the area makes the potential for NPS pollutants from households to be high. The potential for NPS pollutants originating from the industrial and agricultural sectors in this region is also quite high. Based on statistic data for 2021, the largest income in Karawang Regency comes from the manufacturing sector (70.05%), trade (9.83%), and agriculture, forestry and fisheries (4.34%).

5.2. Karawang Regency Land Use

Based on land cover changes data in **Table 4**, in 2009-2019 land cover in Karawang Regency has changed. Many paddy fields have decreased in the last 10 years. Some of them were converted into built-up land, especially settlement. Forest is also a land cover that has decreased during this period. Conversion of paddy fields and forests into residential area shows an increase in population and the need for built-up land. This affects the potential for pollutants that enter the Downstream Citarum Watershed. High population growth and increasing economic activity in Karawang are the driving factors for the decline of paddy fields to built up areas (Murtadho et al., 2020)(Furgała-Selezniow et al., 2022).

Table 4. Area and percentage of landuse during 2009-2019 in Karawang Regency.

No	Land use/land cover classes	The coverage area for each year					
		2009		2014		2019	
		ha	(%)	ha	(%)	ha	(%)
1	Forests	10907.73	5.70	16839.97	8.79	14314.04	7.47
2	Water Bodies	3044.93	1.59	3234.35	1.69	3679.78	1.92
3	Build up Areas	21321.39	11.13	23174.04	12.10	34734.20	18.14
4	Fish ponds	16234.97	8.48	13850.07	7.23	15271.61	7.97
5	Drylands	14978.14	7.82	14769.15	7.71	13557.33	7.08
6	Bare lands	2199.94	1.15	5460.58	2.85	3477.72	1.82
7	Paddy fields	122839.48	64.14	114199.64	59.63	106492.71	55.60
	Total	191526.58	100.00	191526.58	100.00	191526.58	100.00

Source: (Suliman et al., 2022)

Table 5 Landuse in Downstream Citarum Watershed in 2020

Landuse	**Karawang**		**Bekasi**	
	Area (ha)	**Percentage**	**Area (ha)**	**Percentage**
Water Body	959.25	1.17	481.31	0.91
Shrubs	62.73	0.08	0	0.00
Secondary dryland forest	2,577.37	3.14	0	0.00
Forest	3,972.22	4.84	0	0.00
Built up area	10,000.00	12.19	7,571.26	14.33
Plantation	512.39	0.62	0	0.00
Mining area	15.52	0.02	0	0.00
Dryland farming	10,000.00	12.19	2,125.66	4.02
Mix farming	10,000.00	12.19	2,079.97	3.94
Paddy field	30,000.00	36.56	30,000.00	56.77
Pond	10,000.00	12.19	8,699.39	16.46
Bare land	3,963.56	4.83	1,891.76	3.58
Total	**82,063.04**	**100.00**	**52,849.35**	**100.00**

Karawang Regency has various types of land use. In the southern region bordering Purwakarta Regency, the Karawang Regency area has a diverse industrial areas(Figure 6). Money printing, automotive, textiles, medicine, and chemicals are some of the industrial sectors in the region. There are even several industries located in an area called Karawang International Industrial City (KIIC). In the north of the industrial area is the city center which is dominated by residential and commercial areas. A number of hotels, restaurants, business districts dominate the area. In the further north, the agricultural land dominates the land use. Karawang Regency is one of the rice granaries in West Java Province. The flat topography and irrigation flow from the Citarum River also support the development of agricultural land in this region. In the northern coastal area, fish, shrimp and salt ponds dominate land use. The economic value generated from pond cultivation is a driving factor for the community to convert agricultural land on the coast into ponds.

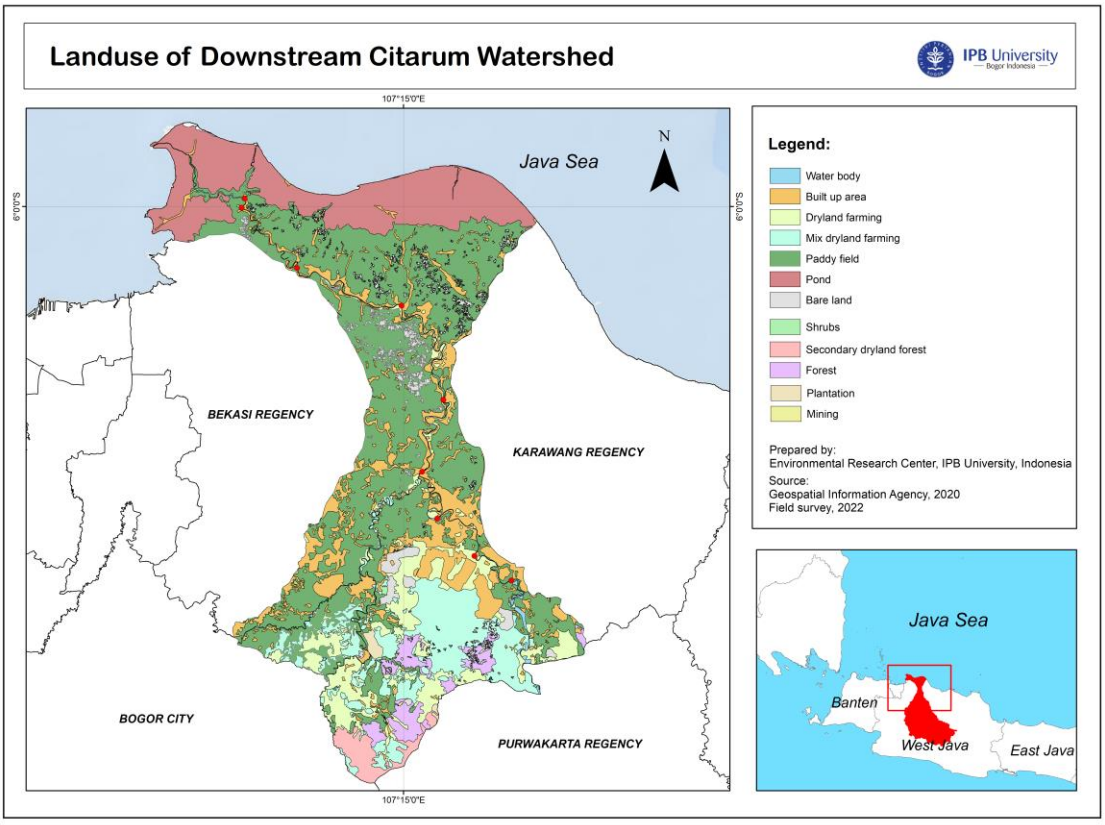


Figure 6 Landuse Map of Citarum Watershed in Karawang and Bekasi Regency

5.3. Water Quality (in situ)

Table 6 Water quality in situ

Sampling Point	Temperature (°C)	pH	DO	Turbidity
1	29.6	7.74	5	24.9
2	32.3	7.78	3	20.3
3	30.3	7.43	3.2	24.92
4	31.9	7.9	4	41.9
5	32.7	7.74	3.6	55
6	30.6	6.99	3.1	848
7	31	6.89	2.3	101
8	29.5	7.23	2.6	909

In situ water quality parameters consist of temperature, pH, DO, and turbidity (**Table 6**). Those parameters were tested directly in the field using several instruments to prevent changes in water conditions. To maintain the validity of the measurement results, the instrument is calibrated periodically. In general, in situ water quality shows a deteriorating trend from upstream to downstream. This can be seen from the dissolved oxygen parameter which shows a decrease from point 1 to 8 (**Figure 7**). In addition, turbidity is increasing in the downstream area. At point 8 there is a high sedimentation so that the turbidity at that point reaches a value of 909 NTU (**Figure 8**).

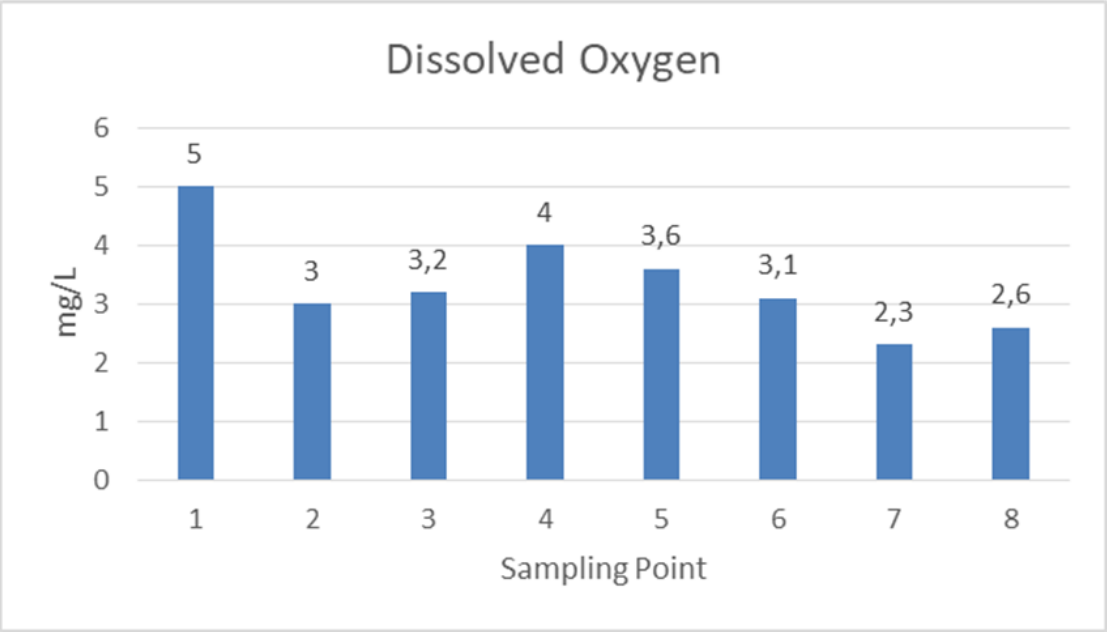


Figure 7 Dissolved Oxygen in Sampling Points

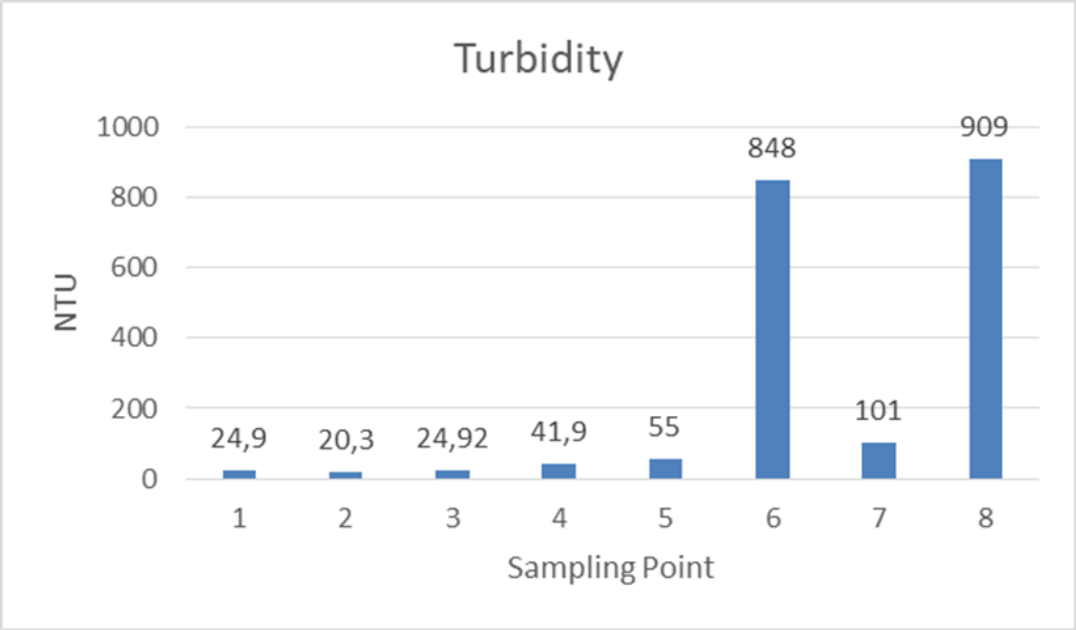


Figure 8 Turbidity in Sampling Points

5.4. Water Quality (Laboratory analysis)

Table 7. Water quality

Sampling Point	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
1	20	1.1	7.82
2	28	2.2	15.57
3	40	3.4	21.08

Sampling Point	TSS (mg/L)	BOD (mg/L)	COD (mg/L)
4	52	3.8	25.81
5	84	3.8	28.54
6	110	2.8	31.59
7	78	2.5	18.32
8	126	2.8	33.85

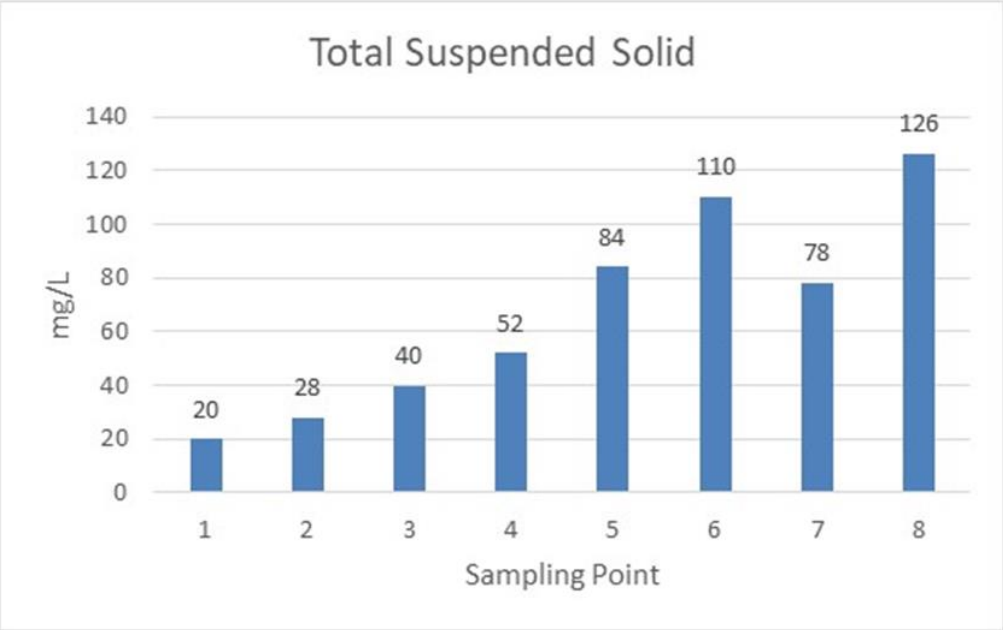


Figure 9 TSS value in 8 sampling points

In general, the TSS value from upstream to downstream has increased (**Figure 9**). The presence of sedimentation in the downstream area makes the TSS value higher in the downstream area, especially at point 8 which reached 126 mg/L. The presence of runoff water due to high rainfall in urban areas poses a great risk of soil sedimentation entering the water body. When sediment accumulates in water bodies, the downstream area has a high vulnerability to high TSS (Kurniawan et al., 2019). The TSS value is strongly associated with turbidity. The higher the TSS value, the higher the turbidity value. In fact, a study states that turbidity can describe the potential for TSS, COD, and total phosphate (Liu et al., 2020). This can be seen in the turbidity value at point 8 which has the highest value compared to other points. TSS and turbidity parameters are closely related to the quality of drinking water and the beauty of water bodies. Therefore, water bodies with high TSS are difficult to use for drinking water sources and tourist sites.

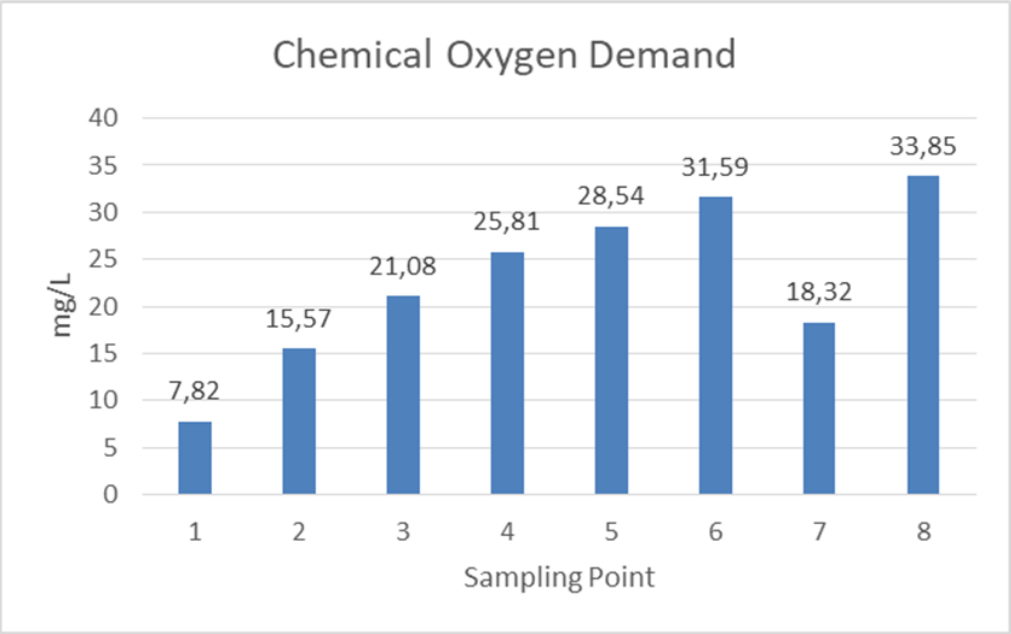


Figure 10 COD value in 8 sampling points

Similar to TSS, COD shows an increase from points 1 to 8 (**Figure 10**). This result also indicated that COD, TSS, and turbidity have a strong relationship. Turbidity is an in situ water quality parameter that can predict other parameters those require laboratory tests such as TSS and COD (Kurniawan et al., 2019). An increase in COD value indicates an increase in chemicals from upstream to downstream areas. In some industrial areas, COD values show an increase due to waste released into water bodies (Swati & Faruqui, 2018). Based on the land cover map, industrial areas in Karawang Regency are concentrated in the upstream (South) area of Karawang Regency. However, in the upstream area, the COD value still meets class I. This increase can be caused by the accumulation of chemicals in the downstream area so that the sampling point in the downstream area shows a high value.

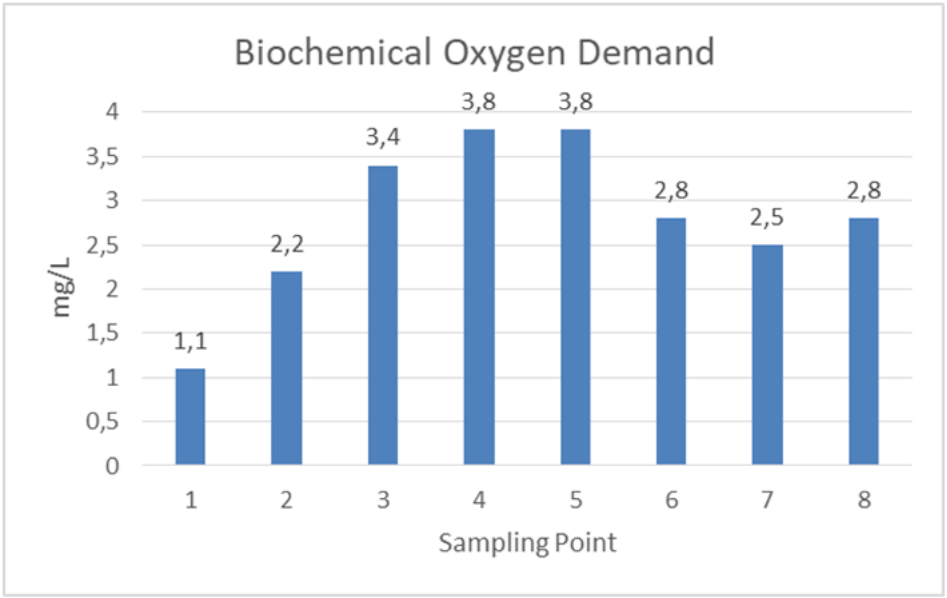


Figure 11 BOD value in 8 sampling points

In contrast to TSS and COD, BOD at points 4 and 5 actually has the highest value (**Figure 11**). Point 4 and 5 are located in Karawang City Center. Karawang City Center is dominated by built-up areas such as settlements and other commercial areas. The high occurrence of BOD within commercial landuse type may be attributed to discharge of organic wastes such as refuse, human and animal excreta and detergents released directly into the water which uptake the oxygen level in the water body. BOD increases due to biodegradation of inorganic materials which exerts oxygen tension in water bodies (Fashae et al., 2019).

Based on the results of the analysis of settlement density in 2003 and 2014, Telukjambe District is one of the most densely populated residential areas in Karawang. This area continues to develop from year to year due to the growing population and economic activity in the region (Murtadho et al., 2020). From the **Figure 12**, Telukjambe is the village with the highest regional development index. This is related to the high BOD pollutant potential around the area (point 3, 4, and 5).

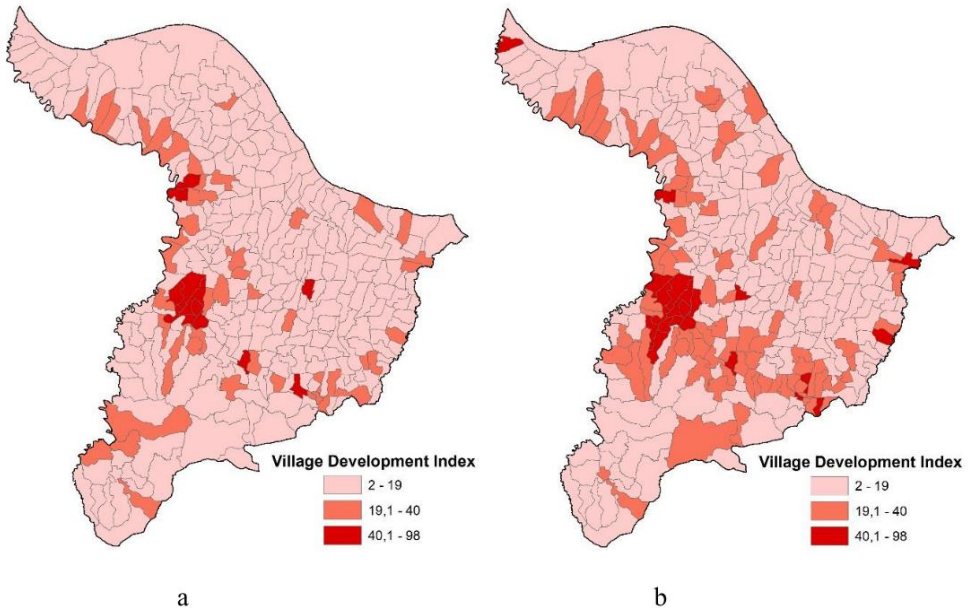


Figure 12 Village Development Index in Karawang Regency in: a) 2003 and b) 2014 (Murtadho et al., 2020)

5.5. Water Quality Comparison Before and After Citarum Harum Program

To find out the changes in the water quality of the downstream Citarum watershed before and after the Citarum Harum Program was implemented, a comparison of the water quality data generated from this study was carried out with other studies conducted before the Harum Citarum. The sampling point chosen in this study is different from other studies. Therefore, comparisons of water quality are only carried out at the same point or at a distance that is not much different. Based on research conducted in 2017, there are several similar parameters such as pH, DO, and BOD (Laili & Sofyan, 2017). However, this study only focused on the southern part of Karawang Regency so that the data for the three parameters could only be compared with points 1, 2, and 3 in this study.

Table 8 Comparison some water quality parameters in Southern Part of Karawang Regency

Point	pH		DO		BOD	
	2017	2022	2017	2022	2017	2022
1	7	7.74	6	5	3	1.1
2	7.8	7.78	4	3	9	2.2
3	7.1	7.43	4	3.2	4	3.4

Based on **Table 8**, water pH in the last 5 years did not show a significant difference. In addition, DO in 2022 showed a decrease when compared to 2017. On the other hand, BOD in 2022 showed a decrease or improvement in value when compared to 2017.

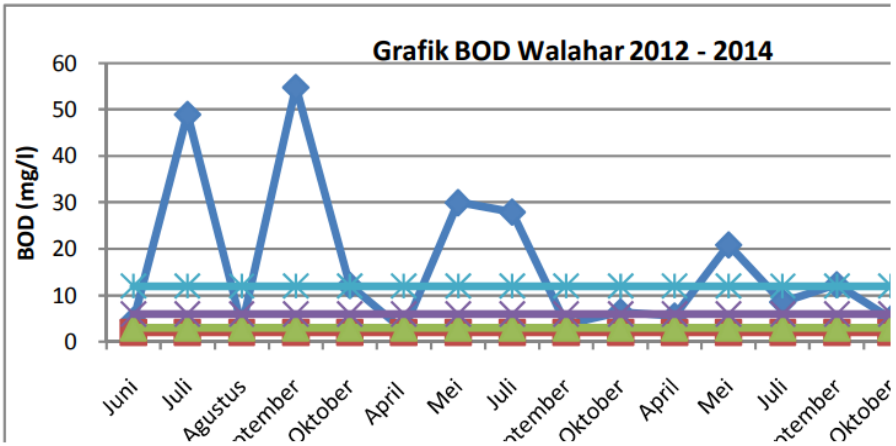


Figure 13 BOD value in 2012-2014 in Bendung Walahar (Point 1)

Further comparisons regarding water quality prior to the implementation of the Citarum Harum program were obtained from water quality data released by government agencies in 2012-2014. At Walahar Dam (Point 1), most of the BOD parameters far exceeded the threshold for class IV ranging from 15 -60 mg/l, some met class IV and only a few met class III (**Figure 13**). Meanwhile, in the measurement in 2022, the highest BOD value in Karawang Regency reached 3.8 or could still meet the class III quality standard. Moreover, in Walahar Dam, the BOD value only reached 1.1 mg/L. In 2012-2014, the majority of DO parameters met class II, and only a few passed the class II quality standard but met class III. This result is not much different from the study in 2022. The DO parameter has improved due to the reaeration process from the Walahar Dam.

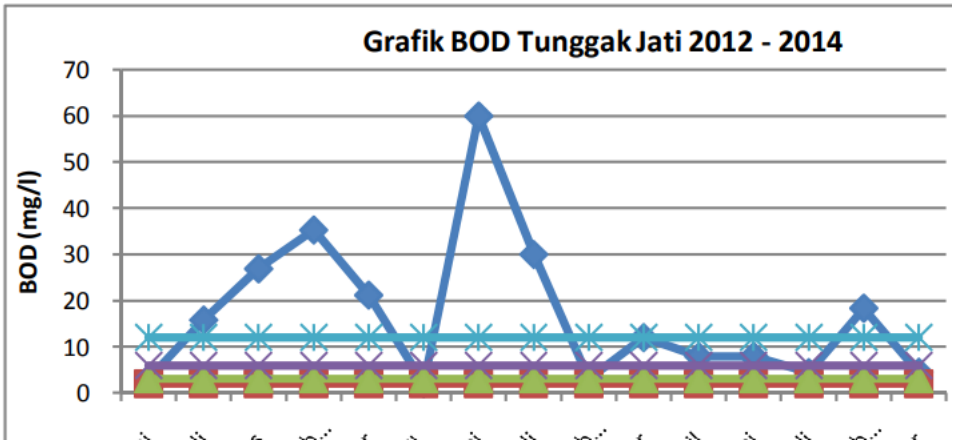


Figure 14 BOD value in 2012-2014 in Tunggakjati (near Point 5)

Almost all BOD parameters at the Tunggakjati monitoring location in 2012-2014 have far exceeded class IV with a range of values from 20 – 140 mg/l, some data meet class IV (**Figure 14**). Only a few monitoring data meet class III. The DO parameter mostly fulfills class II and partially fulfills class III BOD parameter. BOD and DO parameters in 2022 experienced a significant increase in quality. BOD at a location not much different from the Tunggakjati point reached 3.8 mg/L and DO reached 3.6 mg/L. This shows that in the last 10 years, the Citarum Hilir watershed has experienced a significant improvement.

5.6. Pollution Load Capacity

The study location was divided into 2 segments, segment 7 and segment 8. Segment 7 has a segment length of 29.744 km located in Karawang Regency which crosses 5 districts: Ciampel, Klari, Teluk Jambe Timur, West Karawang and East Karawang District. Segment 8 has a length of 66,485 km across 2 regencies, Bekasi and Karawang regencies with total of 9 (nine) districts. In the Bekasi Regency area, it is included in 4 (four) Districts, Kedungwaringin, Pebayuran, Cabangbungin and Muara Gembong District, while in Karawang Regency it is included in 5 (five) Districts: West Karawang, Rengasdengklok, Jayakerta, Batujaya and Pakisjaya District.

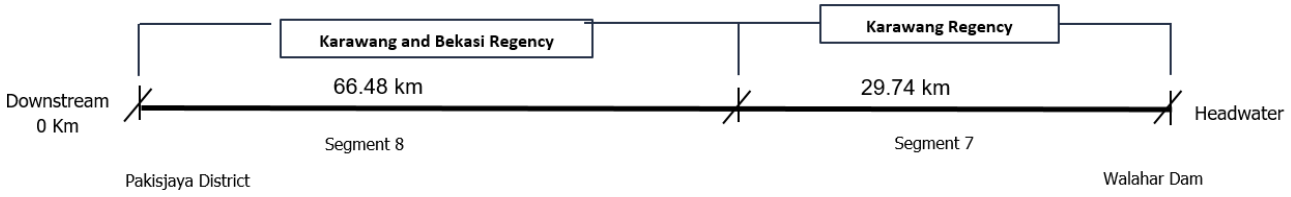


Figure 15 River Segments

The Qual2Kw (Version 5.1) water quality model applies simulations in two different scenarios. Scenario 1 is carried out by using the water quality from upstream sampling (headwater), then inputting the pollutant load from the measurement results for the point source, while the non-point source pollutant load is inputted by trial and error until the simulation results approach the water quality data sampled in the entire study area. The inputted pollutant loads from point and non-point sources are then summed and analyzed. Meanwhile, scenario 2 is executed using the same upstream water quality data as scenario 1, but the input of the pollutant load is carried out so that the simulation results approach class II water quality in all segments of the Lower Citarum River modeled using the scenario (Table 9). In the 2020-2024 period, the Ministry of Environment and Forestry set the Citarum river area from the Jatiluhur reservoir to the coastal estuary at class 2 water quality. This is the reason why in the scenario 2 the simulation results should approach class II water quality.

Table 9 Scenario model calculation of pollution load capacity

Scenario	Treatment in Headwater			Output
	Debit	Water Quality	Pollution Load	
1 Existing pollution load	Based on measurement	Based on measurement	Input Model PS: MoEF 2017 NPS : Trial and error Model	Existing Pollution Load Model

2 Pollution Load Capacity	Based on measurement	Class II	Input Model PS: MoEF 2017 NPS : Trial and error Model	Pollution Load Capacity for Class II

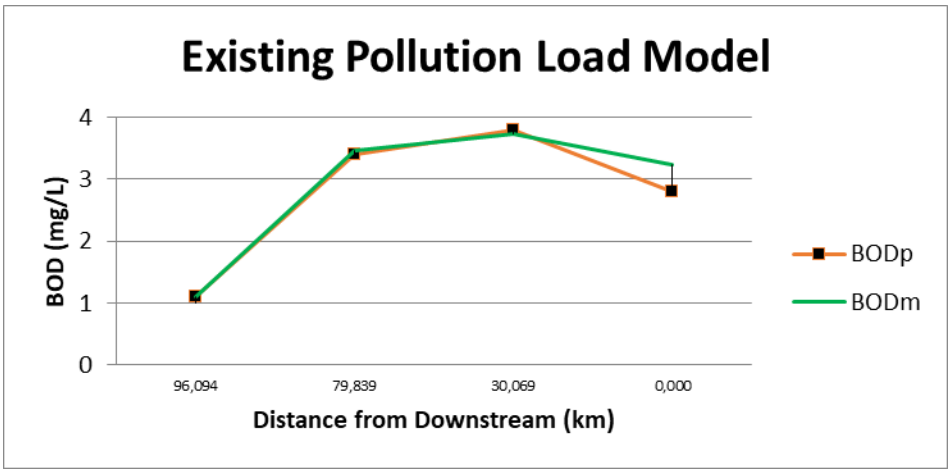
Based on calculations using the Qual2Kw (Version 5.1) water quality model, the results of the existing pollution load and the calculation of the pollution load carrying capacity for BOD parameter are presented in Table 10.

Table 10 Recapitulation of Water Pollution Load Capacity of the Lower Citarum River

Segment	**Existing Pollution Load (kg/day)**	**Percentage**	**Pollution Load Capacity (kg/day)**
	BOD	**BOD**	**BOD**
7	11,380	47%	4,177
8	38,448	53%	30,370
Total	**49,828**	**100**	**34,546**

The results of the calculation of the pollutant load capacity (Table 10) illustrates the relationship between the existing/actual pollutant load both originating from certain sources and unspecified sources entering the river with the pollutant load carrying capacity of the Lower Citarum river. Furthermore, when the value of the incoming pollutant load is greater than the value of carrying capacity, it means that pollution load has exceeded the pollution load capacity. The total pollution load of existing BOD entering the Lower Citarum river body is 49,828 kg/day for BOD. Based on the results of the calculation of the existing pollutant load, it is indicated that the most influential point source is coming from companies that have not been identified by WWTP Companies that dispose of liquid waste into the Citarum river body especially the area Before Walahar Dam. The next thing that affects the downstream area is the Non-Point Source. The study location limits the administrative areas of Bekasi Regency and Karawang Regency, so it is indicated that Bekasi Regency contributes to the load that enters the downstream area of Citarum.

The BOD parameter is a special parameter to see the content of Biochemical Oxygen Demand in a surface which is an indicator for determining water quality. BOD is a parameter measuring the amount of oxygen needed by bacteria to break down almost all dissolved and suspended organic substances in wastewater. It is necessary to calculate the pollution load to find out how much daily pollutant load is in rivers and rivers (kg/day). The following pictures is a graphics of the relationship between BOD parameters and the value of the quality standard and the pollution load capacity, based on the Qual2Kw (version 5.1) water quality model in the study location as shown in Figure 16.



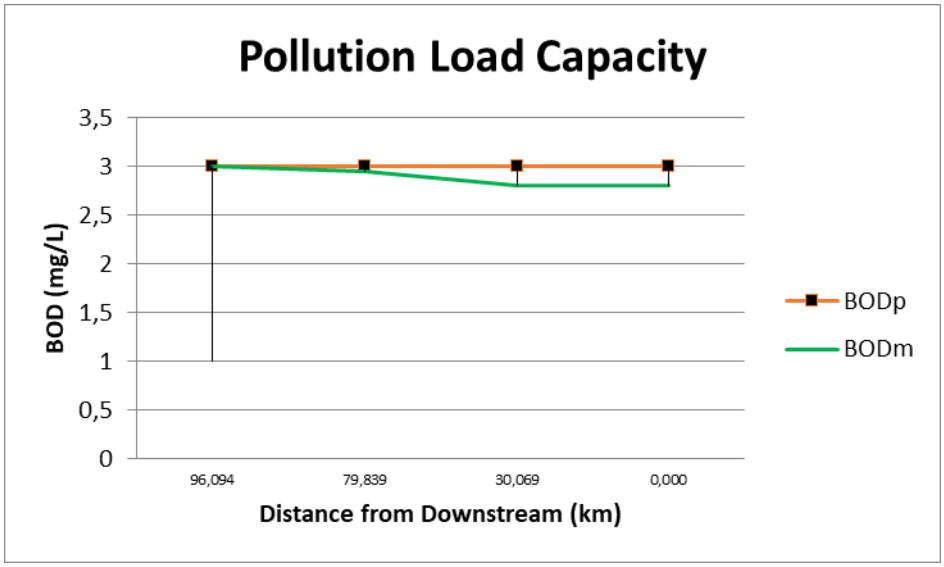


Figure 16 Graphics of the BOD model in the Downstream Citarum River: scenario 1 (above) and scenario 2 (below)

The simulation results using scenario 1 show that in all segments the BOD concentration has exceeded the class II quality standard. This condition means that the Lower Citarum River no longer has the carrying capacity for BOD pollutant loads. The complete results of the PLC calculation for the BOD parameter based on Qual2Kw (with RMSE 0.078) are presented in Table 10. And a simulation graph of the pollution load capacity of the BOD parameter is presented.

Based on Table 10 above, it is identified that the Lower Citarum River has a total existing pollutant load for the BOD parameter of 49,828 kg/day. The largest contributor to the pollutant load for the BOD parameter came from segment 8 at 38,448 kg/day (53%). If it is further analyzed that the pollution load in all segments (7 to 8) has exceeded the pollution load capacity (PLC). So that efforts are needed to reduce the pollution load that exceeds the value of its capacity. From the scenario 1 we can see the existing BOD pollution load which range from 1-4 mg/L. From the scenario 2, the green line shows the ideal condition to be achieved to fulfill the water quality class 2. The orange line in scenario 1 indicates the existing water quality, in scenario 2 indicates the quality standard. The green lines in both

images indicate the model achieved if it follows the existing pollutant and quality standards.

In order to fulfill the pollution load capacity, it is necessary to reduce pollutants both from point source pollutant (industry) and non point source pollutant. In the Table 11, there is a comparison of pollutant loads from PS and NPS and their ideal conditions. Based on the table, it can be seen that the existing PS pollutant from industry does not differ much from its capacity of 130.25 kg/day. However, to meet the quality standards of river water quality, it is still necessary to reduce the concentration of BOD from some industries so that the pollutant load is obtained in accordance with its capacity. Some industries that need to reduce BOD concentrations include PT APF I and PT APF II. All PS pollutant are in segment 7, so all pollutants in segment 8 are from pollutant NPS.

Table 11 Actual and Ideal Pollution Load from Point Source Pollutant

No	Point Source	Distance (Km)	Debit	Actual		Ideal	
				BOD Concentration (Mg/L)	BOD Pollution Load (Kg/Day)	BOD Concentration (Mg/L)	BOD Pollution Load (Kg/Day)
1	PT. PD II	93.635	0.17361	48	720.00	48	720.00
2	PT. CS	93.38	0.00463	21	8.40	21	8.40
3	PT. APF I*	92.63	0.00023	5,210	104.20	260	5.20
4	PT. APF II*	92.63	0.00058	1,025	51.25	400	20.00
5	PT. APF III	92.63	0.00463	499	199.60	499	199.60
6	PT. MKT	92.52	0.00289	23	5.75	23	5.75
7	PT. MS	85.28	0.92592	23	1,839.99	23	1,839.99
8	PT. PF	84.31	0.00006	95	0.47	95	0.47
9	PT. WIT	83.47	0.00009	95	0.76	95	0.76
10	PT. DIC	82.82	0.00556	102	48.96	102.00	48.96
11	PT. CI	73.74	0.00289	324	81.00	324.00	81.00
12	PT. FSJ	73.54	0.00289	41	10.25	41	10.25
13	PT. SMD	71.48	0.00209	324	58.56	324	58.56
14	PT. PD I	69.29	0.03472	47	141.00	47	141.00
	TOTAL				**3,270.18**		**3,139.93**

*Industry that need to reduce BOD concentration

Unlike PS pollutant, NPS pollutant has a large capacity difference between existing and ideal conditions, reaching 15,250 kg/day or more than 100 times PS Pollutant (Table 12). This shows the need for maximum efforts to reduce the concentration of pollutants originating from NPS. If in PS pollutant it takes 2 industries to reduce the concentration of BOD values, in NPS pollutant all points need to reduce BOD concentrations so that ideal conditions are obtained. NPS 1-8 is located in segment 7 and NPS 9-10 is located in segment 8. This shows that the pollutants in segment 7 come from PS and NPS while in segment 8 only comes from NPS.

Table 12 Actual and Ideal Pollution Load from Non Point Source Pollutant

No	Non Point Source	Distance (Km)	Debit	Actual		Ideal	
				BOD Concentration (Mg/L)	BOD Pollution Load (Kg/Day)	BOD Concentration (Mg/L)	BOD Pollution Load (Kg/Day)
1	NPS 1	94.819	0.50000	8	346	3	130

2	NPS 2	88.728	0.50000	8	346	3	130
3	NPS 3	87.836	0.50000	8	346	3	130
4	NPS 4	77.085	0.50000	8	346	3	130
5	NPS 5	76.425	0.50000	8	346	3	130
6	NPS 6	67.054	0.50000	50	2,160	3	130
7	NPS 7	63.545	0.50000	50	2,160	3	130
8	NPS 8	62.095	0.50000	50	2,160	3	130
9	NPS 9	54.775	0.50000	840	36,288	700	30,240
10	NPS 10	40.435	0.50000	50	2,160	3	130
	TOTAL				**46,656**		**31,406**

Based on tables 11 and 12, it is known that the total reduction in pollution load that must be achieved to meet class 2 water quality standards is 15,282 kg/day (Table 13). This decrease came from segment 7 (7,203 kg/day) and segment 8 (8,078 kg/day).

Table 13 Pollutants load that must be reduced

Segment	**BOD (kg/day)**		
	Actual	**Ideal**	**Reduction**
7	11,380	4,177	-7,203
8	38,448	30,370	-8,078
Total	**49,828**	**34,546**	**-15,282**

In the same scenario we can see the comparison from 2022 and 2017 data from MoEF. In the same segment, 2017 data shows higher BOD value which range from 6 until 10 mg/L (Figure 17). So, the data in 2022 shows a better condition from 2017, or 4 years after Citarum harum Program water quality shows many improvement. In 2017, the target class for Citarum River water is class 3 with a BOD concentration of 6 mg/L. To meet this target, a scenario of reducing the pollutant load by up to 75% is required. However, in the scenario used in 2017, the government chose to reduce the pollutant load in the downstream Citarum by up to 50%. The total pollutants in the Citarum watershed in Karawang Regency which must be reduced in 2017 are around 49,761.79 kg/day so that the target water quality of the Citarum River in that period (class 3) can be met. This amount is much larger than the conditions in 2022 which only needed a decrease of 15,282 kg/day to reach class 2.

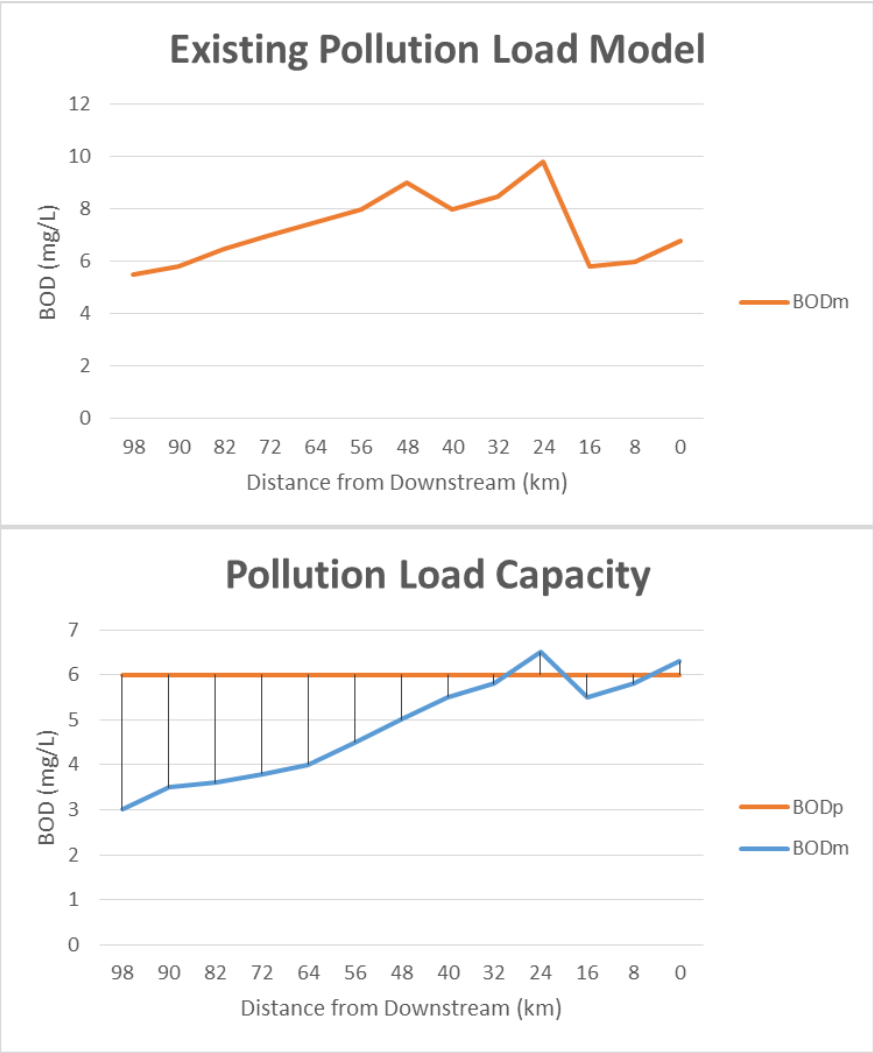


Figure 17 Graphics of the BOD model in the Downstream Citarum River: scenario 1 (above) and scenario 2 (below) in 2017 (MoEF, 2017)

5.7. Citarum Harum Effect

The improvement in water quality in the Lower Citarum River shows the positive influence of the revitalization program organized by the government. Usually, environmental revitalization programs are initiated by the local government and supported by various related institutions in the region. However, the Citarum revitalization was initiated directly by the President of the Republic of Indonesia through Presidential Regulation Number 15/2018. The issuance of this regulation became the fastest President Regulation to deal with the environment in the history of Indonesia. In general, this regulation contains the Acceleration of Pollution and Damage Control of the Citarum River (Chandra et al., 2019).

Because of the command that comes from the president, there are many parties who contribute to the realization of this program. There is a steering board and task force to help run the program. The steering board consists of several ministers while the task force is commanded by the Governor of West Java. In carrying out his duties, the governor of West Java is assisted by the regional military commanders from the provinces of West Java

and Jakarta and the regional police chiefs from the same regions. The Task Force has high authority in controlling pollution, inspecting industries around the Citarum River, and prohibiting residents from constructing buildings on river borders.

This program is planned to run for approximately 7 years. To facilitate implementation and supervision, the Citarum River is divided into several sectors. Each sector has a member of the task force who monitors this program. This program also involves people from community organizations, philanthropy, religious organizations, businessmen, academics, and other stakeholders. Each ministry also contributes to this program. For example, the ministry of environment and forestry plays a role in providing plant seeds, planting programs, and managing waste around rivers.

The contribution from various elements of the government and the government makes the Citarum Harum Program feel very special. The involvement of the military and police in supervising this program made the river revitalization process run effectively (Ayyasy et al., 2021). The involvement of the military in this program has also made the community respect the program and reluctant to do environmental damage. This program is a breakthrough in Indonesia. If the end of this program brings success to the improvement of the Citarum River, it is not impossible to carry out a similar scheme to other environmental revitalization program.

VI. Conclusions and Recommendations

6.1. Conclusion

Water quality and pollution load capacity in the Citarum Hilir River show a significant increase in 2022. This can be seen from the decrease in several water quality parameters such as BOD, COD, and TSS at the study site. The "Citarum Harum" revitalization program initiated by the central government in 2018 is estimated to be one of the factors that has made the water quality in Citarum Hilir increase. The military involvement in river revitalization makes the river cleaning process more effective. This program also changed the mindset of the community to participate in protecting the environment and avoiding throwing garbage in the river.

6.2. Recommendations

Although the downstream Citarum River has achieved improvement 4 years after the program, management still needs to be improved to reach the water class that has been set by the government. Achieving the water quality class II can be done by managing the point and non-point source pollutant load based on its capacity. Non-point pollutant loads originating from households, livestock, and agriculture need to be a concern of the government both in the upstream and downstream areas.

The existence of strict management of industry in Karawang and Bekasi regencies needs to be done to prevent pollution from industrial waste that is not managed properly. The construction of WWTPs around residential areas is also needed to prevent high river pollution by waste originating from household activities. Efficient use of fertilizers and pesticides in agricultural areas is necessary to prevent excessive flow of nutrients and organic matter.

The government through the Minister of Public Works Regulation concerning the Determination of River Border Lines (Permen PU No 28/2015). The stipulation of the river border line aims to limit human activities, especially those related to development, to preserve the river's sustainability, and to protect the ecosystem from damage. The river border line is set at least 50 (fifty) meters from the edge of the highest water level that has ever occurred (Figure 18). The edge of the highest water level that has ever occurred is the river border body.

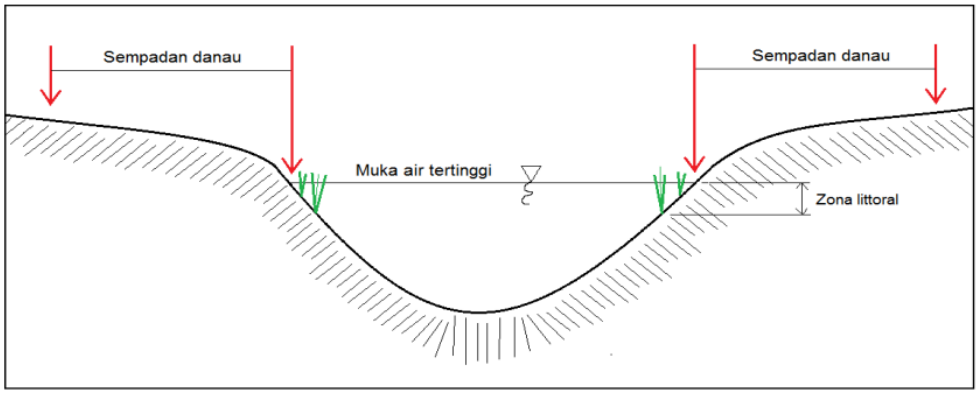


Figure 18 River Border set by the government (Permen PU No 28/2015)

The function of the river border itself is divided into 4: as a place for research and development of science, tourism, sports, and cultural and religious activities. Some buildings that are closely related to the function of the river are still allowed to be placed on the lake border, such as water resources infrastructure; access roads, bridges, and piers; gas and drinking water pipelines; stretch of power and telecommunications cables; tourism, sports, and religious infrastructure; infrastructure and sanitation; and electricity buildings. Outside of these buildings, gradually all buildings must be brought in order to restore the function of the river border.

Acknowledgement

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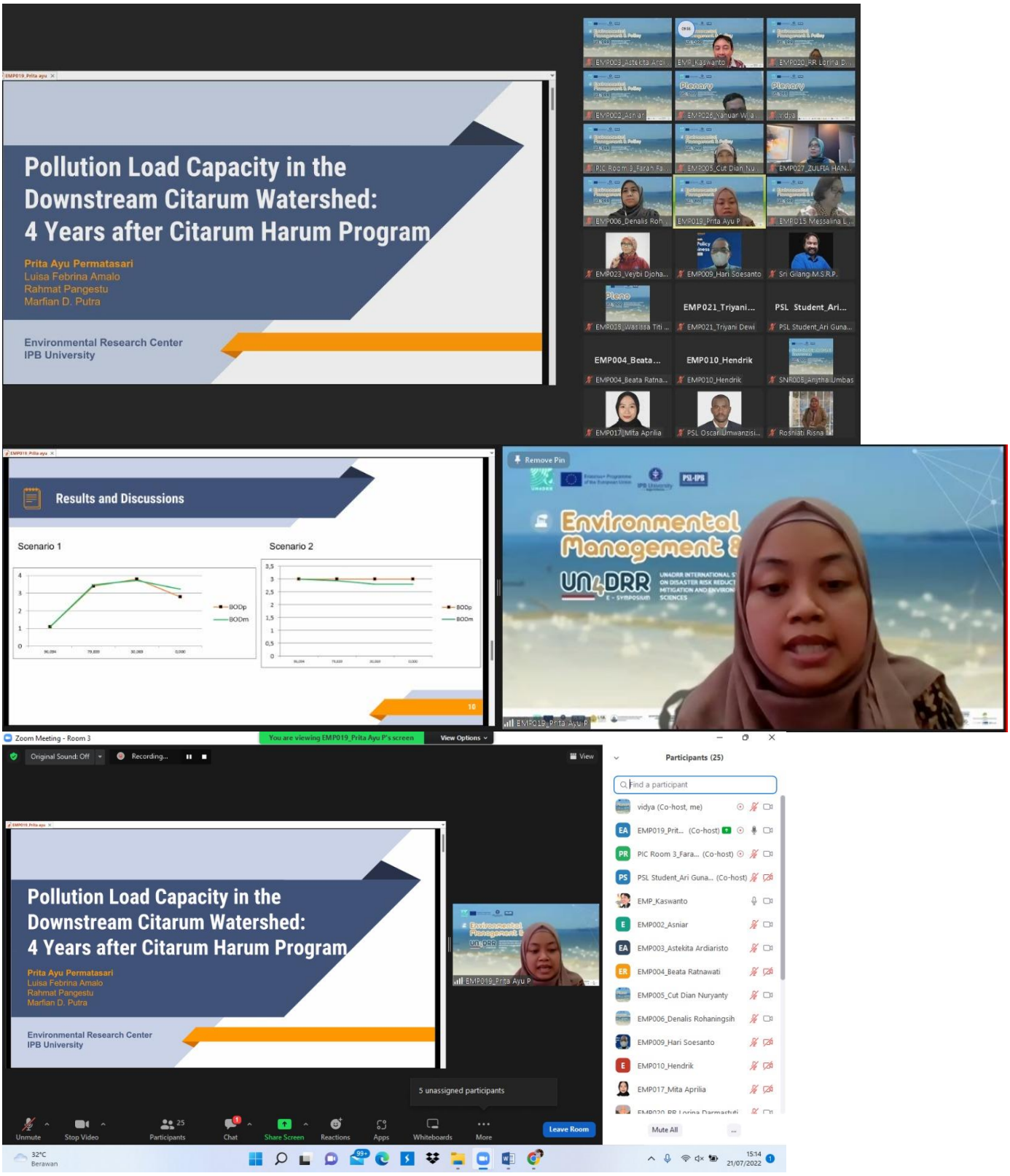
Appendices

Appendix 1. Survey Documentation

Appendix 2. Seminar Documentation

Presentation in UN4DRR International Symposium on Disaster Risk Reduction, Mitigation and Environmental Sciences (The 2022 – UN4DRR SYMPOSIUM) held by IPB University, July 21, 2022



The Osaka Gas Foundation of International Cultural Exchange (OGFICE)

Research Grant FY 2021/2022

Final Report

Development of a Web-Based Data Visualization System

(Case Study: Data Management of ERC IPB Activities in the Field of Natural Resource and Environmental Management)

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EXECUTIVE SUMMARY

Currently, the world is entering the industrial era 4.0, where almost all industrial sectors have started and have used information technology as a tool to support their business activities. One of them is data visualization, which is an attempt to represent data into a form that is easier to understand in analysis.

ERC IPB is one of the oldest research institutions in Indonesia with a focus on activities in the field of natural resources and the environment. For approximately 44 years since its establishment in 1976 until now, there have been many research, service, and training activities as well as cooperation in the field of natural resource and environmental management carried out by ERC IPB with various parties, including government, private and international institutions.

So far, data on research, service, and training activities at ERC IPB have not been managed properly so that the leadership/management has difficulties in monitoring and evaluating the achievement of quality targets, especially regarding the distribution of activity locations and the achievement of the Sustainable Development Goals (SDGs). In addition, the data recapitulation of ERC IPB activities is still made in the form of manual reports (paper) for each period that has not been recorded/stored in the digital system. The manual report allows data to be lost or damaged so that data on activities that have been carried out for years are not recorded.

Based on the problems described above, a systematic effort is needed to build a database to support the data and information needs needed to evaluate and make decisions so that all data and information can be integrated. Making a decision or policy in the field of natural resources and environmental management is closely related to the availability of data so that visualization and digitization are needed in the presentation of data, so that their utilization is more optimal.

The first step to visualize environmental management activity data is to collect data on environmental management activities from research and community service programs, training programs, and environmental services and consulting programs. The second stage is the design of the system interface design. The purpose of this interface design is to make the process of constructing a system/program easier and more structured. The last stage is data processing and data presentation using visual

models of bar charts, pie charts, line charts and maps that will produce data visualization in various forms as needed.

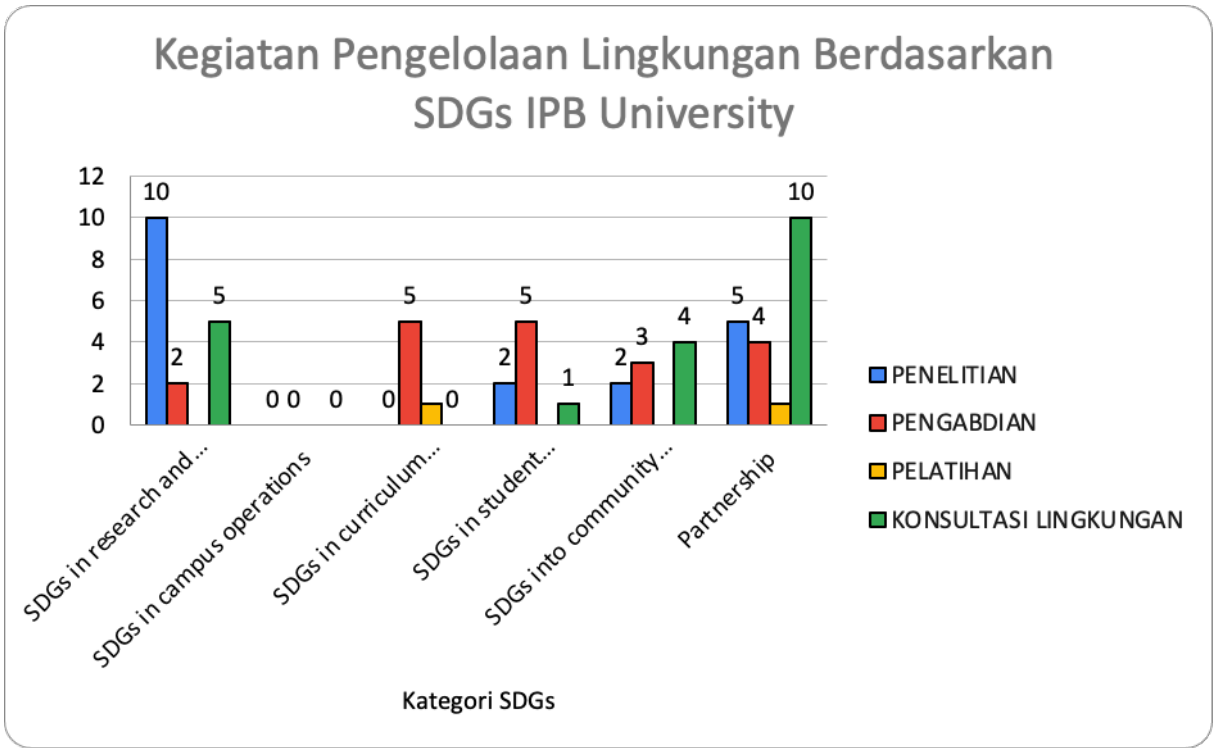

Figure 1. Data Visualization of environmental management activities based on the SDGs of IPB University

One of the efforts to integrate all data and information related to environmental management activities is to build a data visualization system. The development of a data visualization system for environmental management activities at the Center for Environmental Research (PPLH) of the Bogor Agricultural University (IPB) is the first step in processing ERC IPB's data and information to simplify, simplify, speed up, and process data and information into various variations of data presentation.

The measurement of the performance of environmental management activities in the IPB environment is measured using the SDGs of IPB University and the national SDGs. SDGs University consists of 6 objectives, namely 1) SDGs in Curriculum development and learning programs, 2) SDGs into community activities, 3) Partnerships, 4) SDGs in student engagement activities, 5) SDGs in campus operations, and 6) SDGs in research and innovation, while the national SDGS has 17 sustainable development goals.

Based on data processing and data presentation In Figure 1, regarding environmental management activities that have been carried out by ERC IPB over the last 5 years, most of them have contributed to SDGs in Research and Innovation and Partnership,

while the lowest contribution is regarding SDGs in campus operation. Therefore, programs/activities that support SDGs in Campus operation are needed so that all objectives can be achieved. As for the achievement of the SDGs nationally, the majority of ERC IPB's environmental management activities are in the SDGs Goal 6 (clean water and proper sanitation), Goal 11 (sustainable cities and communities), Goal 13 (Tackling climate change) and Goal 15 (land ecosystems).

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I. INTRODUCTION

1.1. Background

Currently, the world is entering the industrial era 4.0, where almost all industrial sectors have started and have used information technology as a tool to support their business activities. One of them is data visualization, which is an attempt to represent data into a form that is easier to understand in analysis.

ERC IPB is one of the oldest research institutions in Indonesia with a focus on activities in the field of natural resources and the environment. For approximately 44 years since its establishment in 1976 until now, there have been many research, service, and training activities as well as cooperation in the field of natural resource and environmental management carried out by ERC IPB with various parties, including government, private and international institutions.

So far, data on research, service, and training activities at ERC IPB have not been managed properly so that the leadership/management has difficulties in monitoring and evaluating the achievement of quality targets, especially regarding the distribution of activity locations and the achievement of the Sustainable Development Goals (SDGs). In addition, the data recapitulation of ERC IPB activities is still made in the form of manual reports (paper) for each period that has not been recorded/stored in the digital system. The manual report allows data to be lost or damaged so that data on activities that have been carried out for years are not recorded.

Based on the problems described above, a systematic effort is needed to build a database to support the data and information needs needed to evaluate and make decisions so that all data and information can be integrated. Making a decision or policy in the field of natural resources and environmental management is closely related to the availability of data so that visualization and digitization are needed in the presentation of data, so that their utilization is more optimal.

One of the efforts to integrate all existing data and information is to build a data visualization system. The main purpose of data visualization is to communicate information clearly and efficiently to users in the form of information graphics such as tables, graphs, and so on, so the data processing process and ultimately the decision-making process can be done quickly and precisely (Friedman, 2008; Maseri, 2008.

Data visualization can also be done in the form of maps. Through the map, the data can be seen the pattern of distribution so that the causes and interrelationships between spaces can be analyzed (Nolleburg, 2007).

1.2. Purpose

The purpose of this research is to design a web-based data visualization system to make it easier for the leadership/management to see the distribution of activities, the achievement of SDGs goals, and the preparation of monitoring-evaluation reports for each period. In addition, later this system is expected to be able to collect the data needed in the evaluation into a single unit to make it easier to search, analyze, and present data in the form of infographics so that the data is easy to understand which can then be used for consideration in decision making.

II. LITERATURE REVIEW

2.1. Environmental Management System

The definition of an environmental management system according to ISO 14001: 2004 is an internationally recognized environmental management system with a certificate issued by a Certificate Agency under the coordination of the International Standard Organization (ISO). The Environmental Management System (EMS) is part of the overall management system which includes organizational structure, activity plans, responsibilities, training or practices, procedures, processes and resources for the development, implementation, evaluation and maintenance of environmental policies (ISO 14001, 2004).

Environmental Management System (EMS) according to Tibor and Feldman (1997) is part of a management system that includes organizational structure, activity planning, responsibilities, practice procedures, processes and resources to develop, implement, achieve, review and maintain environmental policies (Tibor and Feldman, 1997). Based on the explanation above, it can be concluded that the environmental management system is a management system related to company policies that have the potential to impact the company's operating environment, where the management system must cover the entire process starting from planning, research, implementation, accountability, review and maintenance of policies. that has been generated.

Organizations or companies that will implement an EMS (Environmental Management System) need to prepare the following things (Indonesian National Standard (SNI) 19-14001, 2005).

1. Environmental Policy.

   According to ISO 14001: 2015 environmental policy is a document which contains the intent and direction of an organization related to the organization's environmental performance as officially stated by top management. Top management must establish the organization's environmental policy and ensure that the environmental policy is communicated to everyone working on the organization's behalf and includes a commitment to continual improvement and pollution prevention.

2. Planning

   Planning is an important component because if you fail to make a plan, you will experience problems in carrying out further activities. Things that need to be taken into account when making environmental planning are legal requirements, identification of environmental aspects, goals, objectives and environmental programs.

3. Implementation and Operations

   If the hospital expects to properly implement its environmental program, it must develop capabilities to support the environmental management system. The implementation of the environmental management system must pay attention to matters such as the responsibility structure, documentation and communication related to environmental aspects, and document control in order to facilitate effective environmental management.

4. Inspection

   The programs that have been made in the plan will be evaluated periodically through an environmental audit program. When audited, all programs that have been written will be evaluated and seen in the field whether the programs made are implemented or not. Programs that have not been implemented will be questioned about the reasons that led to the non-implementation of the program. Besides that, in an environmental audit, it can be known if there are irregularities in the implementation of the program.

5. Management Review

   Top management shall review the organization's environmental management system periodically, to maintain the continued suitability, adequacy and effectiveness of the system. The review should include assessing opportunities for improvement and the need to make changes to the environmental management system, including environmental policies, objectives, targets, and environmental programs.

2.2. Data Visualization

Data Visualization is the representation and presentation of data that exploits the ability of human visual perception to improve/strengthen thinking power (cognition). Presentation means a way of displaying data with various existing visual forms. Presentation means How to integrate data representation that has been made into an effective communication tool.

Data visualization is nothing new; Visual communication has existed in various forms for hundreds of thousands of years. The most popular techniques such as lines, bars, pies and graphs originated in the 18th century. Part of the growing so that it is considered as a novelty is the taste and interest in data visualization. Apart from that, technology has also developed as a catalyst, as well as a shift in culture towards transparency and ease of obtaining information.

Data Visualization Purpose

The main goals of visualization are:

1) Analysis: how to understand data, retrieve information and be comprehensive.
2) Communication: how to communicate information, involves simplification and involves a sense of value.

Data Visualization Process

The approach to designing good data visualizations can be broken down into several distinct steps. Data visualization steps:

1. Mapping
2. Selection
3. Presentation
4. Interactifivity
5. Publication
6. Evaluation

Data Visualization Techniques

Data visualization as a study of presenting data in a systematic form that includes attributes and variables in one unit of information has several techniques that continue to develop along with technological developments.

Data visualization is a way of simplifying interpretation and relationships. There are several interesting methods that have just been introduced, but are inseparable from implementation and uniformity issues. Here are some popular techniques in data visualization:

1) Table

   Tables are structured formats formed by rows and columns with certain relationships. row has other words like record, tuple or vector. Columns have other names such as field, parameter, attribute or property. Rows represent a set of values from a column.

2) Pie Chart

   Pie chart is also called diagram or circle graph. Pie charts are divided into sectors, each circle representing a proportion of the total. Pie charts are used to show size as a data comparison.

3) Bar Chart

   Bar Chart one of the most frequently used in data visualization. Bar charts are used to represent data horizontally. The vertical lengths of the bars represent the values. This chart is used to represent a single data series and data points related to groups of data in a series.Line

4) Chart

   Line Chart commonly used in various fields. Data points can be represented by symbols or straight lines without icons. This chart is used to visualize data trends over time intervals.

5) Area Chart

   Area chart used to display quantitative data. The area on the diagram represents bar chart data, you can see the comparison of limited areas. Area charts are used to differentiate data with volume distribution for the same entity.

6) Scatter Plot

   Scatter plot is a graphical display of a data set in Cartesian coordinates, showing the relationship between two variables, one variable being the horizontal distance (independent variable) and the second variable the vertical distance (the dependent variable) of the data points from the coordinate axes.

7) Bubble Chart

Bubble Chart actually a variation of the Cratter Plot where the data points are represented by dots and bubbles. The use of this diagram is due to the need to describe three values. One such use is in project management for comparing risk and success where three values must appear as net worth, probability of success and project cost.

8) Map

Map is a form of data visualization that contains geographic elements. In beta there are values formed in polygons. Maps have latitude and longitude values. Data visualization uses usage maps to describe the distribution area of either a country or a smaller or larger coverage.

III. METHODOLOGY

3.1. Place and Time of Research

The research was conducted at the Bogor Agricultural University Environmental Research Center, Bogor City, West Java Province. The duration of the research is 8 months, from January 2022 to August 2022.

3.2. Materials and Tools

The materials used in this study consisted of data from research, service, and training at PPLH IPB, both in the form of research reports or journals/papers. Data sources were obtained from 3 divisions in PPLH, namely community services and consulting division, research and community service division, and training division. The tools used in this study were Ms. Office and Google Data Studio.

3.3. Data Collection and Analysis Techniques

The main purpose of data visualization is to communicate information clearly and efficiently to users in the form of information graphs such as tables, graphs, maps and so on. This is because of the large amount of data and information that is managed by ERC IPB so that systemic efforts are needed to build a database to support the data and information needs needed in a work unit within ERC IPB so that all data and information can be integrated.

The first step to visualize environmental management activity data is to collect data on environmental management activities from research and community service programs, training programs, and environmental services and consulting programs. The second stage is the design of the system interface design. The purpose of this interface design is to make the process of constructing a system/program easier and more structured. The last stage is data processing and data presentation using visual models of bar charts, pie charts, line charts and maps that will produce data visualization in various forms as needed.

IV. GENERAL CONDITION OF STUDY AREAS

Environmental Research Center (ERC) was established in 1976 as Center for Resources and Environmental Management Study. Currently, it is named Environmental Center Research and is one of research centers in IPB University under coordination of Research and Community Services Institution, as of Education and Culture Ministry Decree No.0435/O/1992 on Statuta IPB and IPB Rector Decree No. 116/Um/1994.

ERC IPB is the oldest institution in Indonesia focusing its activities on natural resources and environment. ERC was formed based on necessary to establish a study center with objective to improve research capability and support Graduate School Study Program on Resource and Environmental Management.

As many as 50 researchers and supporting staffs ERC IPB are professionally ready and commit to cooperate and collaborate with various institutions, partners as well as stakeholders, as a contribution, responsibility and involvement in preserving and maintaining the sustainability of natural resources and environmental functions.

ERC has a vision toward a leading center for environmental researches in the sustainable development. ERC IPB acitivites are focusing on: education and training, research and community services, as well as services and public consultation within the scope of environmental management.

The target users of this web-based data visualization system are the leadership/management and data management staff in the ERC IPB work environment. The benefits of this system are:

a. Facilitate data collection, analysis and presentation of data in the form of infographics from ERC IPB activities in the field of environmental management so that it is easy to understand which can then be used for decision making considerations.
b. Facilitate the leadership/management of ERC IPB in monitoring and evaluating the achievement of quality targets, especially the achievement of SDGs goals.
c. Facilitate the leadership/management of ERC IPB in seeing the distribution of activities in the form of map visualization.

V. RESULT AND DISCUSSION

This process contains the preparation process before the data is processed into data visualization using Ms. Excel and Google Data Studio. In this study, the data was obtained by preparing data on research activities, community service and training at ERC IPB. The Data Source or data used for this analysis is research, service, and ERC IPB training data which is used as material for data visualization of the Sustainable Development Goals (SDGs).

The following is the result of data visualization of research, service and training activities registered at the IPB ERC which has been managed by researchers using Ms. Excel and Google Data Studio, based on the results of activities carried out by ERC IPB relating to environmental management with national SDGs indicators.

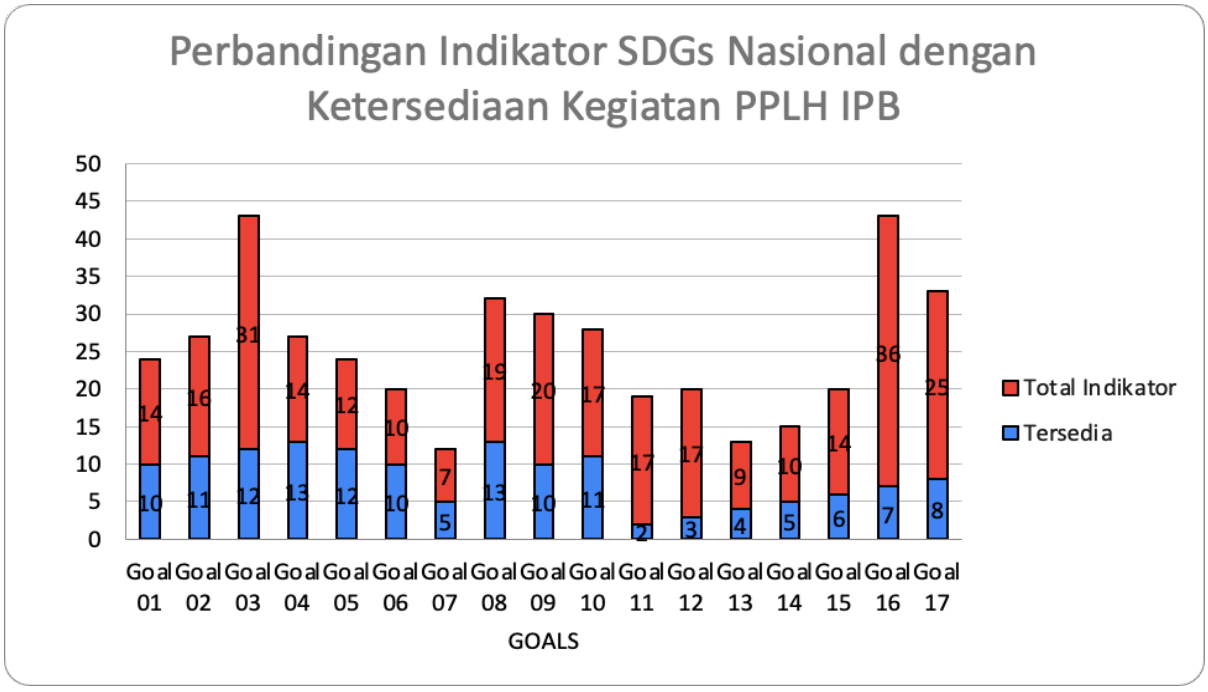

Figure 1. Data Visualization of environmental management activities based on the National SDGS indicators

The graph of the results of the data visualization that has been grouped based on environmental management activities at ERC IPB based on the IPB University SDGs indicators is as follows

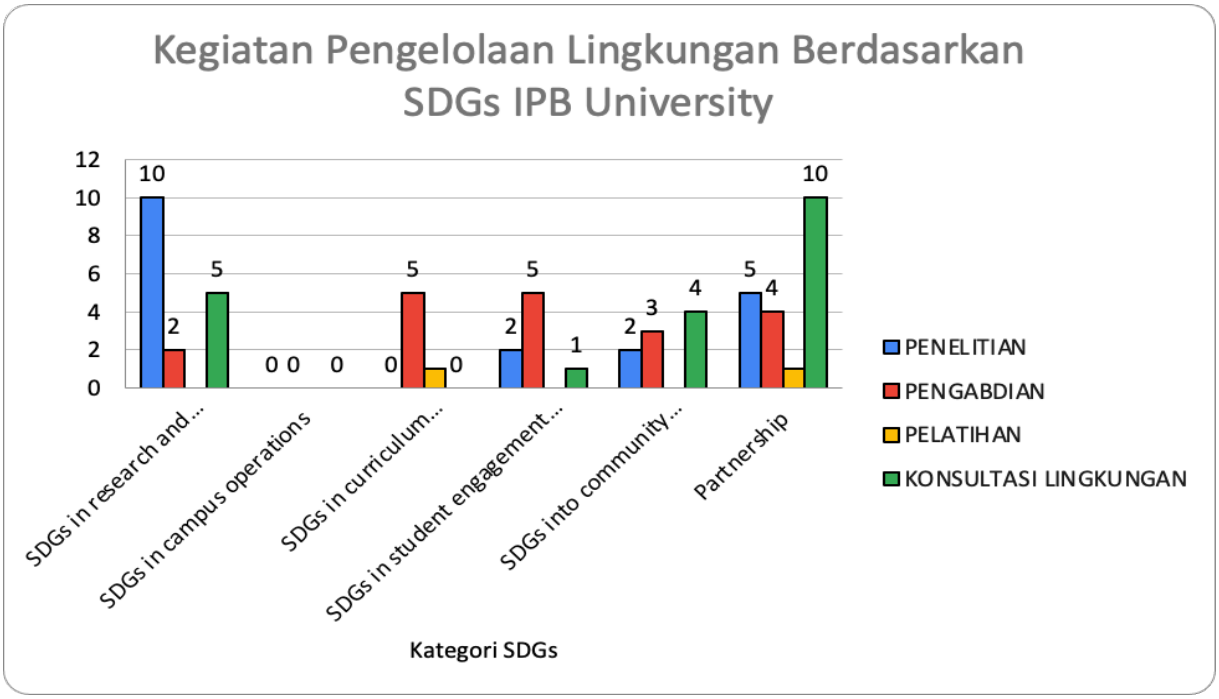

Figure 2. Data Visualization of environmental management activities based on the SDGs of IPB University

The graph of the results of the data visualization that has been grouped based on the total environmental management activities at the ERC IPB based on the SDGs is as follows

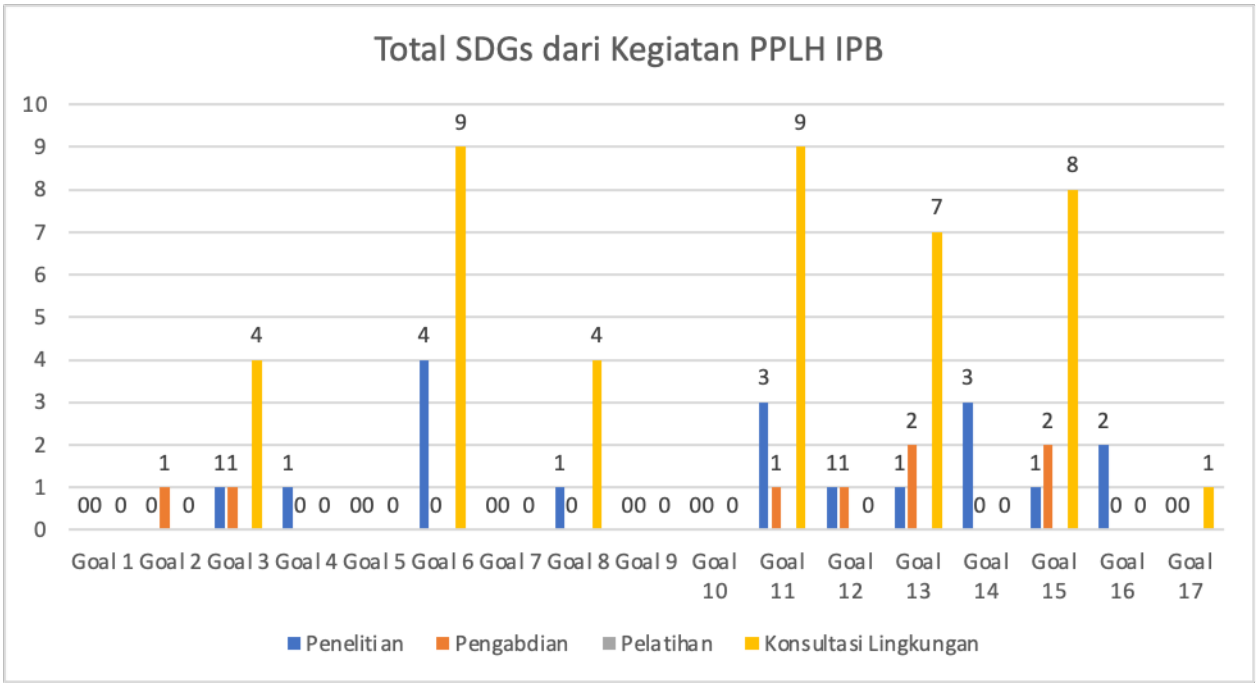

Figure 3. Data Visualization of Total SDGs based on environmental management activities

The results of the data visualization have been grouped based on the distribution of all ERC IPB activities using Ms. Excel and QGIS are as follows

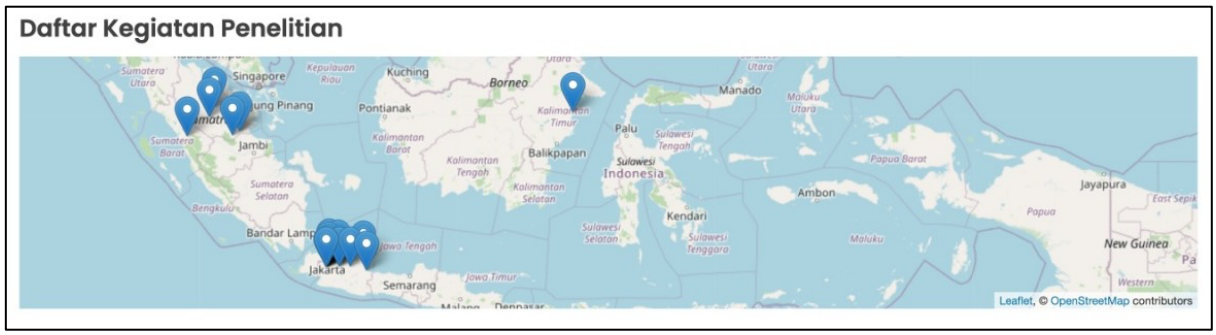

Figure 4. Data visualization of the distribution of ERC IPB research programs in Indonesia

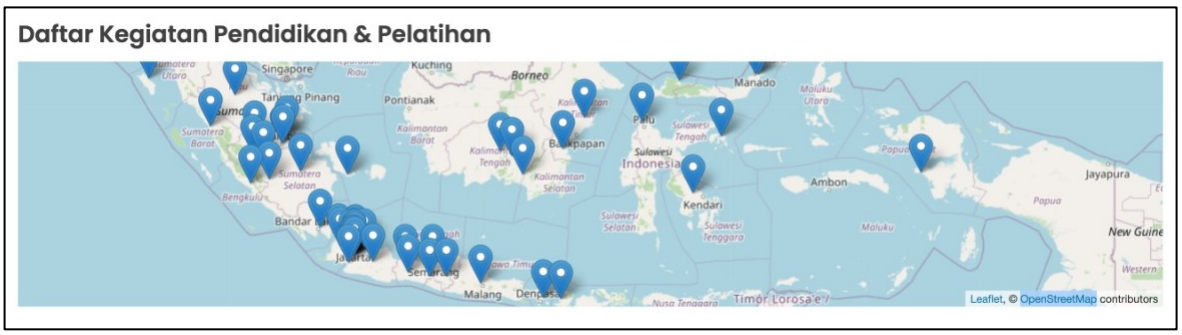

Figure 5. Data visualization of the distribution of ERC IPB education and training programs in Indonesia

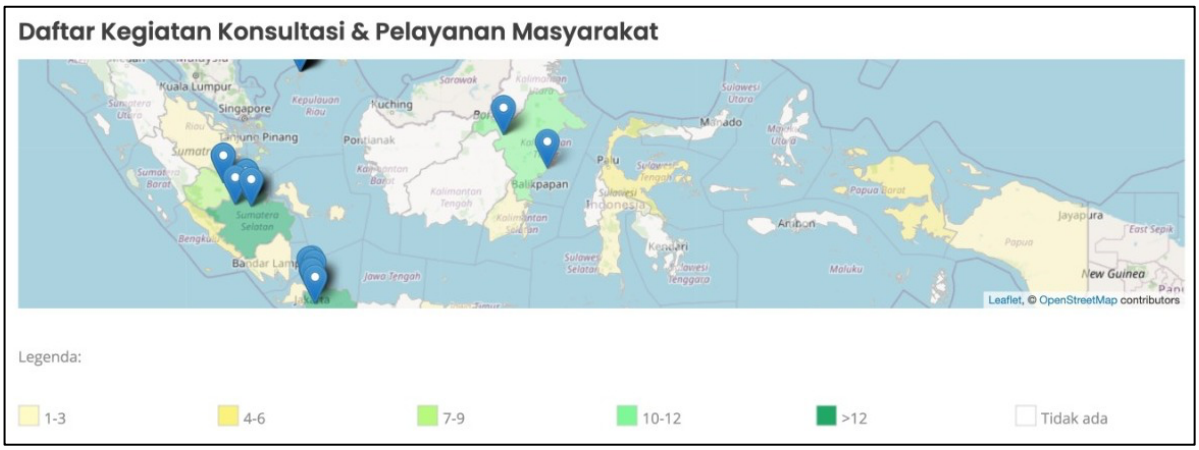

Figure 6. Data visualization of the distribution of ERC IPB services and public consultation programs in Indonesia

One of the efforts to integrate all data and information related to environmental management activities is to build a data visualization system. The development of a data visualization system for environmental management activities at the Center for Environmental Research (PPLH) of the Bogor Agricultural University (IPB) is the first step

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Based on data processing and data presentation In Figure 1, regarding environmental management activities that have been carried out by ERC IPB over the last 5 years, most of them have contributed to SDGs in Research and Innovation and Partnership, while the lowest contribution is regarding SDGs in campus operation. Therefore, programs/activities that support SDGs in Campus operation are needed so that all objectives can be achieved. As for the achievement of the SDGs nationally, the majority of ERC IPB's environmental management activities are in the SDGs Goal 6 (clean water and proper sanitation), Goal 11 (sustainable cities and communities), Goal 13 (Tackling climate change) and Goal 15 (land ecosystems).

VI. CONCLUSION AND RECOMMENDATION

6.1. Conclusion

Based on the results of the discussion above, the conclusion that is obtained is that data on research activities, community service, and ERC IPB training are managed using Ms. Excel, Google Data Studio, and QGIS and produce data visualizations in the form of graphs and maps. The data used is data on environmental management activities that have been carried out by ERC IPB for a period of 5 years. The results of the data visualization are grouped based on activities related to the SDGs and the distribution of IPB's ERC environmental management activities throughout Indonesia.

6.2. Recommendation

1) It is hoped that for further development it can be made into a better system so that it can carry out monitoring and evaluation for managing IPB ERC activity data.
2) It is hoped that other applications can be used to get better results for the development of IPB's ERC activities.

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RINGKASAN LAPORAN AKHIR
GERAN PENYELIDIKAN OSAKA GAS
END OF OSAKA GAS
GRANT REPORT SUMMARY

A.	**Tajuk Projek** ***Project Title***	: Numerical Simulation of Drying Process within a Novel Rotary Drying Machine for Palm Oil Sludge
	Ketua Penyelidik ***Project Leader***	**:** Dr Ahmad Adzlan Fadzli Bin Khairi
	Fakulti/Institut ***Faculty/Institute***	**:** Faculty of Engineering
	Ahli Kumpulan Penyelidik ***Research Team Members***	**:** 1. Assoc. Prof Dr Abdullah Hj Yassin 2. Dr Abang Mohammad Nizam Abang Kamaruddin 3. Assoc. Prof Dr. Mohamed Sukri Bin Mat Ali 4. Dr Nurshafinaz Bt Mohd Maruai
B.	**Tarikh Geran Diluluskan** ***Grant Approval Date***	**:** 4 December 2021
	Tempoh Projek ***Project Duration***	**:** 1 Jan 2022 – 31 Dec 2022 (12 months)
	Peruntukan Yg. Diluluskan ***Budget Approved***	**:** RM 10000.00
	Perbelanjaan Terkini ***Expenditure To-Date***	**:** RM 7999.90

C. Pencapaian Keseluruhan
Overall Achievement

Huraikan pencapaian berbanding objektif, hipotesis serta permasalahan asal yang diselidiki.
Describe the achievements in relation to the original objectives, hypothesis, and research problems.

Based on the objectives of the project:

1. **To compare the efficiency of the rotary drying process between several geometric designs of the rotary drying chamber, e.g., concentric annular chamber, off-centric annular chamber of varying sizes.**

   The performance of annular rotary drums was compared to that of their traditional counterparts, and the results have been obtained. It was discovered that a narrower gap between the inner and outer cylinders of the annular rotary drum leads to a higher pressure in the gap, resulting in improved moisture removal efficiency. However, this finding is only applicable when the centers of the inner and outer cylinders are offset from each other. These findings provide valuable insights into the advantages of using annular rotary drums, potentially leading to more efficient and effective moisture straining methods across various industries.

2. **To propose an efficiency curve for the rotary drying machine being developed against varying rotary speeds and temperature.**

   This research uses a very simplified approach to predicting moisture removal from sludge during the drying process. Rather than relying on a drying efficiency curve, the pressure distribution within the annular gap is based upon to provide valuable information for estimating moisture removal. Higher pressure levels in specific regions of the gap are indicative of greater moisture removal capabilities in the resulting rotary dryer prototype.

3. **To appraise the recommended amount of POMS volume in the rotary chamber in one drying cycle.**

   The process of moisture removal in the annular rotary dryer is dependent on the pressure applied to extract moisture from the sludge. However, the relationship between the volume of Palm Oil Mill Sludge (POMS) and moisture removal in the annular chamber is unclear. It is worth noting that an offset inner cylinder may necessitate a minimum diameter to effectively create a pressure difference within the annular chamber, which facilitates better moisture straining and consequently enhances the drying process.

D. Pencapaian Utama

Key Findings

The key findings of this project are stated as follows:

1. The quality of the mesh is preserved when the centre-offset is zero and the drum is rotated, but the mesh is unusable when an offset is introduced.
2. Separating the inner volume of the rotary drum allows the implementation of an OpenFOAM dynamic mesh handling scheme called arbitrary mesh interface (AMI).
3. Implementing AMI allows the quality of the mesh to be maintained even when the inner cylinder is rotating under nonzero-offset conditions.
4. The use of AMI secures a reliable and reproducible dynamic mesh motion for the implementation of the drying process in the future.

E, Hasil Penyelidikan
Deliverables

Sila tandakan item yang berkaitan pada senarai berikut:
Please tick the relevant items below:

	Item	Bilangan/*Number*
✓	Kertas teknikal/bersiri dalaman *Internal technical/serial papers*	5 (Final Year Project)
	Tesis/disertasi pelajar sarjana *Student's Masters thesis/dissertation*	
	Tesis pelajar PhD *Student's PhD thesis*	
	Kertas persidangan tempatan *Local conference papers*	
	Kertas persidangan antarabangsa *International conference papers*	
	Makalah dalam jurnal tempatan *Local journal papers*	
✓	Makalah dalam jurnal antarabangsa *International journal papers*	1 Journal
	Monograf atau buku *Book/monograph*	

Lain-lain/*others* (sila nyatakan/*please specify*)

Nil

Sila senaraikan maklumat (pengarang, tahun, tajuk, jurnal/penerbit, jilid, halaman) bagi penerbitan/tesis yang dihasilkan (jika ada).
Please specify the publications (authors, year, title, journal/publisher, volume, page nos.) (if any)

All conference papers and journal papers are in the process of publishing.

F. Pengecaman Output
Output Identification

Sila tandakan penerangan yang berkaitan pada senarai berikut:
Please tick the relevant description as given below:

	Suatu sumbangan besar kepada bidang ilmu yang berkaitan *A major contribution to knowledge (new knowledge) in the respective discipline*
√	Suatu sumbangan kecil tetapi bermakna kepada bidang ilmu yang berkaitan *A minor but important contribution to knowledge in the respective discipline*
	Suatu sumbangan besar kepada teknologi/ciptaan/algoritma dalam bidang yang berkaitan *A major contribution to technology/invention/algorithm or a tangible product*
√	Suatu sumbangan kecil tetapi bermakna kepada teknologi/ciptaan/algoritma berkaitan *A minor but important contribution to relevant technology/invention/algorithm*
√	Terdapat potensi yang baik untuk kajian lanjutan ke arah pemasaran *There is a good potential for further R & D and commercialization*
	Suatu sumbangan besar kepada kerangka polisi pengurusan/garis panduan *A major contribution to management policy framework/guidelines (in relevant areas)*
	Suatu sumbangan kecil tetapi bermakna kepada kerangka polisi pengurusan/garis panduan *A minor contribution to management policy framework/guidelines (in relevant areas)*
	Sesuai untuk dijadikan bahan pengajaran/*case study* atau bahan latihan *The finding is suitable for use as a complementary teaching/training material (a case study)*
	Suatu output yang baik dan berpotensi untuk memenangi hadiah penyelidikan *A quality output that has a potential for winning a research award*
	Suatu bahan yang baik/sesuai untuk hebahan atau pameran *A good/suitable material for showcasing/publicizing/exhibition*

Lain-lain/*Others* (Sila nyatakan/*Please specify*)

G. Sinopsis Hasil Penyelidikan bagi Tujuan Promosi

The rotary dryer plays a critical role in promoting sustainable palm oil production by converting the environmentally harmful palm oil mill sludge into fertilizer. This research focuses on investigating rotary dryers with an annular drum design using computational fluid dynamics simulation. The simulation of annular rotary drums creates a framework for evaluating multiple rotary drum designs. Our modular and open-source computational fluid dynamics framework allows for the addition of complexity with minimal effort, simplifying the first stage evaluation of a new annular rotary drum design. Our research findings have the potential to revolutionize sustainable palm oil production practices, contributing to the development of more eco-friendly processes.

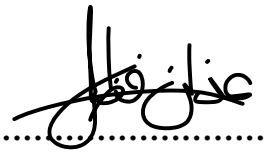
Catatan Penting/Important Notes

Penyelidik diminta mengemukakan kepada Pusat Penyelidikan:

- Borang ini dalam kedua-dua bentuk bercetak dan elektronik

Researchers are required to submit to the Research Centre:

- *This form in both hard- and soft-copies*



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Tandatangan (Penyelidik Utama) **Tarikh**
Signature (Principal Researcher) Date

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RECEIPT DATE: December 16th, 2022
REFERENCE: WCASET2022: 078-061

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Numerical Simulation of Drying Process within a Novel Rotary Drying Machine for Palm Oil Sludge

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ABSTRACT

This study investigated how to model a centre-offset annular rotary drum using OpenFOAM and the meshing software GMSH. The diameter of the outer cylinder D_o is 600 mm, diameter of the inner cylinder D_i 200 mm, the centre-offset $\alpha = 150$ mm, and rotation rate $n = 60$ rpm. When the centre-offset is zero, the quality of mesh is preserved as the drum rotates. Introduction of the offset causes the mesh to be deformed to the point of being unusable as the drum is rotated. The reason was found to be the fixed nodes adjacent to the walls of the outer and inner cylinder. These nodes only respect the motion of the wall they are adjacent to. To circumvent this, we separated the inner volume of the rotary drum to allow the implementation of an OpenFOAM dynamic mesh handling scheme called arbitrary mesh interface (AMI). Implementing AMI allows the quality of the mesh to be kept even when the inner cylinder is rotating under nonzero-offset conditions. This is because AMI permits the sliding of non-conforming meshes next to each other. This preserves the quality of the mesh and secures a reliable and reproducible dynamic mesh motion for the implementation of the drying process in the future.

1. Introduction

Palm oil has been one of the main drivers of the Malaysian economy, in addition to being one of its more effective instruments of expression in the geopolitical arena for over 50 years [1]. However, in recent years, environmental issues have been cited as grounds to impose restrictions on the nation's palm oil exports especially from the European Union and North America [2]. One of the main thrusts of the lobbying effort by the Malaysian government to ease the restrictions is by addressing the environmental concerns stemming from palm oil production. The treatment and repurposing of palm oil mill sludge can significantly cut down the amount of waste products released to the environment and harm the ecosystem, especially when it can be repurposed into fertiliser.

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The sludge is most commonly dried through ponding - or lagooning - as part of the palm oil mill effluent (POME) treatment process. However, ponding is totally reliant on evaporative drying and is therefore time-consuming [3]. Furthermore, this method of treatment results in soil and water quality degradation [4], with immediate adverse effects to communities located within the vicinity of the palm oil industry.

The drying process that is key to the manufacturing of fertiliser is known to be energy intensive. Previous efforts to improve the efficiency of the process includes the introduction of rotation to wring the moisture away from the sludge through centrifugation [5]. This process is known as dewatering as the water content is mechanically removed from the moist substrate whilst in liquid form. Drying, on the other hand, involves removal of moisture whilst in the gas phase; its transport dictated by the relative humidity of air, speed of air flow, and the pressure and temperature of the surrounding air. Increasing the moisture removal rate and ensuring product consistency have been the issues overshadowing further improvement of the rotary dryer, requiring extensive trial-and-error to guide the development process. In this study, we propose that the dewatering a drying process take place simultaneously in an annular rotary drum. In addition, by placing the inner cylinder at an offset from the axis of the outer cylinder, we imposed a pseudo-pressing motion on the sludge to augment the removal of liquid water from centrifugation (Figure 1). The literature review in the next section gives an account of the previous works that inspired this idea.

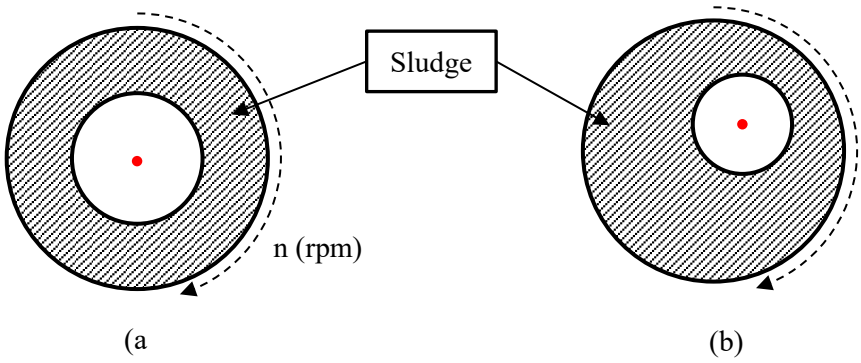

Fig. 1. The proposed annular rotary drum investigated in this study. (a) The coaxial annular rotary drum. (b) The offset annular rotary drum.

Computational fluid dynamics (CFD) can help expedite the trial-and-error loop and automate the testing of novel rotary drum designs and evaluate them against design targets. However, several challenges stand in the way of utilising CFD for numerical study of new rotary drum designs for sludge drying. For example, mathematical modelling of the sludge inside the rotary drum, implementation of the drying process, and imposing the rotation of the offset inner cylinder along a path parallel to the circumference of the outer cylinder. This work focuses on the latter, especially towards maintaining the quality of the mesh as the offset inner cylinder moves through the contents of the outer cylinder (rotary drum).

2. Literature Review

2.1 State-of-the-art of Drying Process

Drying, as opposed to dewatering, relies on the phase transition of water inside the moist substrate from liquid to gas. The change of phase from liquid to gas is mainly dependent on the saturation pressure and temperature of water under current atmospheric conditions. Other factors such as air movement, temperature and relative humidity

also contributes to the rate of drying. In Kaveh & Abbaspour-Gilandeh [6], the temperature of air is manipulated through the use of infrared (IR) lights in their rotary drying chamber for green peas. They demonstrated how the drying rate which is regulated by the temperature elevation, IR intensity and drum rotation speed all enhanced the slope of the drying curve. Kalashnikov & Chernyaev [7] on the other hand, looked into the usage of a fluidised bed as the heat transfer agent to improve uniformity of heating - which - when combined with periodic mechanical stirring, decreased the drying time of livestock feed by a factor of 1.2 to 2.

As higher temperatures in the drying chamber have been shown to improve the drying process, some have investigated how to achieve higher temperatures from a combustive heat source. In Coradi *et al*. [8], the source of heating comes from a gas burner. The combustion gases are then fanned over the moist substrate to accelerate the drying process. This study employed CFD as their methodology. Their results shown in Figure 2 highlighted the significance of convective heat transfer coefficient in determining the maximum temperature in the drying chamber.

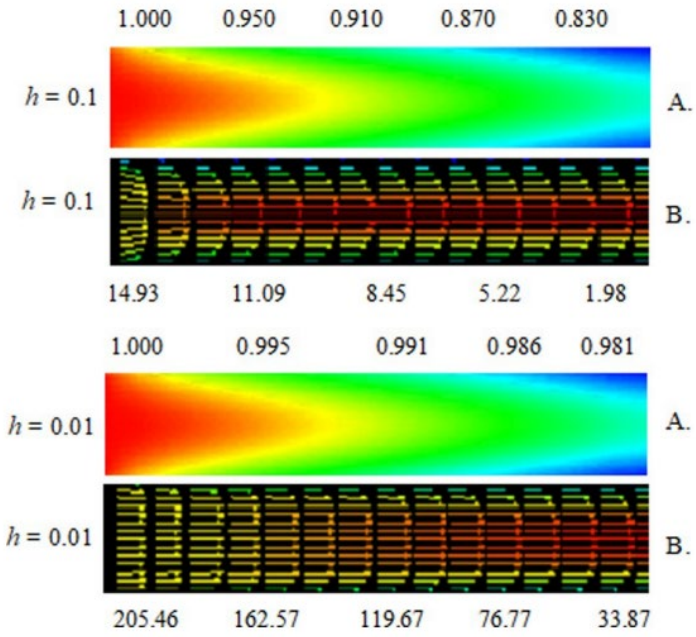

Fig. 2. The temperature map and velocity profiles inside the drying chamber for two different convective heat transfer coefficient h [8].

Inclusion of the drying process in numerical studies of requires using the appropriate mathematical model to simulate the process. To this end, Castro et al. [9] reviewed mathematical models of fruit drying which includes semi-empirical and fully theoretical ones. Semi-empirical models are based on the idea of thin layers, while fully theoretical ones study the heat, mass and momentum transfer in two subdomains: the air domain and the fruit domain. This system of non-linear transport phenomena is made up of partial differential equations (PDEs). The PDEs are equations based on the general transport equation, which can be used to generate physical laws like Newton's law for momentum transfer, Fick's second law for mass transfer, and Fourier's law for heat transmission through conduction. The PDEs might be coupled in their boundary conditions or in the thermophysical characteristics of the air and fruit.

Instead using heat generated from combustion and heating elements, Ploteau et al. [10] took a different approach using heat pumps to dry sewage sludge. Since heat pumps transports heat from a low-temperature thermal reservoir to a higher one, they were able to use the air exiting the drying chamber as their low-temperature thermal reservoir. To provide the desired conditions at the dryer intake, a portion of the dehydrated air is then mixed with ambient air,

depending on its characteristics, before entering the exchanger connected to the condenser. Thus, a small percentage of warm, wet air is released into the surrounding area. In the condenser of a heat pump, this air is heated. Then it interacts with the product at the cooled and humidified dryer stage while moving. Moreover, it is dehumidified fully or partially in the evaporator before being heated in the condenser.

From the literature reviewed thus far, heat is used to increase the kinetic energy of the molecules that make up the moist substrate and promote drying. However, heating often involves combustion and requires proper insulation to minimise unwanted heat loss that reduces the exergy that is otherwise available to accelerate the drying process. Mou & Chen [11] demonstrated a partial solution by blasting ultrasound to sewage sludge as a pre-treatment before the drying process takes place using hot air. They demonstrated the feasibility of this method resulting from reduced stratification of the sludge. This cuts down the drying time and results in more efficient fuel usage for heat supply.

2.2 State-of-the-art of the Dewatering Process

Dewatering involves removing the water content from the moist substrate while it is in the liquid phase. One of the methods used for dewatering is centrifugation. This means spinning the drum containing the moist substrate to force the moisture out by exploiting the centrifugal force. However, since the centrifugal force F_θ is given by

$$F_\theta = \omega r^2, \tag{1}$$

where ω (rad/s) and r (m) are the angular velocity of the object in curvilinear motion and the instantaneous radius of its path respectively, centrifugation is governed by these two parameters ω and r. Thus, to improve centrifugation, our choice is either to increasing ω, r, or both, depending on our dimensional constraints. Centrifugation should be exploited whenever feasible, but there exists another method that can be used for dewatering: mechanical pressing.

The mechanical press has been used to extract oil from seeds and the resulting oil has water as its constituent [12]. The press can either be of the hydraulic type, or the screw type (see Figure 3). If mechanical pressing such as these can be included as part of the overall moisture removal process, we can cut down on the energy expenditure for centrifugation, and for drying, since the moisture level has been reduced prior to the drying stage. Grosshagauer et al. [13] have argued for the conditioning of the moist substrate before the mechanical pressing stage. This includes uniformising the substrate to reduce stratification and lowering its temperature. Mushtaq et al. [14] also suggested that the mechanical pressing be done without heating. This is echoed in other works as well. For example, Satriana et al. [15], Muangrat et al. [16], Maestri et al. [17], and Patel et al. [18].

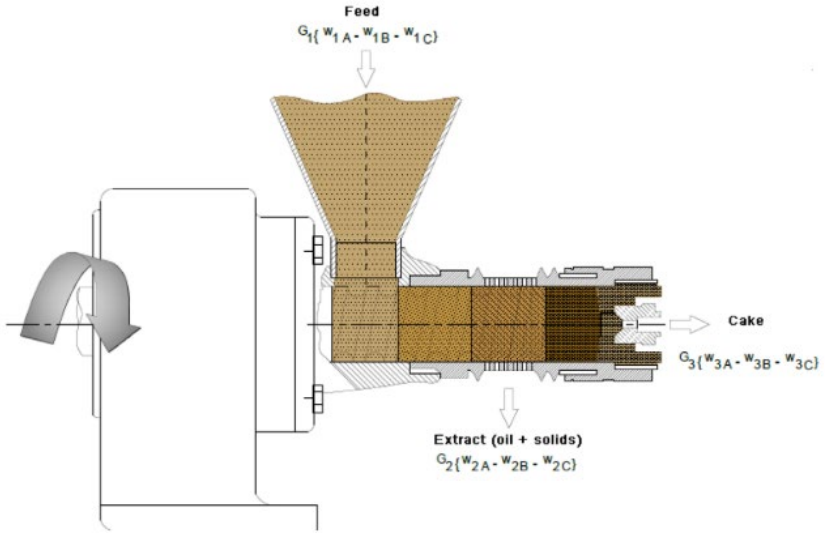

Fig. 3. A typical schematic of a screw press, from Maestri et al. [17].

It should be noted, nevertheless, that the literature cited above that argues for mechanical pressing at low temperatures are working towards extracting oil from seeds - not water. Therefore, they paid great attention to the purity and quality of the oil. Higher temperatures during the mechanical pressing leads to a drop in oil quality for the consumer because less desired chemicals are extracted through the process. This, however, can be a desirable result in dewatering palm oil mill sludge as we only want the water to be removed from the sludge, while other chemical components remain with the sludge to make a high-quality fertilizer.

On the subject of hydraulic pressing, Ivanov et al. [19] experimented with hydraulic pressing of moist peat soil in a bucket. They pointed to the importance of understanding the characteristics of pressure transfer in thin layers in selecting the hydraulic pressure to be applied. They also brought attention to the total perforated area on the bucket surface as a parameter that increases the efficiency of the drying. Mechanical drying has also been shown to cut down drying time for coffee beans [20].

Overall, the literature seems to suggest that there is still no precedent to the moisture removal process that includes centrifugation, mechanical pressing, and convective drying in one package. Therefore, this study seeks to address this gap by focusing our attention to the study of an annular rotary drum as sketched in Figure 1.

3. Methodology

3.1 Problem Geometry

The annular rotary drum is modelled as two cylinders of different diameters, with the smaller one placed inside the larger, shown in Figure 4. The diameter of the inner cylinder is denoted as D_i, diameter of the outer cylinder D_o, centre-offset between the axis of the inner to the outer cylinder α, and the rotation rate, n. In this investigation, $D_o = 600$ mm, $D_i = 200$ mm, $\alpha = 150$ mm and $n = 15$ rpm. These parameters are selected to allow simple testing of the ability to keep a good quality mesh while the rotary drum is spinning. To simplify the problem, the sludge is taken as possessing the properties of a Newtonian fluid.

(a) (b)

Fig. 4. The geometry of the annular rotary drum, where D_i, D_o, α, and n are the diameters of the inner and outer cylinders, offset between the axes of the inner to the outer cylinder, and the rotation rate of the drum, respectively.

To impose the mechanical pressing to the contents of the annulus, only the outer cylinder is rotated at n (rpm), while the inner cylinder has its position fixed during the tumbling cycle. Following momentum transport, the fluid inside the drum will start to spin in the same direction as the outer cylinder. While in rotation, the flux will pass through the narrow area when the inner and outer cylinder shells are at their closest. This repetitive pass-through creates a squeezing motion that creates the mechanical pressing for this setup.

3.2 Meshing and Dynamic Mesh Handling Procedures

Meshing is done using GMSH, a three-dimensional finite element mesh generator with built-in pre- and post-processing facilities. As shown in Figure 5, in GMSH, the annular cylinder is defined as two cylinders with diameters D_o and D_i - where $D_o > D_i$ - and the cylinder with diameter D_i placed inside the cylinder with diameter D_o. In the concentric annular drum, the inner and outer cylinders share the same axis. The internal region of the annulus is then divided into four equal areas, each with four sides. This allows us to implement quadrilateral cells inside the annulus (Figure 5(a)).

In Figure 5(b) the meshing for the off-centre annular drum is shown, and it also follows a similar scheme. The difference between Figures 5(a) and 5(b) lies in the area of each of the four regions the internal of the annulus is divided into - they are not of equal area. This cannot be overcome due to the offsetting of the internal cylinder. To ensure the use of quadrilateral cells inside the annulus, the region still needs to be divided into four enclosures, each with exactly four sides. As the inner cylinder is now closer to one side of the outer cylinder compared to the other, the mesh density in enclosure 1 is less than in enclosure 2 because both have the same number of cells, but the area of enclosure 2 is larger than enclosure 1.

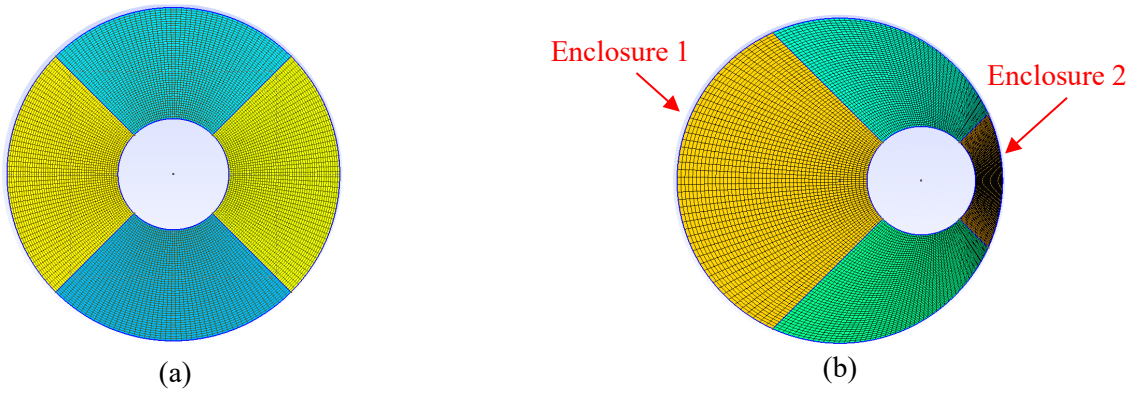

Fig. 5. Visualisation of the meshing scheme used for the annular cylinder. (a) shows the meshing for the concentric annular drum, while (b) shows the off-centre annular drum.

OpenFOAM is a free and open source C++ libraries developed to handle field operations and manipulations. It runs natively on Linux-based operating systems and can also be made to run on Windows and Mac operating systems with a few additional steps. As OpenFOAM runs natively on Linux, its interface is mainly textual, with the end used setting up case files and dictionaries that specify the simulation's initial and boundary conditions, fluid parameters and solver settings. The directory structure of a typical OpenFOAM case is shown in Figure 6, where the "0" (zero) directory lists the initial and boundary conditions, the "const" directory lists the fluid, thermal, and other parameters, while the "system" directory lists the solver control for the simulation.

The textual interface allows the OpenFOAM user to tap into the power of extensible text editors such as VIM or Emacs, and it also allows the user to quickly check their case files into a source control workflow, e.g., using Git. In OpenFOAM, several libraries exist natively to the platform for handling moving meshes. To access this capability, the user must define a dictionary, i.e., a text file, specifying how the motion of the mesh is defined - if predetermined - and handled - if resulting from the solution of the governing equations.

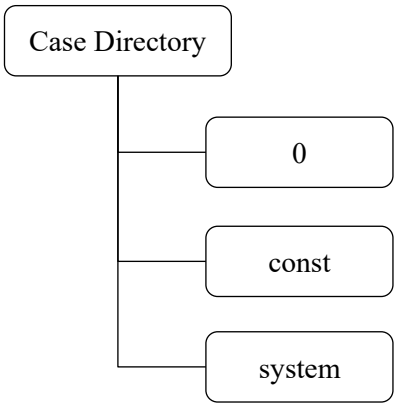

Fig. 6. A typical directory structure for an OpenFOAM case.

In prescribing the motion of the annulus, which in this case is rotational motion, a dictionary that describes the dynamic motion of the mesh - the "dynamicMeshDict" - is defined. For our case, a prescribed rigid body motion is chosen, as we are just looking to emulate the tumbling motion of the rotary drum. Therefore, the dynamicMeshDict is defined as the following code block in Figure 7. The code block specifies that the cell zone named "outerCylinder" is to be prescribed a rotational rigid-body motion that centers at coordinates $(x, y, z) = (0,0,0)$, and the angular velocity of the `outerCylinder` is kept constant at $15\ \text{rpm} = 90°/\text{s}$. OpenFOAM specifies the angular velocity of cell zones in degrees per second (°/s).

```
cellZone outerCylinder;
        solidBodyMotionFunction axisRotationMotion;
        axisRotationMotionCoeffs
        {
            origin         ( 0 0 0 );
            radialVelocity ( 0 0 90);
        }
```

Fig. 7. Defining the dynamicMeshDict for this mesh setup. The radial velocity is specified is units of degree per second (°/s).

4. Discussions

A simple implementation of the rigid-body motion described in Figure 7 on the mesh depicted in Figure 5(b) results in a severe deformation of the mesh inside the annulus. In OpenFOAM, it is possible to test the dynamic mesh motion without starting the solver. This is done by running the `moveDynamicMesh` utility on the case directory. This allows us to test the prescribed motion and study whether our setup of the mesh movement in sufficiently robust for the actual simulation.

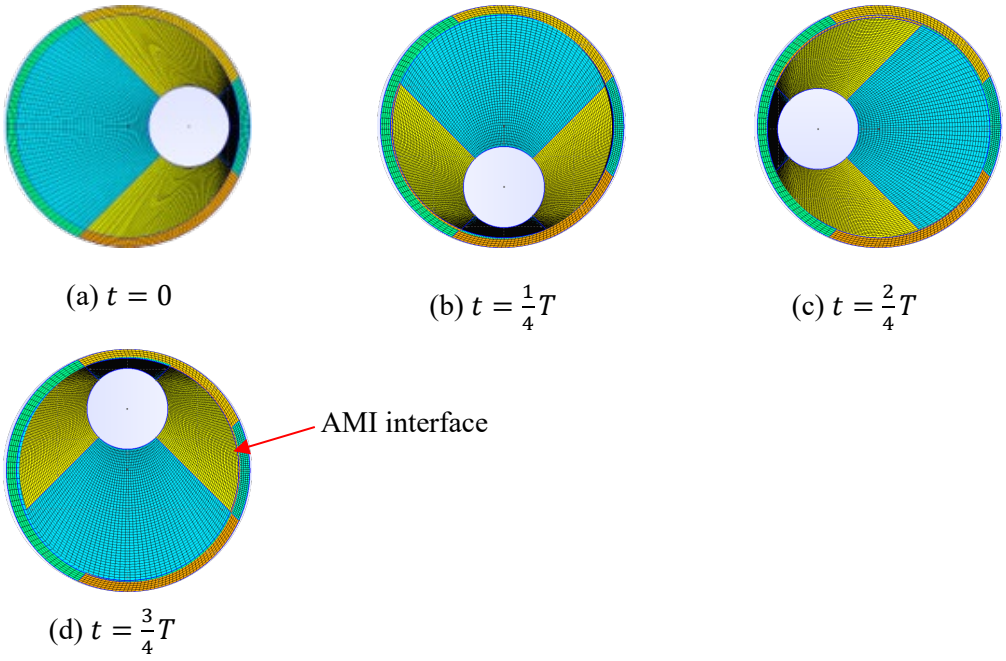

Fig. 8. The mesh motion of the offset-centre rotary drum at quarter cycle timings. Here, T is the period of the rotation.

As showcased in Figure 8, when the gap between the offset inner cylinder and the outer cylinder is further divided into separate regions, it is possible to implement the arbitrary mesh interface protocol to the mesh motion, while keeping a good quality mesh. This is because the mesh sliding can take place at the interface of the separation. As such, the problem of severe deformation of the mesh is circumvented, the mesh is now fit for use in further simulations.

5. Conclusions

This study investigated how to model a centre-offset annular rotary drum using OpenFOAM and the meshing software GMSH. The diameter of the outer cylinder D_o is 600 mm, diameter of the inner cylinder D_i 200 mm, the centre-offset $\alpha = 150$ mm, and rotation rate $n = 60$ rpm. When the centre-offset is zero, the quality of mesh is preserved as the drum rotates. Introduction of the offset causes the mesh to be deformed to the point of being unusable as the drum is rotated. Separating the inner volume of the rotary drum allows the implementation of an OpenFOAM dynamic mesh handling scheme called arbitrary mesh interface (AMI). Implementing AMI allows the quality of the mesh to be kept even when the inner cylinder is rotating under nonzero-offset conditions. This secures a reliable and reproducible dynamic mesh motion for the implementation of the drying process in the future.

Acknowledgement

The authors acknowledge Osaka Gas Foundation for Intercultural Exchange (INT/F02/IG-OSAKA/85049/2022) and Universiti Malaysia Sarawak for supporting this project. This research was also supported by UTM Fundamental Research, reference number PY/2019/01810 and cost number Q.K130000.2543.21H16.

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RINGKASAN LAPORAN AKHIR
GERAN PENYELIDIKAN OSAKA GAS
END OF OSAKA GAS
GRANT REPORT SUMMARY

A.	**Tajuk Projek** ***Project Title***	: Effects of Absorbed Vibration Energy on the Musculoskeletal Response of the Hand-Arm-Shoulder System of a Power Tool User
	Ketua Penyelidik ***Project Leader***	**:** Abang Mohamad Aizuddin bin Abang Mohamad Mohtar
	Fakulti/Institut ***Faculty/Institute***	**:** Faculty of Engineering
	Ahli Kumpulan Penyelidik ***Research Team Members***	**:** 1. Dr. Mohd Syahmi bin Jamaludin 2. Dr. Muhamad Fadzli bin Ashari 3. Hazmi Hijazi bin Abdul Halim 4. Azfar Satari bin Abdullah
B.	**Tarikh Geran Diluluskan** ***Grant Approval Date***	**:** 1 October 2021
	Tempoh Projek ***Project Duration***	**:** 1 Jan 2022 – 31 Dec 2022 (12 months)
	Peruntukan Yg. Diluluskan ***Budget Approved***	**:** RM 10,000.00
	Perbelanjaan Terkini ***Expenditure To-Date***	**:** RM 7,859.20

C. Pencapaian Keseluruhan
Overall Achievement

Huraikan pencapaian berbanding objektif, hipotesis serta permasalahan asal yang diselidiki.
Describe the achievements in relation to the original objectives, hypothesis and research problems.

Based on the updated objectives of the project:

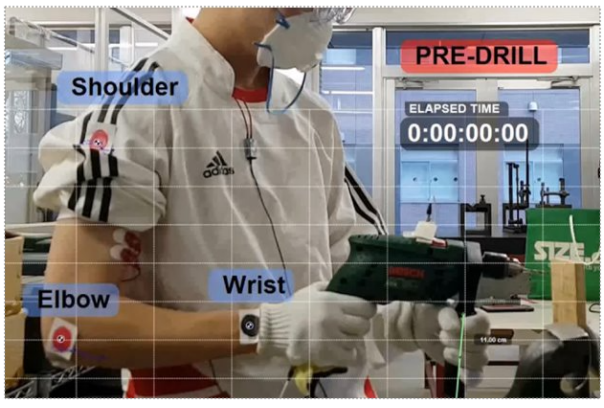
1.To examine the effects of vibration on the musculoskeletal response of the hand-arm-shoulder vibration (HASV) system.

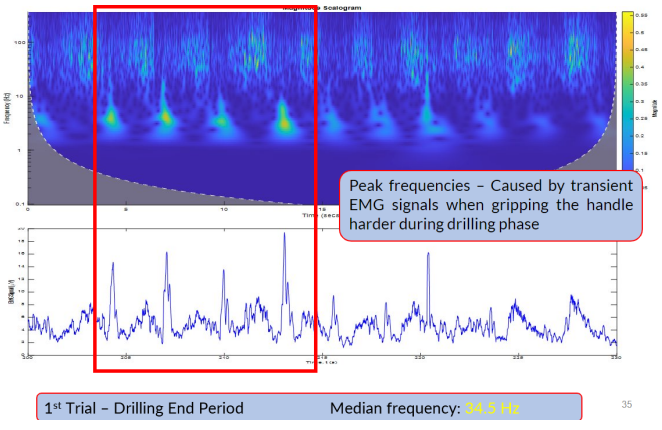
A testing rig was designed and fabricated to allow for recorded measurements of human subjects using power tool. However, vibration transmissibility measurements were not able to be obtained due to equipment and time constraints. This can be achieved in future research.

2.To measure and analyse the muscle activities of the HASV system using surface electromyography (sEMG) measurement system.

Muscle activities were recorded using a sEMG measurement system. A potential use of using Arduino based system will be recommended as a cost-effective system to acquire measurements. Employed Continuous Wavelet Transform (CWT) analysis as the chosen EMG data analysis. Possible use of CWT scalogram as a visual inspection analysis method for determining muscle fatigue is possibile.

Example of Results and Figures:





Example of Table of Results:

Muscle	Trial 1 Median frequency (Hz)		Trial 3 Median frequency (Hz)	
	Start	End	Start	End
Flexor carpi ulnaris	48.3	↓ 34.5	55.7	↓ 47.5
Biceps brachii	7.5	50.0	50.0	↓ 8.6
Trapezius p. descendenz	4.1	89.3	50.0	↓ 7.9

Observed decrease of median frequencies when comparing Start and End phases of the trials

36

Overall, the research was only able to achieve certain objectives and were not able to publsh within the project duration due to time and equipment constraints. More improvements were recommended and suggested such as below:

1. More testing using more human subjects with the designed test rig.
2. Conducting vibration musculoskeletal response measurements.
3. Finishing design of cost effective Arduino based sEMG measurement system.
4. Additional muscle grip strength comparison to validate muscle fatigue.

D. Pencapaian Utama

Key Findings

The key findings of this project are stated as follows based on the CWT scalograms:

1. Possible use of Continuous Wavelet Transform (CWT) scalogram as a visual inspection analysis method for determining muscle fatigue.
2. Median frequencies shift decrease indicates *flexor carpi ulnaris* muscle fatigue after 5 minutes of drill task. Median frequencies shift decrease indicates *biceps brachii* and *trapezius p. descendenz* muscle fatigue at the end of three trials of 5 minutes of drill task.
3. Peak frequencies were caused by transient EMG signals when gripping the handle harder during drilling phase. Brighter stripe zones indicates higher muscle activity.
4. Absorbed vibration energy during drilling (power tool activity) may contribute to faster muscle fatigue especially at the lower arm.

E, Hasil Penyelidikan
Deliverables

Sila tandakan item yang berkaitan pada senarai berikut:
Please tick the relevant items below:

	Item	Bilangan/*Number*
✓	Kertas teknikal/bersiri dalaman *Internal technical/serial papers*	5 (Final Year Projects)
	Tesis/disertasi pelajar sarjana *Student's Masters thesis/dissertation*	
	Tesis pelajar PhD *Student's PhD thesis*	
	Kertas persidangan tempatan *Local conference papers*	
	Kertas persidangan antarabangsa *International conference papers*	
	Makalah dalam jurnal tempatan *Local journal papers*	
	Makalah dalam jurnal antarabangsa *International journal papers*	
	Monograf atau buku *Book/monograph*	

Lain-lain/*others* (sila nyatakan/*please specify*)

Nil.

Sila senaraikan maklumat (pengarang, tahun, tajuk, jurnal/penerbit, jilid, halaman) bagi penerbitan/tesis yang dihasilkan (jika ada).
Please specify the publications (authors, year, title, journal/publisher, volume, page nos.) (if any)

No publication output was managed to be achieved within time. However, the results of this research can be published in an international conference in the future.

F. Pengecaman Output

Output Identification

Sila tandakan penerangan yang berkaitan pada senarai berikut:
Please tick the relevant description as given below:

	Suatu sumbangan besar kepada bidang ilmu yang berkaitan *A major contribution to knowledge (new knowledge) in the respective discipline*
√	Suatu sumbangan kecil tetapi bermakna kepada bidang ilmu yang berkaitan *A minor but important contribution to knowledge in the respective discipline*
	Suatu sumbangan besar kepada teknologi/ciptaan/algoritma dalam bidang yang berkaitan *A major contribution to technology/invention/algorithm or a tangible product*
	Suatu sumbangan kecil tetapi bermakna kepada teknologi/ciptaan/algoritma berkaitan *A minor but important contribution to relevant technology/invention/algorithm*
	Terdapat potensi yang baik untuk kajian lanjutan ke arah pemasaran *There is a good potential for further R & D and commercialization*
	Suatu sumbangan besar kepada kerangka polisi pengurusan/garis panduan *A major contribution to management policy framework/guidelines (in relevant areas)*
	Suatu sumbangan kecil tetapi bermakna kepada kerangka polisi pengurusan/garis panduan *A minor contribution to management policy framework/guidelines (in relevant areas)*
√	Sesuai untuk dijadikan bahan pengajaran/*case study* atau bahan latihan *The finding is suitable for use as a complementary teaching/training material (a case study)*
	Suatu output yang baik dan berpotensi untuk memenangi hadiah penyelidikan *A quality output that has a potential for winning a research award*
	Suatu bahan yang baik/sesuai untuk hebahan atau pameran *A good/suitable material for showcasing/publicizing/exhibition*

Lain-lain/*Others* (Sila nyatakan/*Please specify*)

G. Sinopsis Hasil Penyelidikan bagi Tujuan Promosi

The purpose of this research is to investigate the effects of absorbed vibration energy on muscle activity of the hand-arm-shoulder (HAS) system when performing a drilling exercise using an electric power tool. Muscle activity of the HAS system during a drilling exercise has been measured using a sEMG system. Simultaneous vibration and motion data were also collected to analyse the relation between the vibration effects to the muscles. The results showed that the median frequencies shift decrease indicating flexor carpi ulnaris muscle fatigue after 5 minutes of drill task. Median frequencies shift decrease indicated biceps brachii and trapezius p. descendenz muscle fatigue at the end of three trials of 5 minutes of drill task. This may imply that absorbed vibration energy during drilling (power tool activity) may contribute to faster muscle fatigue especially at the lower arm. As a conclusion, this research has investigated the effects of absorbed vibration on a power tool user and explored the possible use of Continuous Wavelet Transform (CWT) scalogram as a visual inspection analysis method for determining muscle fatigue.

Catatan Penting/Important Notes

Penyelidik diminta mengemukakan kepada Pusat Penyelidikan:

- Borang ini dalam kedua-dua bentuk bercetak dan elektronik

Researchers are required to submit to the Research Centre:

- *This form in both hard- and soft-copies*

…….	03 /03/2023 ……
Tandatangan (Penyelidik Utama) Signature (Principal Researcher)	**Tarikh** Date

DEVELOPMENT OF DRILLING TEST RIG FOR THE INVESTIGATION OF HAND ARM VIBRATION

Development Of Drilling Test Rig For The Investigation Of Hand Arm Vibration

NUR AMILEA BINTI RAHMAN

A dissertation submitted in partial fulfilment
of the requirement for the degree of
Bachelor Of Engineering with Honours
(Mechanical and Manufacturing

Faculty of Engineering
Universiti Malaysia Sarawak
2022

ABSTRACT

Drill is one of power tools that was commonly being used. Hand drill is used to make hole in a variety object. Hand drill can increase workers capacity and efficiency. However, hand drill user is exposed to physical stress such as hand arm vibration. Vibrating hand drill can be dangerous and can cause injury. Study on relationship between human and power tools has been conducted. Data on vibration is taken from the drilling activity from the experiment setup. However, there is no particular experiment set up on the experiment as mostly the experiment was held using a wood that clamped toward structure. Discomfort happened and experiment data error occur as the experiment need to be set up once again and the setup is not accurate every time. Solution in preventing the problem happened again is to conduct study on available test rig on drill with suitable functionality, to design a test rig for drilling activities and to analyze static analysis using software. In this study, a process of designing the test rig was made with combining and generating idea on solving the problem. Design was done step by step by analyzing concept selection and Pugh method until a design was generated using AutoCAD software and finalized design was produced. Simulation was later is made to validate and prove the structure is strong enough through static analysis. The design has slight deformation and the model show that the only slight bending and stress occur at the structure after it been applied by force. Lastly, after analysis have been made, the criteria that were set up is achieved and the design will not fail under load from drill.

THE DEVELOPMENT OF AN ACOUSTIC DETECTION SYSTEM FOR CHARACTERIZATION OF POWER TOOL ACTIVITY

Fikriwaihi Bin Hamzah

Bachelor of Engineering with Honours

(Mechanical and Manufacturing Engineering)

2022

ABSTRACT

Besides providing advantages such as saving energy and efficiency, the application of power tools also causes side effects to its users. One of the side effects mentioned is the arms injury such as Hand-arm Vibration Syndrome (HAVS) and arms muscle disorder. Previous research has been done to study this issue, regarding the analysis of power tools and its relationship with arms injury among the operators. However, there are still less research done to address the efficient step and method that can be used to avoid or lowering the risk of getting this injury from operating power tools. In order to solve this problem, a method or system need to be developed. One of the methods that can be proposed is to develop a detection system to alert the user regarding the level or characteristic of activity during operating power tools. Since this issue has a strong relationship between power tools operation and vibration level, there are several approaches that can be used for the detection system which are through muscle response using electromyography, video, and acoustics. To build a system that is more portable and ~~less prone to error~~, acoustic might be the best choice due to its non-complicated setup which only requires only microphone as sensor, and the measured signal also is airborne, which travels through sound waves making ~~it less prone to error.~~ Thus, this paper describes the development of acoustic detection system to characterise the power tools activity and the acoustic study of power tools activity. Therefore, through information gathered from this research, a risk prevention system could be developed to reduce the risk of using power tools among operators.

MOTION ANALYSIS ON HAND ARM SHOULDER MUSCULOSKELETAL SYSTEM OF A POWER TOOL USER

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2022

ABSTRACT

A power tool is a tool that is driven by a mechanism and power source rather than manual labor with hand tools. Just like any other machine, power tool is designed specifically to make the life of its operator easier. Power tools allow the user to be more productive and more efficient when completing their day-to-day task as they use less energy when compared to normal manual labor. As much as it brings so much benefit there are also some drawbacks. Oscillating mechanism in the power tool produce vibration. Excessive hand-transmitted vibration from the power tool could introduce health risk on the arm such as Hand-arm Vibration Syndrome (HAVS) and arms muscle disorder to the power tool user. Previous research has been done to investigate this issue. However, there are not enough research done regarding method and ways to analyze to find the optimal movement to reduce the risk of harming the power tool user when operating it. Therefore, a reliable analysis system is needed to solve this problem. Since this issue involves the movement of power tool user and the vibration from the power tool, motion capture analysis of power tool user is the best approach to analyze it. Basic of performing a motion capture analysis will require a camera and video annotation software such as Kinovea. By designing a motion capture analysis system to capture human movement and correlate it with muscle activity response during a power tool activity, an in-depth analysis can be made. The purpose of this paper is to discuss the process in designing and developing a motion analysis of the hand arm shoulder musculoskeletal system of a power tool user. At the end of this research paper, the likelihood of a power tool user to suffer a health risk on their arm due to a power tool is reduced.

DESIGN OF VIBRATION MEASUREMENT SYSTEM TO MEASURE VIBRATION OF HANDHELD POWER TOOLS

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2022

ABSTRACT

Power tools, in addition to delivering benefits such as energy savings and efficiency, also have negative side effects for their users. Arm damage, such as Hand-Arm Vibration Syndrome (HAVS) and arms muscle condition, is one of the negative effects described. Previous research into this subject has focused on the analysis of power tools and their relationship to arm injury among operators. However, there is currently a lack of study into the most effective step and method for avoiding or reducing the risk of this injury when using power tools. Vibration measurement system was to be studied. To design a simple and low-cost vibration measurement system, identification of the sensors and tools for vibration measurements were performed. Development of graphical user interface with MATLAB programming as tool for vibration measurement was also conducted and the visualizations of the vibration characteristics such as the acceleration, amplitude, frequency were also illustrated by implementations of the MATLAB vibration analysis program and MATLAB signal analyzer. The design was then undergoing a preliminary test by applying the fabricated vibration measurement system to measure vibration of a cordless hand driller in the horizontal and vertical directions.

INVESTIGATION ON EFFECTS OF HAND-TRANSMITTED VIBRATION ON THE MUSCLE ACTIVITY OF THE HAND-ARM-SHOULDER SYSTEM OF A POWER TOOL USER

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Mechanical and Manufacturing Engineering

2022

ABSTRACT

Power tools or hand-held vibrating tools such as electric hand drills, hand grinders, chain saws, jack leg drills, and many others are frequently used by workers in various industry. Contact with such power tools transmits vibration energy to a person's body, especially at hand-arm shoulder while working with them. This exposure to a portion of the worker's body is referred to as "vibration transmission." Hand-arm vibration syndromes (HAVS) and muscle fatigue, which affect the hands and arms, are the most typical side effects of such exposure. The major effects of transmitted vibration can be classified as vascular, neurological and musculoskeletal. This vibration not only influences the health but also efficiency and social life of workers. On the other side, electromyography (EMG) is a study of muscle function through the analysis of electrical signals emanated during muscular and muscle contractions. EMG signals, which produced by muscle activity have information such as muscle contractions, muscle strength and muscle weakness. The main objective of this research is to investigate the effects of hand-transmitted vibration on the muscle activity of the hand-arm-shoulder system of a power tool user by using EMG signal analysis. Several designated methodologies and methods are developed to fulfil and achieve the required objectives. In this study, three muscles at hand-arm shoulder system, which are biceps brachii, flexor carpi ulnaris and trapezius p. descendenz are monitored and recorded by using EMG and the signal are analyzed by using Matlab software. This research is a laboratory experimental study in which the subject was required to drill the wood under an exposure duration of 5 minutes using the electric hand drill in an upright standing position. The EMG signal processing method is used in the analysis. The results show that the all the three muscles were influenced by the transmitted-vibration produced by power tool, which flexor carpi ulnaris muscle is the most affected once compared to the other two muscles.