

ISBN: 978-979-8510-59-5

KATALOG

JURNAL MAHASISWA PASCASARJANA UNIVERSITAS LAMPUNG

VOLUME 2 NOMOR 1 TAHUN 2022



**BUKU 4
FT**



**PASCASARJANA
UNIVERSITAS LAMPUNG
MEI 2022**

TIM PENELAAH

PENANGGUNG JAWAB

Prof. Dr. Ahmad Saudi Samosir, ST., MT

PELAKSANA HARIAN

Dr. Maulana Mukhlis, S.Sos, M.IP

TIM PENELAAH

Prof. Rudy Situmeang, M.Sc
Prof. Drs. Simon Sembiring, Ph. D
Hari Kaskoyo, S.Hut., M.P., Ph.D
Hasan Azhari Nawi, S.Kom
Hernadi Susanto, S.H
Ahyani, S.I.Kom
Haidawati, S.T.P., MSi.
Hardian Sanjaya, S.Pd.

Desain Cover dan Tata Letak

Tim Aura Publishing

ISBN :

978-979-8510-59-5

Penerbit

Pascasarjana Universitas Lampung

Alamat Redaksi

PASCASARJANA
UNIVERSITAS LAMPUNG

Jalan Prof. Dr. Soemantri Brojonegoro, No. 1 Gedong Meneng
Bandar Lampung, 35145
Telp (0721) 783682
e-mail: pasca@kpa.unila.ac.id

SAMBUTAN DIREKTUR PASCASARJANA

Assalamu'alaikum Warahmatullahi Wabaraakatuh



Segala puji dan syukur kita panjatkan kehadirat Allah SWT, Tuhan Yang Maha Kuasa atas keberhasilan Pascasarjana Universitas Lampung menerbitkan “Katalog Jurnal Mahasiswa Pascasarjana Universitas Lampung Volume 2 Nomor 1 Tahun 2022” ini. Melalui penerbitan katalog ini, diharapkan dapat menjadi informasi dan membuka jalan interaksi yang lebih intens antara Pascasarjana Universitas Lampung dengan *stakeholders* di luar kampus. Katalog Jurnal Mahasiswa Pascasarjana ini dimaksudkan sebagai upaya penyebarluasan hasil penelitian mahasiswa Magister (S2) sehingga pemanfaatan hasil-hasil penelitian tersebut dapat dioptimalkan dalam meningkatkan kontribusi Universitas Lampung terhadap pembangunan daerah, bangsa, negara, serta bagi kemanusiaan, dan peradaban.

Saat ini, Pascasarjana sedang bertransformasi baik pada aspek kelembagaan, penjaminan mutu maupun aspek tridarma perguruan tinggi sebagai *core business* utamanya. Pada aspek kelembagaan, Pascasarjana sedang berupaya untuk meningkatkan status menjadi sekolah yang secara teknis berimplikasi terhadap skenario pembukaan program studi baru baik pada jenjang magister maupun jenjang doktor. Pada aspek penjaminan mutu, Pascasarjana sedang mendesain sistem penjaminan mutu internal yang lebih relevan dan aplikatif sehingga target peningkatan jumlah program studi magister dan doktor yang terakreditasi unggul dapat dicapai. Adapun pada aspek tri darma, sistem pembelajaran yang relevan dengan dunia kerja terus dikembangkan termasuk di dalamnya penelitian, pengabdian, dan publikasi ilmiah dosen maupun mahasiswa.

Atas nama pimpinan Pascasarjana Universitas Lampung, saya menyampaikan ucapan terima kasih kepada Tim Penelaah, para mahasiswa Pascasarjana di lingkungan Universitas Lampung, dan seluruh pihak yang telah berkontribusi dan bekerja keras sehingga Katalog Katalog Jurnal Mahasiswa Pascasarjana Universitas Lampung Volume 2 Nomor 1 Tahun 2022 ini dapat diterbitkan. Semoga Allah SWT; Tuhan Yang Maha kuasa senantiasa memberikan kemudahan dan petunjuk-Nya untuk kita semua.

Wassalamu'alaikum warahmatullahi wabarakatuh

Bandar Lampung, 16 Mei 2022
Direktur.

Prof. Dr. Ahmad Saudi Samosir, ST, MT
NIP. 197104151998031005

DAFTAR ISI

ANALISIS PRIORITAS PENANGANAN PERMUKIMAN KUMUH MENGGUNAKAN AHP DI KABUPATEN TULANG BAWANG BARAT Alhadi Pratama Bintang, Rahayu Sulistyorini, Vera Agustriana Noorhidana	1
LOW-CYCLE FATIGUE OF COLD-DRAWN TYPE 304 AUSTENITIC STAINLESS STEEL WITH ANNEALING TREATMENT Ambar Pambudi, Mohammad Badaruddin, Sugiyanto, Muh Thohirin	10
OPTIMIZATION OF PV/T-TEG GEOMETRY ON DIFFERENT OPERATING CONDITIONS USING CFD SIMULATION AND TAGUCHI DESIGN OF EXPERIMENT Prabowo. Angga, Nalis. Amrizal, Ibrahim. Gusri	18
CORRELATION OF RAINFALL DATA TRMM AND BMKG IN KALIMANTAN ISLAND Budi Setiyawan, Ahmad Zakaria, and Endro P. Wahono	34
DAMPAK MEKANIS DARI BATU LEMPUNG YANG DISEBABKAN OLEH SLAKING Dian Triyanto, Andius Dasa Putra, Endro Prasetyo Wahono	42
VALIDASI DATA CURAH HUJAN POS PENAKAR HUJAN DENGAN DATA CURAH HUJAN TRMM Hary Wijanarko, Ahmad Zakariab, Endro Prasetyo Wahonoc	54
THE DEVELOPMENT OF TANJUNG KARANG TRAIN STATION AREA BASED ON TRANSIT ORIENTED DEVELOPMENT (TOD) Heby Rakasiwi , Citra Persada , Rahayu Sulistyorini	64
THE DEVELOPMENT OF TANJUNG KARANG TRAIN STATION AREA BASED ON TRANSIT ORIENTED DEVELOPMENT (TOD) Heby Rakasiwi , Citra Persada , Rahayu Sulistyorini	80
THE RATIO OF BMKG AND TRMM RAINFALL DATA IN WEST JAVA PROVINCE BY USING STATISTICAL PARAMETER AND CORRELATION ANALYSIS Rian Alfian, Ahmad Zakaria, Endro Prasetyo Wahono, Dyah Indriana Kusumastuti, Ahmad Herison.....	95
SIMULATION OF IRRIGATION AREA BY USING DEPENDABLE FLOW BASIC YEAR AND BASIC MONTH JD Lantika, A Zakaria, and DI Kusumastuti,	112

ANALISIS PISANG METODE TRESHOLDING	KARAKTERISASI MENGUNAKAN	PENYAKIT KAMERA	PADA TERMAL	TANAMAN DENGAN	
Elka Pranita1, Dr. Eng. Helmy Fitriawan, S.T., M.Sc. 2, Dr. Eng. F.X. ArintoS., S.T., M.T.					121
FREQUENCY STABILITY CONTROL IN LOW - INERTIA POWER SYSTEM USING VIRTUAL SYNCHRONOUS GENERATOR					
Novia Utami Putri 1, Khairudin, Nining Purwasih.....					132
GREEN BUILDING ASSESSMENT AND RECOMMENDATIONS FOR OPTIMIZATION CASE STUDY OF THE RECTORATE BUILDING UNIVERSITY OF LAMPUNG					
Nur Syahidah Aini, Ika Kustiani, Masdar Helmi, Ratna Widayawati					139
BENEFIT ANALYSIS OF APPLICATION OF RAINWATER HARVESTING IN DUCK FARMING BUSINESS IN TERBANGGI BESAR-CENTRAL LAMPUNG					
Puji Tri Andika, Endro P. Wahono, Dyah Indriana Kusumastuti					147
PENGARUH PENGGUNAAN LAPISAN CAT DAN MATERIAL DINDING TERHADAP OVERALL THERMAL TRANSFER VALUE (OTTV) DINDING BANGUNAN					
Ruli Boyke Hastien, Muhammad Irsyad, Amrul					157
RELAY-BASED CLUSTERING METHOD FOR INTERFERENCE MANAGEMENT IN HETEROGENEOUS WIRELESS CELLULARNETWORK					
Misfa Susanto, Sitronella Nurfitriani Hasim, and Helmy Fitriawan.....					168
ANALISA DAMPAK MASUKNYA PHOTOVOLTAIC (PV) DALAM SKALA BESAR TERHADAP PERFORMA SISTEM TENAGA LISTRIK					
Ubaidah, Khairudin, Dikpride Despa, Lukmanul Hakim.....					190
KAJIAN KINERJA DAN KEBERLANJUTAN SPAMPERDESAAN DI LAMPUNG SELATAN					
Yeddy Andriansyaha, Endro P. Wahnob, Ahmad Zakaria					198

ANALISIS PRIORITAS PENANGANAN PERMUKIMAN KUMUH MENGGUNAKAN AHP DI KABUPATEN TULANG BAWANG BARAT

Alhadi Pratama Bintang^{*1}, Rahayu Sulistyorini², Vera Agustriana Noorhidana³

¹Mahasiswa Magister Teknik Sipil, Fakultas Teknik, Universitas Lampung

^{2,3}Dosen Teknik Sipil, Fakultas Teknik, Universitas Lampung

Jl. Prof. Dr. Sumantri Brojonegoro Bandar Lampung, 35145

Abstrak

Salah satu masalah yang sering timbul dalam proses pengembangan wilayah perumahan dan kawasan permukiman di Kabupaten Tulang Bawang Barat adalah masalah kekumuhan. Diperlukan penanganan yang efektif dan efisien terhadap masalah permukiman kumuh tersebut. Salah satunya dengan melakukan analisis prioritas kriteria permukiman kumuh dalam rangka penanganan daerah kumuh di Kabupaten Tulang Bawang Barat. Untuk itu dilakukan penelitian dalam menentukan sub kriteria yang paling prioritas pada daerah kumuh di Kabupaten Tulang Bawang Barat serta menentukan daerah kumuh yang menjadi prioritas penanganan dibanding daerah kumuh lain. Dalam penelitian ini analisis yang dilakukan menggunakan metode *Analytic Hierarchy Process* (AHP). Berdasarkan analisis dari hasil wawancara dan kuisioner terhadap 25 responden dengan kriteria khusus, maka diperoleh sub kriteria paling prioritas di Kelurahan Daya Murni adalah Ketidaksesuaian dengan Persyaratan Teknis Bangunan, di Kelurahan Mulya Asri adalah Kualitas Konstruksi Drainase, di Kelurahan Panaragan Jaya adalah Ketidakmampuan Mengalirkan Limpasan Air, Di Tiyuh Pulung Kencana adalah Sistem pengelolaan persampahan tidak sesuai standar teknis, di Tiyuh Bandar Dewa adalah Ketidakterediaan Akses Aman Air Minum dan Di Tiyuh Menggala Mas adalah Prasarana dan sarana pengelolaan air limbah tidak sesuai standar teknis. Selain itu diperoleh hasil bahwa Kelurahan Daya Murni merupakan daerah kumuh yang memerlukan penanganan lebih dibandingkan daerah kumuh lainnya.

Kata Kunci : Analisis Prioritas; Permukiman Kumuh; AHP.

Abstract

One of the most common problems in the process of developing residential areas in Tulang Bawang Barat District is slums. An effective and efficient handling of the problem of slum settlements is needed. One of them is by analyzing the priority criteria for slum settlements in the context of handling slum areas in Tulang Bawang Barat District. Therefore, research was conducted to determine the most priority sub-criteria in slum areas in Tulang Bawang Barat and to determine which slum areas were the priority for handling compared to others. In this study, the analysis was carried out using the Analytic Hierarchy Process (AHP) method. Based on the analysis of the results of interviews and questionnaires to 25 respondents with special criteria, the most priority sub-criteria in Daya Murni Village is Non-compliance with Building Technical Requirements, in Mulya Asri Village is Quality of Drainage Construction, in Panaragan Jaya Village is Inability to Flow Water Runoff, In Pulung Kencana Village, the waste management system is not in accordance with technical standards, in Bandar Dewa Village is the Unavailability of Safe Access to Drinking Water and in Menggala Mas Village, the infrastructure and facilities for waste water management are not in accordance with technical standards. In addition, the results obtained that the Daya Murni Village is a slum area that requires more handling than others.

Keywords : Priority Analysis; Slums; AHP.

A. PENDAHULUAN

Pengembangan wilayah perumahan dan kawasan permukiman merupakan salah satu pekerjaan utama yang di-laksanakan hampir diseluruh kabu-paten/kota di Indonesia. Hal ini tertuang dalam Undang-Undang Nomor 1 Tahun 2011 tentang Perumahan dan Kawasan Permukiman, yang menjelaskan bahwa Pemerintah provinsi dan pemerintah kabupaten/kota mempunyai tugas untuk menyusun rencana pembangunan dan pengembangan perumahan dan kawasan permukiman. Seperti yang dilakukan di Kabupaten Tulang Bawang Barat.

Salah satu masalah yang sering timbul dalam proses pengembangan suatu daerah adalah masalah permukiman kumuh. Upaya penanganan yang selama ini telah dilakukan selalu berbanding lurus dengan munculnya kawasan per-mukiman kumuh yang baru. Berdasarkan Keputusan Bupati Tulang Bawang Barat Nomor B/56/II.04/HK/TUBABA/2021 Tahun 2021 tentang Penetapan Lokasi Perumahan dan Permukiman Kumuh di Kabupaten Tulang Bawang Barat, ter-dapat enam daerah permukiman kumuh di Kabupaten Tulang Bawang Barat, yaitu di Kelurahan Daya Murni, Ke-lurahan Mulya Asri, Kelurahan Panaragan Jaya, Tiyuh Pulung Kencana, Tiyuh Bandar Dewa dan Tiyuh Menggala Mas.

Berdasarkan hal di atas, dalam rangka pencegahan dan peningkatan kualitas permukiman kumuh, Pemerintah Kabupaten Tulang Bawang Barat wajib melakukan perencanaan penanganan daerah kumuh dengan matang. Untuk itu, dilakukan penelitian dengan meng-analisis prioritas kriteria permukiman kumuh untuk mengetahui faktor yang paling dominan yang menyebabkan munculnya permukiman

kumuh pada masing-masing daerah permukiman kumuh di Kabupaten Tulang Bawang Barat sehingga penanganan permukiman kumuh di setiap daerah permukiman kumuh tersebut dapat dilaksanakan dengan efektif dan efisien

Dalam penelitian ini digunakan sistem pengambilan keputusan berupa *Analytic Hierarchy Process (AHP)*. AHP adalah suatu model/sistem pengambilan keputusan yang berguna dan fleksibel untuk membantu dalam menentukan prioritas dan membuat keputusan terbaik. Idris (2012) mengatakan AHP dilakukan dengan cara perbandingan berpasangan antara kriteria satu dengan kriteria yang lain serta subkriteria satu dan subkriteria yang lain. Hasil perbandingan ber-pasangan dibagi dengan jumlah elemen yang ada, sehingga diperoleh nilai prioritas dari setiap kriteria dan subkriteria yang dimaksud. Selanjutnya, nilai prioritas dikalikan dengan nilai keadaan alternatif untuk mendapatkan nilai akhir..

B. TINJAUAN PUSTAKA

1. Kawasan Permukiman Kumuh

Menurut Undang-Undang Nomor 1 Tahun 2011, pengertian kawasan permukiman merupakan bagian dari lingkungan hidup di luar kawasan lindung, baik berupa kawasan perkotaan maupun perdesaan, yang berfungsi sebagai lingkungan tempat tinggal atau lingkungan hunian dan tempat kegiatan yang mendukung perikehidupan dan penghidupan. Permukiman terbentuk dari kesatuan kata isi dan wadah, yaitu kesatuan antara manusia sebagai peng-huni (isi) dengan lingkungan hunian (wadah) akan membentuk suatu ko-munitas yang secara bersamaan dapat membentuk suatu permukiman yang mempunyai dimensi yang sangat luas, dimana batas dari permukiman biasanya berupa batasan geografis yang ada dipermukaan bumi, misalnya suatu wilayah atau benua yang terpisah karena lautan (Maretta dkk, 2019).

Jumlah penduduk Kabupaten Tulang Bawang Barat berdasarkan Sensus Penduduk tahun 2020 sebanyak 286.162 jiwa yang terdiri atas 146.355 jiwa penduduk laki-laki dan 139 807 jiwa penduduk perempuan. Kepadatan pen-duduk di Kabupaten Tulang Bawang Barat tahun 2020 mencapai 238 jiwa/km². Pertumbuhan penduduk Kabupaten Tulang Bawang Barat pada tahun 2020 terhadap tahun 2010 adalah sebesar 0,013% setiap tahunnya (BPS Kabupaten Tulang Bawang Barat, 2021). Pertumbuhan dan perkembangan pen-duduk yang cukup pesat saat ini berdampak pada berbagai bidang di-antaranya di bidang fisik lingkungan, sosial, maupun ekonomi yang me-merlukan ketersediaan prasarana dan sarana dasar yang secara umum akan bersifat susul menyusul dengan laju pertumbuhan penduduk. Kurang ter-sedianya sarana dasar ini akan meng-akibatkan tumbuhnya beberapa bagian wilayah menjadi kawasan kumuh.

Menurut Wiarni, dkk (2018), kawasan kumuh merupakan suatu wilayah yang memiliki kondisi ling-kungan yang buruk, kotor, penduduk yang padat serta keterbatasan ruang (untuk ventilasi cahaya, udara, sinitasi, dan lapangan terbuka). Kondisi yang ada seringkali menimbulkan dampak yang membahayakan bagi kehidupan manusia (misalnya kebakaran dan kriminalitas) sebagai akibat kombinasi berbagai faktor (Hariyanto, 2007).

2. Kriteria Permukiman Kumuh

Menurut Peraturan Menteri PUPR Nomor 2 Tahun 2016 Tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, terdapat beberapa kriteria yang di-gunakan untuk menentukan kondisi kekumuhan pada perumahan kumuh dan permukiman kumuh. Kriteria pertama yaitu kondisi bangunan gedung yang terdiri dari ketidakteraturan bangunan, tingkat kepadatan bangunan dan ketidak-sesuaian dengan persyaratan teknis bangunan. Kriteria kedua yaitu kondisi jalan lingkungan yang terdiri dari cakupan pelayanan jalan lingkungan dan kualitas permukaan jalan lingkungan. Kriteria ketiga yaitu kondisi penyediaan air minum yang terdiri dari ketidak-tersediaan akses aman air minum dan tidak terpenuhinya kebutuhan air minum.

Kriteria keempat yaitu kondisi drainase lingkungan yang terdiri dari ketidakmampuan mengalirkan limpasan air, ketidaktersediaan drainase, ketidak-terhubungan dengan sistem drainase, tidak terpeliharanya drainase dan kualitas konstruksi drainase. Kriteria kelima yaitu kondisi pengelolaan air limbah yang terdiri dari sistem pengelolaan air limbah tidak sesuai standar teknis serta prasarana dan sarana pengelolaan air limbah tidak sesuai standar teknis. Kriteria keenam yaitu kondisi pengelolaan persampahan yang terdiri dari prasarana dan sarana persampahan tidak sesuai standar teknis, sistem pengelolaan persampahan tidak sesuai standar teknis, dan tidak ter-peliharanya sarana dan prasaran. Kriteria terakhir yaitu kondisi proteksi kebakaran yang terdiri dari ketidaktersediaan pra-sarana proteksi kebakaran dan ketidak-tersediaan sarana proteksi kebakaran.

3. *Analytic Hierarchy Process* (AHP)

AHP merupakan salah satu sistem pengambilan keputusan yang memiliki keunggulan dibandingkan sistem peng-ambilan keputusan yang lain. Menurut Pahtoni dan Tasrif (2020), hal ini disebabkan proses penentuan keputusan dilakukan dengan terstruktur, melakukan bobot penilaian kepentingan sebanyak dua kali dan hasil dari perhitungan dapat dijadikan acuan dalam proses penentuan keputusan.

AHP menuntun ke suatu perkiraan menyeluruh tentang kebaikan dan keburukan setiap alternatif, mempertim-bangkan prioritas-prioritas relatif dan berbagai faktor, dan memilih alternatif terbaik berdasarkan tujuan dalam pengambilan keputusan (Maharani, 2017). AHP merupakan suatu model pendukung keputusan yang dikembang-kan oleh Thomas L. Saaty. Model pendukung keputusan ini akan mengurai-kan masalah multi faktor atau multi kriteria yang kompleks menjadi suatu hirarki (Saaty, 1993).

Tahapan yang dilakukan dalam penggunaan metode AHP adalah pe-nyusunan hirarki, menentukan prioritas dengan cara menyusun matriks ber-pasangan, menghitung nilai eigen dan rata-ratanya, serta dihitung pula nilai konsistensi logis sebagai pembuktian akan kualitas data.

C. METODOLOGI PENELITIAN

1. Lokasi Penelitian

Penelitian ini dilakukan pada Daerah Permukiman Kumuh di Kabupaten Tulang Bawang Barat yaitu Kelurahan Daya Murni, Kelurahan Mulya Asri, Kelurahan Panaragan Jaya, Tiyuh Pulung Kencana, Tiyuh Bandar Dewa dan Tiyuh Menggala Mas.

2. Pengumpulan Data

Data Primer didapatkan dengan cara wawancara dan penyebaran kuisioner kepada beberapa stakeholder dengan teknik *purposive sampling* yaitu responden dianggap sebagai orang yang mengetahui tentang permukiman kumuh di Kabupaten Tulang Bawang Barat seperti Dinas Perumahan, Kawasan Permukiman dan Pertanahan, Dinas Pe-kerjaan Umum dan Tata Ruang, Badan Perencanaan Pembangunan Daerah serta para tenaga ahli yang berkompeten dengan total responden berjumlah 25 orang yang memiliki pengalaman mini-mal 1 tahun dibidang permukiman kumuh. Sedangkan data sekunder didapat dari studi literatur dan kepustakaan.

Prosedur penelitian dilakukan dengan cara identifikasi masalah, di-lanjutkan dengan pengumpulan dan pengolahan data, kemudian dilakukan analisis data untuk selanjutnya ditarik kesimpulan.

Tabel 1. Kriteria Dan Sub Kriteria Permukiman Kumuh

Kriteria (Kode)	Sub kriteria (Kode)
Kondisi Bangunan Gedung (K1)	Ketidakteraturan Bangunan (S1)
	Tingkat Kepadatan Bangunan (S2)
	Ketidaksesuaian dengan Persyaratan Teknis Pembangunan (S3)
Kondisi Jalan Lingkungan (K2)	Cakupan Pelayanan Jalan Lingkungan (S4)
	Kualitas Permukaan Jalan Lingkungan (S5)
Kondisi Penyedia Air Minum (K3)	Ketidakterediaan Akses Aman Air Minum (S6)
	Tidak Terpenuhi Kebutuhan Air Minum (S7)
Kondisi Drainase Lingkungan (K4)	Ketidakkampuan Mengalirkan Limpasan Air (S8)
	Ketidakterediaan Drainase (S9)
	Ketidakterhubungan dengan Sistem Drainase (S10)
	Tidak terpeliharanya drainase (S11)
Kondisi Pengolahan Limbah (K5)	Kualitas Kontruksi Drainase (S12)
	Sistem Pengelolaan Air Limbah tidak sesuai standar teknis (S13)
Kondisi Penglolaan Sampah (K6)	Prasarana dan sarana pengelolaan air limbah tidak sesuai standar teknis (S14)
	Prasarana dan sarana persampahan tidak sesuai standar teknis (S15)
	Sistem Pengelolaan persampahan tidak sesuai standar teknis (S16)
Kondisi Proteksi Kebakaran (K7)	Tidak terpeliharanya sarana dan prasarana (S17)
	Ketidakterediaan prasarana proteksi kebakaran (S18)
	Ketidakterediaan sarana proteksi kebakaran (S19)

D. HASIL DAN PEMBAHASAN

Pengumpulan data didapatkan dengan cara wawancara dan pembagian kuisioner. Setelah data yang diinginkan didapat, dilakukan analisis dengan menggunakan metode AHP. Hal pertama yang dilakukan adalah penyusunan matriks perbandingan nilai prioritas berdasarkan data yang didapatkan sebelumnya. Kemudian dilakukan perhitungan nilai eigen beserta nilai rata-ratanya. Selain itu dilakukan pula pengecekan nilai konsistensinya sebagai penanda bahwa data yang diolah adalah konsisten. Selanjutnya dilakukan perbandingan terhadap alternatif penanganan daerah permukiman kumuh di Kabupaten Tulang Bawang Barat sehingga didapatkan perangkingan prioritas penanganan pada masing-masing daerah permukiman kumuh tersebut seperti terlihat pada Tabel 2.

Tabel 2. Prioritas sub kriteria pada Daerah kumuh Di Kabupaten Tulang Bawang Barat

Rangking	Daerah Permukiman Kumuh					
	Daya Murni	Mulya Asri	Panaragan Jaya	Pulung Kencana	Bandar Dewa	Menggala Mas
1	S3	S12	S8	S16	S6	S14
2	S12	S13	S14	S9	S15	S18
3	S10	S18	S6	S19	S13	S8
4	S17	S1	S13	S8	S1	S4
5	S2	S15	S5	S7	S14	S6
6	S11	S11	S1	S10	S18	S11
7	S4	S6	S18	S5	S8	S13
8	S9	S3	S15	S14	S16	S17
9	S16	S4	S7	S17	S4	S9
10	S5	S19	S2	S2	S9	S19
11	S7	S9	S19	S6	S19	S3
12	S19	S10	S17	S4	S3	S7
13	S18	S7	S16	S13	S10	S10
14	S1	S5	S4	S1	S11	S1
15	S15	S8	S11	S18	S5	S15
16	S8	S16	S9	S15	S7	S12
17	S14	S14	S10	S11	S12	S5
18	S6	S17	S3	S3	S2	S2
19	S13	S2	S12	S12	S17	S16

Kemudian dilakukan pula perangkingan daerah permukiman kumuh yang diprioritaskan untuk dilakukan penangan-an seperti terlihat pada Tabel 4.

Tabel 3. Prioritas Penanganan Daerah Kumuh

Rangking	Daerah Permukiman Kumuh	Nilai Prioritas
1	Daya Murni	1.174709229
2	Pulung Kencana	0.843778464
3	Mulya Asri	0.765268609
4	Panaragan Jaya	0.461425874
5	Menggala Mas	0.339443383
6	Bandar Dewa	0.308308925

Berdasarkan hasil analisis data menggunakan metode AHP yang telah dilakukan pada enam daerah permukiman kumuh di Kabupaten Tulang Bawang Barat didapatkan data sub kriteria prioritas setiap daerah yang berbeda-beda guna pengentasan masalah daerah permukiman kumuh. Pada Kelurahan Daya Murni, sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah ketidaksesuaian dengan persyaratan teknis yang terdapat pada kriteria utama kondisi bangunan gedung. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, kondisi bangunan gedung pada perumahan dan permukiman yang tidak sesuai dengan persyaratan teknis terdiri dari pengendalian dampak lingkungan, pembangunan bangunan gedung di atas dan/atau di bawah tanah, di atas dan/atau di bawah air, di atas dan/atau di bawah prasarana/sarana umum, keselamatan bangunan gedung, kesehatan bangunan gedung, kenyamanan bangunan gedung serta kemudahan bangunan gedung. Pada kondisi eksisting, terlihat indikator ketidaksesuaian dengan persyaratan teknis, hal ini ditandai dengan terdapatnya beberapa bangunan yang berada dibawah area irigasi yang posisinya berada di dalam garis sepadan saluran irigasi serta terdapatnya bangunan yang posisinya berada di dalam garis sempadan bangunan.

Pada Kelurahan Mulya Asri sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah kualitas konstruksi drainase yang terdapat pada kriteria utama kondisi drainase lingkungan. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, kualitas konstruksi drainase lingkungan buruk merupakan kondisi dimana kualitas konstruksi drainase karena berupa galian tanah tanpa material pelapis atau penutup atau telah terjadi kerusakan. Pada kondisi eksisting, terlihat indikator kualitas konstruksi drainase yang buruk, hal ini ditandai dengan banyaknya saluran drainase yang telah mengalami kerusakan dan beberapa saluran drainase dengan konstruksi masih berupa galian tanah tanpa pelapis.

Pada Kelurahan Panaragan Jaya sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah ketidak mampuan mengalirkan limpasan air yang terdapat pada kriteria utama kondisi drainase lingkungan. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, drainase lingkungan yang tidak mampu mengalirkan limpasan air hujan sehingga menimbulkan genangan merupakan kondisi dimana jaringan drainase lingkungan tidak mampu mengalirkan limpasan air sehingga menimbulkan genangan dengan tinggi lebih dari 30 cm selama lebih dari 2 jam dan terjadi lebih dari 2 kali setahun. Pada kondisi eksisting, didaerah tersebut memang terdapat drainase lingkungan yang tidak mampu mengalirkan limpasan air hujan, sehingga menimbulkan genangan di sekitar permukiman masyarakat.

Pada Tiyuh Pulung Kencana, sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah sistem pengelolaan persampahan tidak sesuai standar teknis yang terdapat pada kriteria utama kondisi persampahan. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, sistem pengelolaan persampahan tidak memenuhi persyaratan teknis merupakan kondisi dimana pengelolaan persampahan pada lingkungan

perumahan atau permukiman tidak memenuhi persyaratan sebagai pewadahan dan pemilahan domestik, pengumpulan lingkungan, pengangkutan lingkungan serta pengolahan lingkungan. Pada kondisi eksisting, sistem pengelolaan persampahan di daerah tersebut memang belum berjalan secara maksimal. Masih terdapat penumpukan sampah di beberapa TPS.

Pada Tiyuh Bandar Dewa, sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah ketidaktersediaan akses aman air minum yang terdapat pada kriteria utama kondisi penyediaan air minum. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, ketidaktersediaan akses aman air minum merupakan kondisi dimana masyarakat tidak dapat mengakses air minum yang memenuhi syarat kesehatan. Pada kondisi eksisting, di daerah tersebut masih terdapat beberapa masyarakat yang belum mendapatkan akses air minum yang memenuhi syarat kesehatan.

Pada Tiyuh Menggala Mas, sub kriteria prioritas yang memiliki nilai bobot tertinggi adalah prasarana dan sarana pengelolaan air limbah tidak sesuai standar teknis. Sub kriteria tersebut terdapat pada kriteria utama kondisi pengelolaan air limbah. Berdasarkan Peraturan Menteri PUPR No. 2 tahun 2016 tentang Peningkatan Kualitas Terhadap Perumahan Kumuh dan Permukiman Kumuh, Prasarana dan sarana pengelolaan air limbah tidak memenuhi persyaratan teknis merupakan kondisi prasarana dan sarana pengelolaan air limbah pada perumahan atau permukiman dimana kloset leher angsa tidak terhubung dengan tangki septik atau tidak tersedianya sistem pengolahan limbah setempat atau terpusat. Pada kondisi eksisting, di daerah tersebut masih terdapat beberapa masyarakat yang menggunakan jamban yang tidak sehat, tidak terhubung dengan tangki septik serta sistem pengelolaan air limbah (SPAL) setempat atau terpusat.

E. KESIMPULAN

Terdapat perbedaan sub kriteria prioritas disetiap masing-masing daerah kumuh di Kabupaten Tulang Bawang Barat. Pada Kelurahan Daya Murni yaitu Ketidaksesuaian dengan Persyaratan Teknis Bangunan (0,4146), pada Kelurahan Mulya Asri yaitu Kualitas Konstruksi Drainase (0,2548), pada Kelurahan Panaragan Jaya yaitu Ketidakmampuan Mengalirkan Limpasan Air (0,1310), pada Tiyuh Pulung Kencana yaitu Sistem pengelolaan persampahan tidak sesuai standar teknis (0,2623), pada Tiyuh Bandar Dewa yaitu Ketidaktersediaan Akses Aman Air Minum (0,075) serta pada Tiyuh Menggala Mas yaitu Prasarana dan sarana pengelolaan air limbah tidak sesuai standar teknis (0,079).

Oleh sebab itu, perbedaan prioritas sub kriteria permukiman kumuh pada masing-masing daerah kumuh tersebut, dapat dijadikan bahan pertimbangan bagi Pemerintah Daerah Kabupaten Tulang Bawang Barat dalam rangka pengentasan daerah permukiman kumuh di masing-masing daerah tersebut yang efektif dan efisien. Bagi Masyarakat informasi perbedaan prioritas sub kriteria permukiman kumuh tersebut dapat dijadikan pembelajaran dalam rangka menjaga lingkungan sekitar sehingga penanganan daerah kumuh dapat berjalan dengan lebih efektif dan efisien serta tidak muncul permukiman kumuh yang baru.

DAFTAR PUSTAKA

- Badan Pusat Statistik Kabupaten Tulang Bawang Barat. 2021. *Kabupaten Tulang Bawang Barat Dalam Angka*. 275: 49-50.
- Hariyanto, A. 2007. *Strategi Penanganan Kawasan Kumuh Sebagai Upaya Menciptakan Lingkungan Perumahan Dan Pemukiman Yang Sehat*. Bandung: Jurnal PWK Unisba 7 (2), 11-37.
- Idris, S.A.L. 2012. *Analisis Perbandingan Metode Analytical Hierarchy Process (AHP) Dengan Simple Additive Weighting (SAW)*. Gorontalo: Skripsi Universitas Negeri Gorontalo.
- Keputusan Bupati Tulang Bawang Barat Nomor B/56/II.04/HK/TUBABA/2021 Tahun 2021 tentang Penetapan Lokasi Perumahan dan Permukiman Kumuh di Kabupaten Tulang Bawang Barat.
- Maharani, D. 2017. *Pemilihan Strategi Kebijakan Transportasi Di Bandar Lampung Dengan Menggunakan Metode Analytical Hierarchy Process*. Bandar Lampung: Skripsi Universitas Lampung.
- Pahtoni, T.Y., dan Tasrif, E. 2020. *Komparasi Metode Analytical Hierarchy Process Dengan Simple Additive Weighting Dalam Penentuan Prioritas*. Padang: Jurnal Universitas Negeri Padang P-ISSN: 2302-3295, E-ISSN : 2716-3989.
- Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 2 Tahun 2016 Tentang Peningkatan Kualitas Terhadap Perumahan Kumuh Dan Permukiman Kumuh.
- Saaty, T.L. 1995. *The Analytical Hierarchy Process*. New York: McGraw-Hill.
- Undang-Undang Nomor 1 Tahun 2011 tentang Perumahan dan Kawasan Permukiman.
- Wiarni, S., Mononimbar, W. dan Supardjo, S. 2018. *Analisis Tingkat Kekumuhan Kawasan Permukiman Di Kecamatan Kotamobagu Timur*. Makassar: Jurnal Spasial Universitas Sam Ratulangi Vol 5. No. 1.

LOW-CYCLE FATIGUE OF COLD-DRAWN TYPE 304 AUSTENITIC STAINLESS STEEL WITH ANNEALING TREATMENT

AMBAR PAMBUDI^{1*}, MOHAMMAD BADARUDDIN², SUGIYANTO², MUH THOHIRIN¹

¹Department of Mechanical Engineering, Faculty of Engineering, Universitas Sang Bumi Ruwa Jurai, Jl. Imam Bonjol No.486, Langkapura, Bandar Lampung, 35118 Lampung, Indonesia

²Department of Mechanical Engineering, Faculty of Engineering, Universitas Lampung, Gedung A Lt. 2, Jl. Prof. Soemantri Brojonegoro No. 1, Bandar Lampung, 35143, Lampung, Indonesia

ABSTRACT:

Type 304 austenitic stainless steel, or better known as SS304, generally has alloying elements: C < 0.1%, Cr 18 – 20%, Fe 66 – 74%, Mn <2%, Ni 8 – 10.5%, P <0.045%, Si <1%, and S <0.030%. In general, this material has good ductility, high tensile strength, and excellent corrosion resistance. One of its uses is for fossil fuels, cooling coils, pressure vessels, valves, textile equipment, nuclear vessels, feedwater tubing, evaporators, and piping systems for high-pressure gases. In application, type 304 stainless steel will be subjected to repeated loading, and eventually, the material will undergo plastic deformation, which leads to structural failure in a short life. The failure of 304 stainless steel is generally due to the inability of the material to repeat loading, which results in large amounts of plastic deformation so that the 304 stainless steel will experience fatigue and then fracture. Based on the description above, this study aims to evaluate the low cycle fatigue properties of 304 CDS stainless steel with annealing heat treatment. The parameter used was the strain amplitude 0.003 – 0.013 mm/mm. The results of this study revealed that the highest fatigue life in the low-cycle fatigue test was experienced by steel with heat treatment at an amplitude of 0.003 mm/mm with 48367 cycles. On the other hand, at the amplitude condition of 0.013 mm/mm, the fatigue life of the steel decreased drastically with the resulting plastic strain being larger, namely 0.00949 mm/mm and elastic strain of 0.00350 mm/mm, with an average modulus of elasticity 194.09 GPa. Annealing treatment conditions experienced decreased mechanical strength but tended to be ductile. Empirical equations to predict low cycle fatigue of 304 stainless steel can be carried out using the approximation of the plastic-elastic strain amplitude to the number of cycles reversal (reversal to failure, $2N_f$ (Basquin-Coffin-Manson Equation)):

$$\Delta \epsilon_t = 2640,5(2N_f)^{-0.1205} + 0,0496(2N_f)^{-0.3179}$$

Key Words: Steel, SS304, low cycle fatigue, annealed

1. INTRODUCTION

Type 304 austenitic stainless steel, or better known as SS304, generally has alloying elements: C < 0.1%, Cr 18 – 20%, Fe 66 – 74%, Mn <2%, Ni 8 – 10.5%, P <0.045%, Si <1%, and S <0.030% [1]. In general, this material has good ductility, high tensile strength, and excellent corrosion resistance. One of its uses is for fossil fuels, cooling coils, pressure vessels, valves, textile equipment, nuclear vessels, feedwater tubing, evaporators, and piping systems for high-pressure gases.

The properties and capabilities of this metal are widely used in all sectors of the field with several conditions that must be met to be perfectly applied in accordance with the application [2], as in the application of heat treatment to materials to improve the mechanical properties of a material. In the cold tensile manufacturing process or cold drawing, it will increase mechanical properties in the form of increased ductility. Cold drawing has been developed commercially on 304 stainless steel in the form of cylinders, pipes, or high-pressure vessels.

In application, type 304 stainless steel will be subjected to repeated loading, and eventually, the material will undergo plastic deformation, which leads to structural failure in a short life. The failure of 304 stainless steel is generally due to the inability of the material to repeat loading, which results in large amounts of plastic deformation so that the 304 stainless steel will experience fatigue and then fracture [3].

Fatigue is a form of material failure that occurs in the structure due to dynamic loads that tend to rise and fall. The dynamic load occurs under yield strength for a long time and, of course, repeatedly. Fatigue in the plastic state that occurs in short cycles below 10⁴ is called low cycle fatigue. Meanwhile, fatigue in elastic conditions with cycles between 10⁴ and 10⁷ is known as high cycle fatigue.

In this case, the plastic deformation resulting from cold drawing in the 304 stainless steel material will significantly affect its fatigue behavior. The low-cycle fatigue properties and parameters of materials can be a major consideration in the design of structural members, where the predicted structure is still within safe limits despite experiencing large plastic deformation [4].

Moreover, mechanical properties of materials, such as modulus of elasticity, yield strength, maximum tensile strength, elongation, and cross-sectional area reduction, are the most basic parameters in the design of components and structural elements. Material structures that operate under dynamic or fluctuating load conditions tend to experience a decrease in performance over time the components operate. The decrease or degradation of the strength of the material due to load fluctuations is known as fatigue, which seriously affects the material's behavior on the structural member during working conditions [5]. Therefore, the structural design must consider the fatigue strength of the material to prevent unexpected structural failure due to fatigue.

A study [6] examined cold drawn type 316 stainless steel, tested for low cycle fatigue. The softening cycle occurred at strain amplitudes of 0.31% and 0.35%. Cold-drawn type 316 stainless steel provided higher fatigue life with strains below 80%. In addition, the interaction between dislocation and twinning was observed during the cycle; it resulted in uniform deformation and delayed crack initiation in 316 austenitic

stainless steel. Also, a previous study [7] was carried out on 304 stainless steel, which had been annealed. After being annealed, the fatigue life of 304 stainless steel increased by 6.95%. The increase in fatigue life of the material was seen when the material was annealed.

In this regard, type 304 austenitic stainless steel has relatively high mechanical strength, with large ductility and good corrosion resistance. During application, material components often experience shutdown and starting conditions due to the maintenance process. In addition, the geographical conditions where earthquakes frequently occur greatly affect the material's properties, which causes the material to undergo plastic deformation, as is often the case in Indonesia. Some of these factors must be taken seriously in designing engineering components, which involve the structural performance of materials undergoing plastic deformation. For this reason, the evaluation of fatigue performance and fatigue life becomes an essential content in a safe design against fatigue failure to be carried out.

However, the manufacturing process of technical components, such as pipes made of type 304 stainless steel through cold drawing, has not been widely conducted or even carried out by several overseas researchers. In fact, the cold-tensile manufacturing process developed on structural components of high-alloy low carbon steel (304 austenitic stainless steel) generally improves mechanical strength performance with good material ductility [8].

Based on the description above, the authors are interested in researching "Low-Cycle Fatigue of Cold Drawn Type 304 Austenitic Stainless Steel with Annealing Treatment." Microstructural analysis and observation of the fracture cross-section of the sample would be carried out after the material was tested under low cycle fatigue conditions to explain the fatigue failure mechanism during the test n an attempt to make formatting easy, you can use the style menu just under the standard menu. Every button has a name similar to style name in brackets after each paragraph. (Normal).

2. RESEARCH METHODS

2.1. Materials and specimens

Cold-drawn type 304 stainless steel had a shaft or cylinder shape of 15 mm in diameter and 220 mm in length. Tensile test specimens were prepared according to ASTM E8 standards, while low cycle fatigue test specimens were prepared following ASTM E606 standards.

2.2. Low cycle tensile and fatigue testing

Tensile test specimens were shaped according to ASTM E8 standards (Figure 1). Meanwhile, the dimensions and sizes of the low-cycle fatigue test specimens were made under the ASTM E606-92 standard (Figure 2). Tensile test results were plotted in the form of a stress-strain curve. The stress-strain hysteresis curve at half-cycle of fracture life ($0.5N_f$) was also plotted. Low cycle fatigue analysis was then performed based on the plastic strain and elastic strain data using the Coffin – Manson – Basquin approach to determine the low cycle fatigue parameters of type 304 stainless steel.

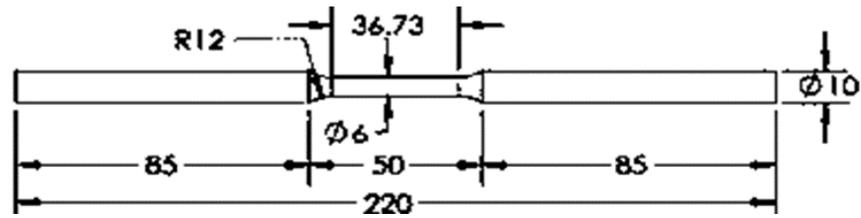


Fig. 1. Tensile test specimen shape and size (ASTM E8)

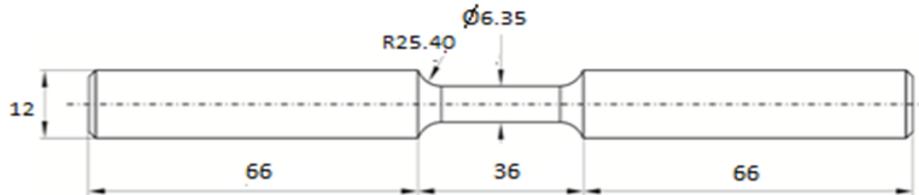


Fig. 2. Low-cycle fatigue test specimen's shape and size (ASTM E606-92) (1)

3. RESULTS AND DISCUSSION

3.1. Analysis of mechanical properties of type 304 stainless steel

The following is the tensile test result data in the form of stress vs. strain curve (Figure 3.).

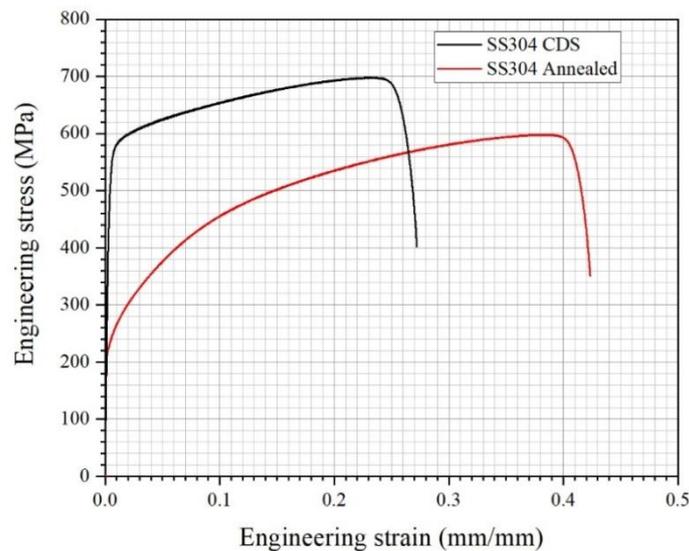


Fig. 3. The curve of stress vs. strain in type 304 stainless steel with annealing treatment

Based on Table 1, the average static tensile test results of 304 stainless steel obtained different values. The result of cold drawing treatment on 304 stainless steel could increase the plastic area, which can be seen in the increased plastic energy value (kJ) in the annealed specimens. It could improve the low cycle fatigue properties of the steel because the steel underwent a wider plastic deformation during the low cycle fatigue test process. The effect of the annealing treatment, namely the mechanical properties of 304 stainless steel, increased, which can be seen based on the increase in the yield stress and ultimate tensile stress values. The yield stress and ultimate tensile stress values increased significantly in the annealed specimen compared to the untreated specimen. Meanwhile, the yield stress and ultimate stress did not significantly differ between the annealed specimens with different holding times.

The yield stress and young modulus values for the low cycle fatigue test parameters were taken from the tensile test results of specimens with annealing treatment. The annealed specimen (SS304 Annealed) produced a yield stress value of 220.545 MPa and ultimate tensile stress of 594.87 MPa. In addition, the value of the young modulus of type 304 stainless steel, which can be determined using the least-squares method with a linear range of curves vs. strain stress (σ vs. ϵ), was equal to 20% (ASTM E8). Meanwhile, the young modulus with annealing treatment was 194.09 GPa. In other words, the engineering strain increased significantly with the annealing treatment compared to the untreated specimen. The annealing treatment will make the specimen ductile so that the strain and reduction of the cross-sectional area increase.

Table 1: Static tensile test results on type 304 stainless steel

Specimen	Stress (MPa)	
	Yield (0.2%)	Ultimate
SS 304 Annealed	220.54	594.87

3.2. Low-cycle fatigue analysis

The results of the low-cycle fatigue test with different strain amplitude variations are shown in full in Tables 2 under conditions of $0.5N_f$.

Then, the low-cycle fatigue test was carried out using six variations of strain amplitude: 0.003 mm/mm, 0.005 mm/mm, 0.007 mm/mm, 0.009 mm/mm, 0.011 mm/mm, and 0.013 mm/mm. Based on Table 4.2, cycle value is a benchmark for measuring fatigue life in specimens, where the higher the cycle value produced, the longer the durability or lifespan of the specimen, and conversely, a cycle with a low value indicates that the life of the specimen is short. Meanwhile, the fatigue testing results on CDS specimens that had been annealed showed that the highest cycle was in the first specimen (CDS304_A1) with a strain amplitude of 0.003 mm/mm with 48367 cycles, whereas the lowest cycle was in the sixth specimen (CDS304_A5) with a strain amplitude of 0.013 mm/mm with 268 cycles.

Table 2: LCF Test Results Data on Type 304 Stainless Steel with Annealing

Specimen	Strain Amplitude ($\frac{\text{mm}}{\text{mm}}$)	Frequency (H_z)	Plastic Strains ($\frac{\text{mm}}{\text{mm}}$)	Elastic Strains ($\frac{\text{mm}}{\text{mm}}$)	Elastic Modulus (GPa)	Fracture Cycle (N_f)
CDS304_A1	0.003	0.4167	0.00193	0.00107	196.58	48367
CDS304_A2	0.005	0.2500	0.00309	0.00191	198.70	4625
CDS304_A3	0.007	0.1786	0.00480	0.00221	205.27	1058
CDS304_A4	0.009	0.1389	0.00591	0.00309	208.72	829
CDS304_A5	0.013	0.0962	0.00949	0.00350	202.79	268

In the low-cycle fatigue test, there was a relationship between the peak stress and the number of cycles. This relationship was used to see the hardening and softening behavior of type 304 stainless steel annealed during low-cycle fatigue testing with a given variation of the strain amplitude. The highest plastic strain was owned by the

tested specimens with high strain amplitudes, namely 0.013 mm/mm, 0.00895 mm/mm, and 0.00949 mm/mm. Meanwhile, the smallest plastic strain values were 0.00095 mm/mm and 0.00193 mm/mm. In addition, the specimens tested had the highest elastic strains with high strain amplitudes, namely 0.013 mm/mm, 0.00405 mm/mm, and 0.00350 mm/mm. Meanwhile, the smallest elastic strain values were 0.00205 mm/mm and 0.00107 mm/mm.

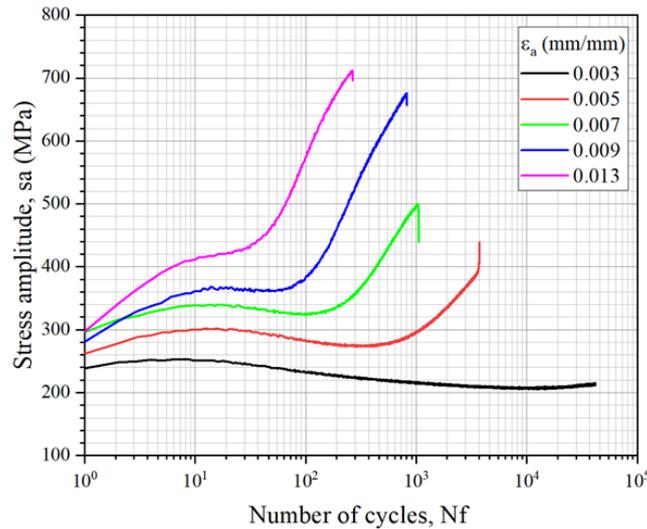


Fig. 4. The relationship of peak stress to the number of cycles of type 304 stainless steel, treated with annealing treatment at low-cycle fatigue tests, with variations in strain amplitude

In Figure 4, the strain amplitude of 0.003 in cycles 1 to 100 the specimen underwent cyclic hardening, and after that, it was softened to fracture. Similarly, with a strain amplitude specimen of 0.005, cyclic softening occurred from the beginning to the 200th cycle and, after that, underwent progressive cyclic hardening and breaking. Then, in specimens with a strain amplitude of 0.007 – 0.013, the cyclic pattern tended to be the same. The low cycle underwent softening and then hardening to fracture

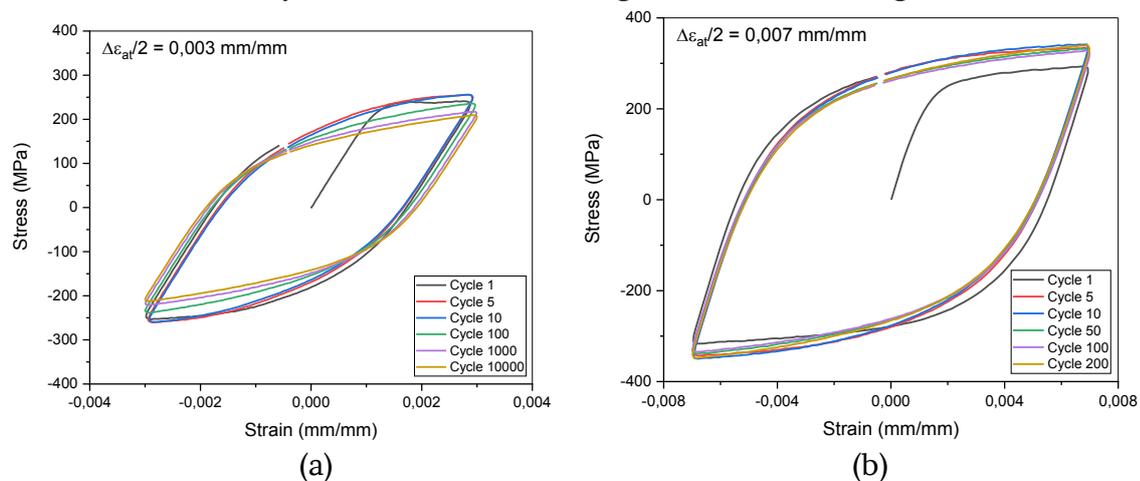


Fig. 5. The evolution of the stress-strain changes in each different cycle under the conditions of the strain amplitude of (a) 0.003 mm/mm (b) 0.007 mm/mm

The hardening and softening behavior of the annealed 304 stainless steel could be analyzed further on the hysteresis curve (stress vs. strain). Based on Figure 5, the evolution of stress-strain changes in each cycle or the hysteresis curve on the results of the low-cycle fatigue test was found in Figure 5, with a strain amplitude of 0.007 mm/mm. In the first cycle, 304 stainless steel experienced tensile stress of 293.3 MPa and compressive stress of -316.53 MPa. In the fifth cycle, the steel experienced increased tensile stress of 334.32 MPa and compressive stress of -343.25 MPa. Furthermore, in the tenth cycle, the steel experienced increased tensile stress again to 341.5 MPa and an increase in compressive stress to -349.5 MPa. In the low-cycle fatigue test with a strain amplitude of 0.007 mm/mm, it underwent a large plastic deformation, characterized by unpredictable crack initiation through a change in stress drop of 10% from the condition after the stable cycle (half-life), and steel also continued to experience an increase in stress before just at the time of failure (failure cycle). Analyzing the fatigue life requires the relationship between the stress amplitude and the total strain amplitude to see the strain hardening material from cyclic loading. The values of the parameters include the cyclic strength coefficient (K') and the cyclic strain hardening exponent (n'), obtained from the data based on the low-cycle fatigue test results on half-cycle hysteresis loops with different strain amplitudes, as shown in Figure 6 and Table 3

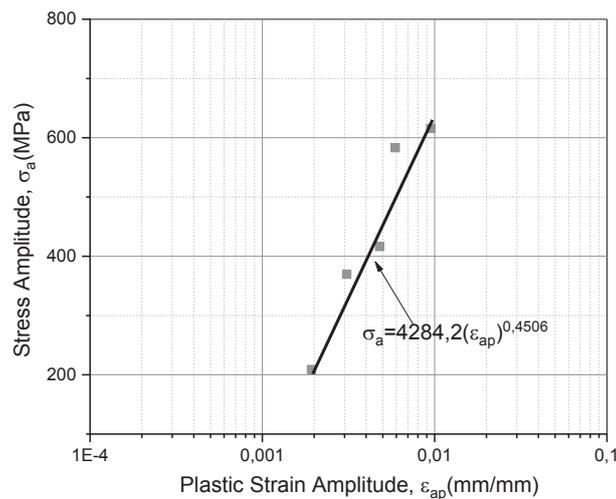


Fig. 6. Graph of cyclic stress amplitude vs. the plastic strain amplitude from the low-cycle fatigue test results using type 304 stainless steel at different strain amplitudes with annealing

Table 3: The parameter value of LCF on 304 Stainless Steel with Annealing Treatment

Low-cycle fatigue parameter	Annealing
Cyclic strength coefficient, K' (MPa)	4284.2
Fatigue strength coefficient, σ'_f (MPa)	2640.5
Cyclic strain hardening exponent, n'	0.4506
Fatigue power exponent, b	-0.1205
Fatigue ductility coefficient, ϵ'_f mm/mm	0.0496
Fatigue ductility exponent, c	-0.3179

4. CONCLUSION

Annealing treatment of 304 stainless steel decreased tensile strength compared to untreated 304 stainless steel, indicated by yield stress decreased by 55% and ultimate stress decreased by 18%. On the other hand, the coefficient of cyclic strength (K') and the exponential value of cyclic stress (n') increased significantly. The empirical equation for predicting the fatigue life of strain-based annealed 304 stainless steel is:

$$\Delta \varepsilon_t = 2640,5(2N_f)^{-0,1205} + 0,0496(2N_f)^{-0,3179}$$

REFERENCES

- [1] Ye, D., Matsuoka, S., Nagashima, N. and Suzuki, N., 2006. The low-cycle fatigue, deformation and final fracture behaviour of an austenitic stainless steel. *Materials Science and Engineering: A*, 415(1-2), pp.104-117.
- [2] Nip, K.H., Gardner, L., Davies, C.M. and Elghazouli, A.Y., 2010. Extremely low cycle fatigue tests on structural carbon steel and stainless steel. *Journal of constructional steel research*, 66(1), pp.96-110.
- [3] Srinivasan, V.S., Sandhya, R., Rao, K.B.S., Mannan, S.L. and Raghavan, K.S., 1991. Effects of temperature on the low cycle fatigue behaviour of nitrogen alloyed type 316L stainless steel. *International journal of fatigue*, 13(6), pp.471-478.
- [4] Hong, S.G. and Lee, S.B., 2004. The tensile and low-cycle fatigue behavior of cold worked 316L stainless steel: influence of dynamic strain aging. *International Journal of Fatigue*, 26(8), pp.899-910.
- [5] Hong, S.G., Lee, S.B. and Byun, T.S., 2007. Temperature effect on the low-cycle fatigue behavior of type 316L stainless steel: Cyclic non-stabilization and an invariable fatigue parameter. *Materials Science and Engineering: A*, 457(1-2), pp.139-147.
- [6] Xie, X., Ning, D. and Sun, J., 2016. Strain-controlled fatigue behavior of cold-drawn type 316 austenitic stainless steel at room temperature. *Materials Characterization*, 120, pp.195-202.
- [7] Naik, R.P., Samatham, M., Patangay, V.K. and Teja, M.S., 2020. Experimental Study on the Effect of Annealing on Fatigue Life of SS 304 Steels
- [8] Roy, S.C., Goyal, S., Sandhya, R. and Ray, S.K., 2012. Low cycle fatigue life prediction of 316 L (N) stainless steel based on cyclic elasto-plastic response. *Nuclear engineering and design*, 253, pp.219-225

OPTIMIZATION OF PV/T-TEG GEOMETRY ON DIFFERENT OPERATING CONDITIONS USING CFD SIMULATION AND TAGUCHI DESIGN OF EXPERIMENT

Prabowo. Angga^{1,a}, Nalis. Amrizal^{2,a}, and Ibrahim. Gusri A^{3,a,*}

Prabowo. Angga¹ University of Lampung Bandar Lampung Indonesia

Nalis. Amrizal² University of Lampung Bandar Lampung Indonesia

Ibrahim. Gusri A³ University of Lampung Bandar Lampung Indonesia

E-mail: ^aangga.dprabowo@gmail.com, ^{b,*}amrizal@eng.unila.ac.id (Corresponding author)

Abstract.

PV/T – TEG system can increase electrical efficiency by keeping PV in optimal operating temperature and generating additional electricity. The performance of the PV/T-TEG system is measured by the ability to absorb excess heat from PV and generate a temperature difference between the hot side of TEG and the cold side of TEG. In order to obtain a PV/T-TEG system with excellent performance, an optimization process is carried out to get the optimal value of geometric parameters and operating conditions. The optimization process uses Taguchi Design of Experiment with five factors, three levels, and two responses. Two separated responses are used as PV temperature needs to be lower to achieve optimal condition; otherwise, the TEG temperature difference needs to be higher. Computational fluid dynamics (CFD) is used as an approach to generate the responses numerically. The result shows the combination to obtain optimal PV temperature is the full TEG configuration, 75mm of fin height, 3mm of fin thickness, 80 gr/s of mass flow, and 400 W/m² heat absorbed by PV. Meanwhile, the combination to obtain optimal TEG temperature difference is the staggered TEG configuration, 25mm of fin height, 1mm of fin thickness, 80 gr/s of mass flow, and 800 W/m² heat absorbed by PV. Based on the Analysis of Variance, factors that significantly influence PV temperature response are TEG configuration, fin thickness, mass flow rate, and heat absorbed. While, factors that significantly influence TEG temperature difference response are TEG configuration, fin height, fin thickness, and heat absorbed.

Keywords: PVT, TEG, CFD, Taguchi.

Introduction

Fossil fuels are the most widely used energy source today because they are easy to convert into other forms of energy and have high scalability. Behind their advantages, fossil fuels are non-renewable energy sources that negatively impact the socio-economic when fossil fuels begin to become scarce ^[1]. Besides that, the residual gas from fossil fuels combustion is also one of the main causes of global warming, which causes severe long-term damage ^[2]. The transition from fossil fuels to renewable energy continues to be developed in order to minimize the negative impact of using fossil fuels.

One of the most abundant sources of energy on earth is solar energy. The sun emits 3.8×10^{23} kW of energy and 1.8×10^{14} kW is captured by the earth in the form of light and heat. Nevertheless, only 0.7% of the total global energy sources are solar energy [3].

There are several methods to generate electrical energy from solar radiation. Those are Photovoltaic (PV), molten salt cogeneration system with Organic Rankine Cycle (ORC), and Solar Updraft Tower, which utilizes the buoyancy force of hot air due to absorbing solar radiation so the force can rotate turbines inside the tower. Among these methods, photovoltaic is the most commonly used system to convert solar energy into electrical energy. Photovoltaic has two sides of the semiconductor (silicon), which has a positive and negative polarity and separated by a junction. This construction functions to convert photons or incoming sunlight into electricity. The electricity generated by photovoltaic is direct current so to adapt to household electricity, direct current generated by photovoltaic has to be converted into alternating current using an inverter. Another problem of using photovoltaic is that solar energy fluctuates, which can be overcome by storing the electrical energy into the battery [4].

The lack of popularity of solar energy is due to the relatively low efficiency of solar cells or photovoltaic (PV) between 10-15% and was predicted maximum efficiency that can be achieved with the development of photovoltaic materials is only 27% [5]. To accommodate these limitations, an additional system is needed to utilize the residual energy in the form of heat from the photovoltaic system. Energy in the form of heat stored in photovoltaics causes an increase in temperature and reduces photovoltaic efficiency by 6-7.2% if heat is not transferred to heatsink or converted into other forms of energy [6]. Efforts to maintain the optimal photovoltaic temperature are carried out by adding a cooling system that transfers heat from the photovoltaic to the environment both passively and actively. There is 80% of irradiation energy from the sun that is absorbed as heat in the PV module [7]. However, in order to increase efficiency of the conversion of solar energy into electrical energy, a TEG (Thermoelectric Generator) is used, which is a device that functions to convert the temperature difference TEG has been used to convert waste heat from engine exhaust into electricity [8]. In PV/T application, TEG can convert temperature difference between photovoltaic and environmental temperature into electrical energy. TEG with 1.6mm of length and 1.4mm of width generate 0.0357 watts with 4.9% of efficiency from total heat absorbed on the hot side [9]. Theoretically, the addition of TEG to a photovoltaic flat absorber plate with natural convection cooling system can generate additional energy of 5% and increase the efficiency of the PV-TEG hybrid system by 6% [10]. This value can still be increased by optimizing the temperature difference between the photovoltaic absorber plate or the hot side of the TEG and the heatsink on the cold side of the TEG. Increasing the temperature on the hot side of TEG cannot be done because it has an impact on decreasing PV efficiency, but on the contrary, decreasing the temperature on the cold side of TEG can increase the energy produced and the efficiency of the whole system (hybrid).

Experimental research has been carried out on the effect of adding a finned heatsink and forced convection is applied through the finned heatsink. The result says

the system can reduce the PV temperature by 11% compared to PV with flat absorber plate ^[11]. Cooling system applied on the cold side of the TEG can reduce the temperature of the cold side of the TEG and increase the energy produced and the overall system efficiency (hybrid). Based on these studies, it can be concluded that the addition of TEG and finned flatbed with forced airflow can improve PV/T performance. Therefore, further studies are needed to investigate the effect of geometry and operating conditions on the thermal performance of finned PV/T-TEG hybrid systems with forced convection.

Variations in the combination of operating parameters are still feasible experimentally using one PV/T-TEG experimental unit, but geometric variations such as fin configuration, fin height, and TEG configuration require PV/T-TEG experimental units as many as the combination of varied parameters.

Numerical study of variations in fin configuration has been carried out on the thermal performance of finned heatsink using numerical simulation software which shows that there is no significant difference between the trend of the graph of convective heat transfer coefficient on the Reynolds number experimentally and numerically. Therefore, numerical software can be used in the study on the thermal effect of geometric and operating conditions variations of finned heatsink ^[12].

Numerical simulation software has been developed since 1960 where it was used to simulate transonic fluid flow. Computer programming languages are used to solve the linear potential equation in the first development, nonlinear potential equation in the 1970s, Euler equation in the 1980s, and Reynold Averaged Navier Stokes (RANS) equation that has been used until now^[13]. Nowadays, numerical simulation software is packed and can be used with ease without the need to write any programming language to describe model geometry and boundary conditions. One of the modern numerical simulation software is ANSYS. ANSYS software can significantly lower research costs. In order to get optimal performance, the optimization process is conducted by simulating several combinations of parameters based on the rule of design of experiment (DoE).

The Taguchi method is used to obtain the optimal combination with a smaller number of combinations but still generate robust results by taking Signal to Noise Ratio (SNR) into the calculation. Finned PV/T optimization research has been carried out with controlled factors of fin material, PV temperature, and airflow velocity with 3 levels on each of the factors. In this study, the Taguchi method with L9 orthogonal array was used to get the best combination to achieve optimum performance of finned PV/T. The result shows the best material to generate the higher thermal efficiency among other materials used in this study was copper. The relationship between PV surface temperature and airflow velocity is proportional to the thermal efficiency of the PV/T system. Combining with Analysis of Variance, the most significant factor affecting PVT performance is fin material with a contribution of 88.14 % ^[14].

Another previous research was carried out to get the best PCM material and operating condition of PCM-based solar collector. Taguchi Method was used in this study with L9 orthogonal arrays. The result shows that coconut oil is the best PCM material among grease and wax. The best operating conditions to get optimal

performance are 90 minutes of operation, 1525 W/m² of irradiation, and 30 °C of ambient temperature. Combining with ANOVA, PCM material is the most significant factor affecting PCM base solar collector performance. With 82.35 % of contribution^[15].

Besides being used in optimization with the data from the experimental study, the Taguchi Method can also be used in the optimization process with the data from numerical study^[16]. Previous research has been conducted to obtain the TEG system's optimal geometry and operating conditions with heat source from solar radiation. A robust result was achieved using the integrated Taguchi method and Computational Fluid Dynamics to get optimal geometry and operating conditions of finned PV/T-TEG. Based on previous research, the combination of CFD using ANSYS software and the Taguchi method is feasible to use in this study to obtain an optimal combination of geometric and operating conditions of the PV/T-TEG system.

1. Methods

1.1. Equipments and Materials

Numerical simulation conducted in this study assisted by numerical simulation software Ansys to create the model study, meshing, setup boundary conditions, and solve the numerical equation. Before numerical simulation is conducted, Ansys is validated by comparing simulation results with experimental data from previous research. Statistical analysis on this study assisted by Minitab using Taguchi design of experiment. The flow process of this study is described on Fig 1.

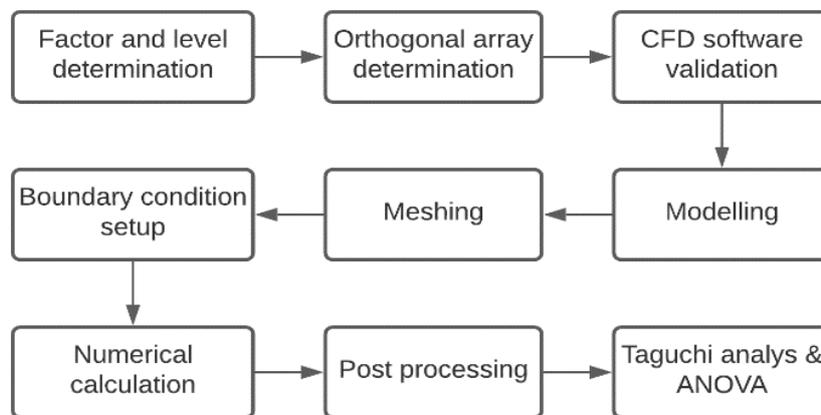


Fig. 1. Study flowchart

1.2. Design of Experiment

In this study, five control factors with three levels each were set. The first factor determined is the TEG configuration. The previous research studied the effect of straight and staggered fin configuration. Fin configuration affects PV cooling in natural convection but has not been tested on PV with additional TEG and forced air flow^[17]. In addition to straight and staggered configurations, the full configuration were tested to determine whether increasing the number of TEGs and fins affected the thermal performance of PV/T-TEG. The following control factor is fin height. Based on the research conducted by Kasaeian et al., the height of the PV/T channel affects the thermal performance of the PV/T. The results of this study indicate that the channel

height of 50mm is better than the channel height of 100mm and 150mm^[18]. In the present study, the channel height or fin height was 25mm, 50mm, and 75mm.

The third control factor is fin thickness. There is not much literature discussing fin thickness's effect on PV/T thermal performance. Based on the principle of heat transfer on the fin. The heat transfer process consists of conduction and convection heat transfer. The thickness of the fin affects heat transfer by conduction, where the thicker the fin, the more the heat that flows through the fins. However, further analysis of the effect of fin thickness on the thermal performance of PV/T-TEG is needed to conduct. The level chosen is the standard size of the available fin thickness; those are 1mm, 2mm, 3mm. Apart from being able to be tested numerically, it can also be tested experimentally.

The fourth control factor is air mass flow. Air mass flow affects the convection heat transfer coefficient. The greater the air mass flow, the bigger the heat transfer coefficient. In this study, the level values to be varied are 40 gr/s, 60 gr/s, and 80 gr/s. The fifth control factor is the amount of heat absorbed by the PV. Heat absorbed affects the thermal performance of PV/T-TEG. The more heat absorbed by PV, the higher the temperature of the PV. It makes the electrical performance of the PV decrease because of overheating. The specified level values are 400 W/m², 600 W/m², and 800 W/m² because the average peak radiation by the sun is 1000 W/m² while only 80% is absorbed as heat by PV/T in the form of heat. Based on these statements, 5-factor with three levels each are shown in Table 1.

Table 1. Factors and value of each level

Code	Factor	Level 1	Level 2	Level 3
A	TEG configuration	Straight	Staggered	Full
B	Fin height	25mm	50mm	75mm
C	Fin thickness	1mm	2mm	3mm
D	Mass flow	40 gr/s	60 gr/s	80 gr/s
E	Heat absorbed	400 W/m ²	600 W/m ²	800 W/m ²

The responses of the design of experiment used in this study are PV surface temperature (R1) and the temperature difference between the hot and cold sides of TEG (R2). The PV surface temperature response has the bigger is better condition, while the TEG temperature difference response has the smaller is better condition. Because of the two different conditions, the two responses could not be analyzed simultaneously but had to be examined separately. Based on Taguchi's experimental design with five factors and three levels, each has a degree of freedom value of 10. The L9 orthogonal array could not be selected because the number of tests was smaller than the degrees of freedom ^[19]. Thus, an orthogonal array larger than L9, namely L27 fulfills the requirement of an orthogonal array that must be greater than the degrees of freedom. Combinations for orthogonal array and statistical analysis of Taguchi design of experiment in this study are calculated using Minitab software.

1.3. Model Geometry

A Digital model of PV/T-TEG is created using CAD software with a width of 510mm and a length of 700mm. The height of the channel is not fixed but follows the height of the fin with a constant gap. Fig 2 shows the cross-section of PV/T-TEG.

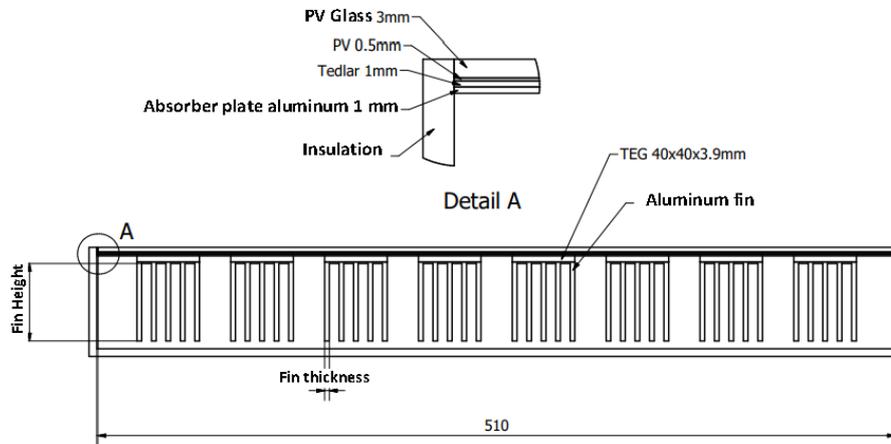


Fig. 2. Cross section of PV/T-TEG system

The finned PV/T-TEG consists of PV with cooling system in the form of finned TEG which heat is transferred by forced airflow through rectangular channels. PV module consists of 3 layers of materials, those are glass, PV cells, and tedlar^[20] that have thermal properties shown in Table 2.

Table 2 PV module materials

Material	Thick-ness (mm)	CP (J/kg.K)	K (W/m.K)	Density (kg/m ³)
Glass	3	500	1.8	3000
PV Cell	0.5	677	148	2330
Tedlar	1	1250	0.2	1200

An aluminum plate is placed under the PV system as a heat-absorbing plate and TEG base. Aluminum was chosen because it has a high conductive heat transfer coefficient and is relatively cheaper than other materials with a high conductivity^[21]. TEG was placed below the absorber plate with 40mm square dimension and 4mm thickness. TEG material is bismuth telluride with 7740 kg/m³ density, 159 J/kg.K heat capacity, and 1.52 W/m.K conductive heat transfer coefficient^[22]. To obtain optimal TEG temperature difference, aluminum fins placed on the cold side of the TEG was varied in thickness and height. The fins are cooled by forced airflow with varying mass flow. Besides fin geometry and operating conditions, TEG configuration is also varied to obtain the optimal configuration varying in straight, staggered, and the full configuration, as shown in Fig 3.

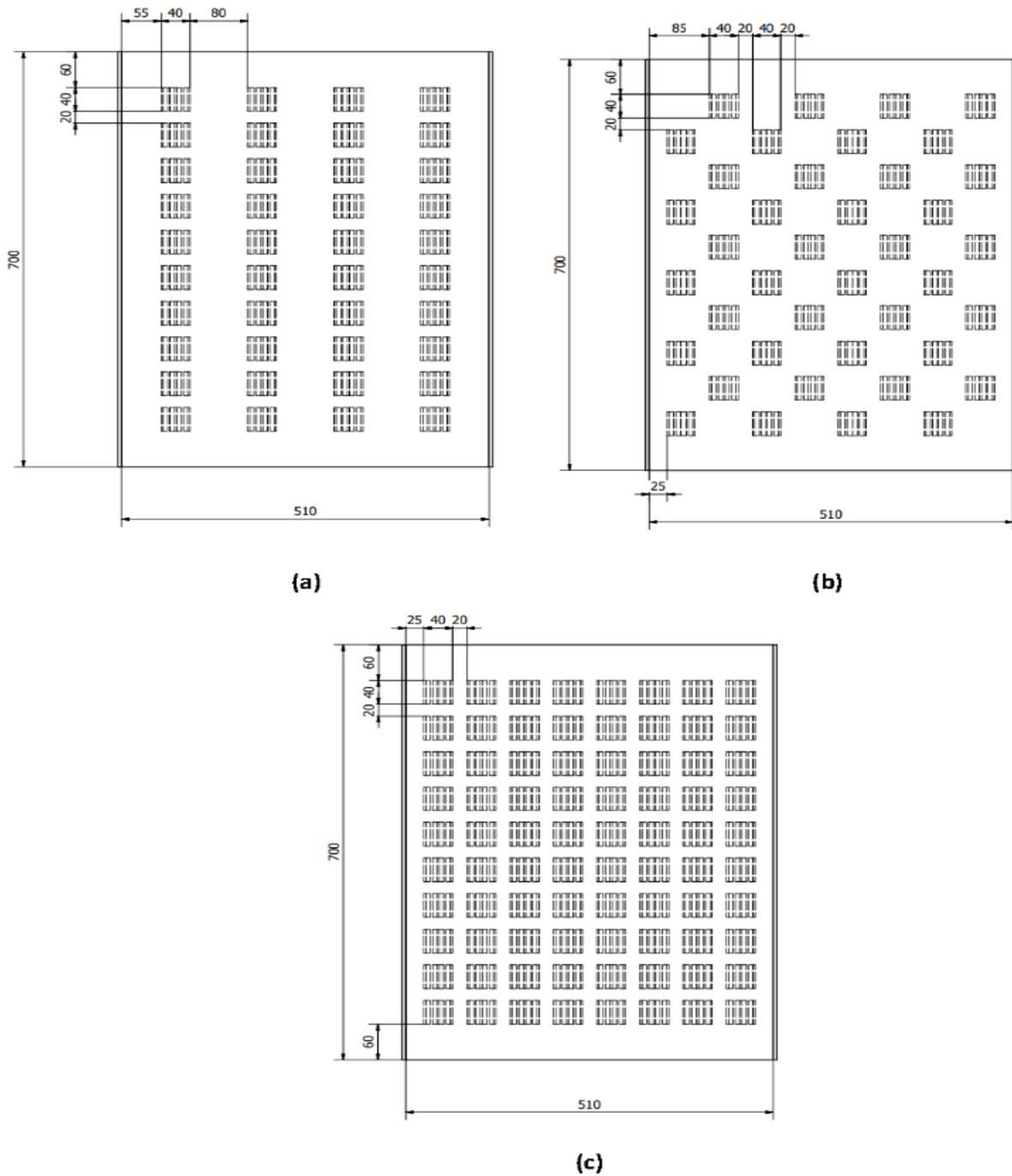


Fig. 3. TEG configuration (a) straight, (b) staggered, and (c) full

There are 40 TEGs in 4 column configuration in the straight configuration with 10 TEGs each. Each row has a horizontal spacing of 60mm and a vertical spacing of 20mm. In the staggered configuration, there are 40 TEGs in an 8-line configuration, each consisting of 5 TEGs and arranged in a zig-zag. There are 80 TEGs in an 8-line configuration with 10 TEGs each in the full configuration. Each row has a horizontal spacing of 20mm and a vertical distance of 20mm.

1.4. Numerical Simulation

Numerical simulation is carried out using Ansys AIM. The model meshed into 1.2×10^6 elements for 25mm fin height, 2.4×10^6 elements for 50mm fin height, 3.6×10^6 elements for 75mm fin height to be calculated numerically as a matrix. The calculation is conducted until target convergence 1×10^{-5} is satisfied. Boundary conditions applied are inlet, outlet, isolation wall, irradiation approached by heat flux absorbed, and natural convection from PV glass to the environment. In the post-processing process, average PV surface temperature and temperature difference between the hot side and the cold side of TEG are used as response values.

2. Results and Discussion

2.1. Software Validation

Software validation is carried out by comparing the results of numerical simulation using ANSYS software with the experimental result carried out by previous research^[23] with the same model dimensions and operating conditions. The validation process ensures that the software generates values close to the experimental values of one of the rectangular channel models in the previous experimental study, which has 300mm in width, 100mm in height, and 600mm in length. Air with Reynold number 1500 streamed through arrays of fins inside the channel with 600mm long, 25mm height, and 8mm fin space while Non-dimensional Rayleigh number is varied 4×10^7 , 2×10^8 , 6×10^8 , and 7×10^8 . The comparison between experimental and numerical results can be seen in Fig 4.

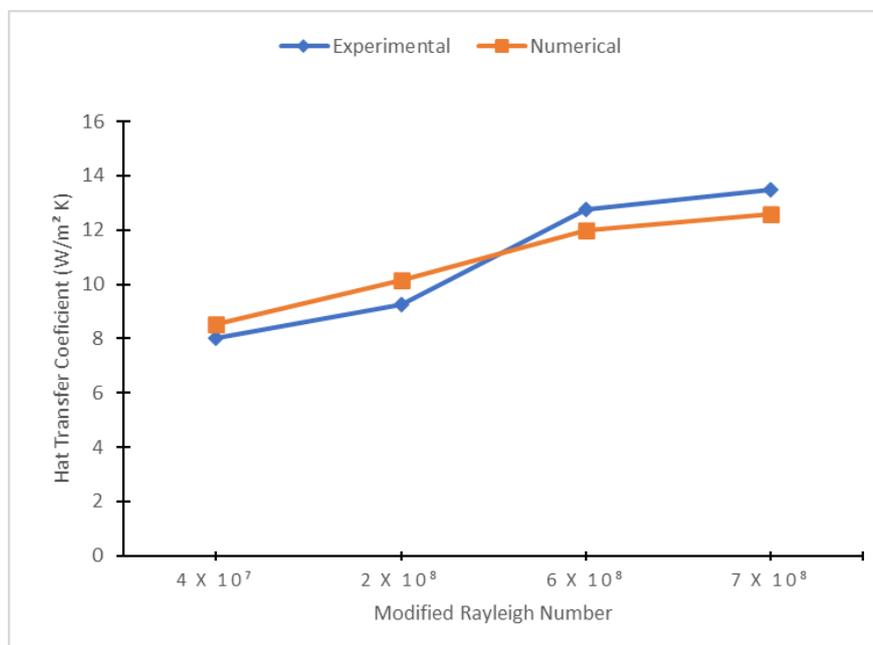


Fig 4. Comparison between experimental and numerical value

Based on the chart in fig 4, the experimental and numerical results have no significant difference in heat transfer coefficient varied with modified Rayleigh Number. The difference occurs because the numerical simulation is carried out by assuming the system conditions are ideal. However, in the experimental study, some conditions are

difficult to control. However, as both graphs show the same trendline and there is no significant difference in value, numerical simulation is feasible to use.

2.2. Taguchi Analysis

Orthogonal array consisted of 27 combinations is determined and each of the combinations is modeled and numerically simulated. Average PV temperature (R1) and temperature difference of hot side and cold side (R2) of TEG are achieved from post processing of numerical simulation as shown in Fig 5.

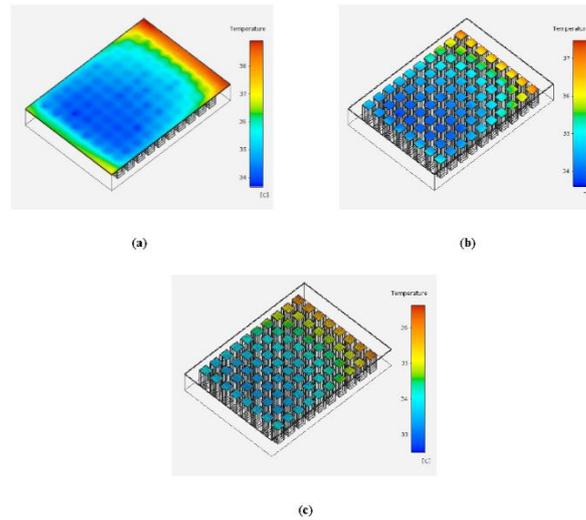


Fig. 5. Temperature contour generated in post processing process (a) PV temperature, (b) TEG hot side temperature, and (c) TEG cold side temperature

The average value of temperature contour is used as response values of Taguchi analysis. The orthogonal array with response values is shown in Table 4.

Table 4. Orthogonal array with response values

No	A	B	C	D	E	R1 (°C)	R2 (°C)
1	1	1	1	1	1	43.4	2.68
2	1	1	1	1	2	50.09	4.18
3	1	1	1	1	3	56.78	5.63
4	1	2	2	2	1	41.07	1.92
5	1	2	2	2	2	46.61	2.96
6	1	2	2	2	3	52.18	3.97
7	1	3	3	3	1	37.56	1.84
8	1	3	3	3	2	44.83	2.76
9	1	3	3	3	3	49.01	3.68
10	2	1	2	3	1	38.28	2.92
11	2	1	2	3	2	42.42	4.37
12	2	1	2	3	3	46.55	5.83

No	A	B	C	D	E	R1 (°C)	R2 (°C)
13	2	2	3	1	1	39.1	1.82
14	2	2	3	1	2	43.15	2.76
15	2	2	3	1	3	48.19	3.61
16	2	3	1	2	1	38.7	2.36
17	2	3	1	2	2	43.54	3.38
18	2	3	1	2	3	47.37	4.28
19	3	1	3	2	1	35.77	2.32
20	3	1	3	2	2	38.51	1.78
21	3	1	3	2	3	41.72	2.41
22	3	2	1	3	1	36.32	2.22
23	3	2	1	3	2	38.6	1.9
24	3	2	1	3	3	41.48	2.55
25	3	3	2	1	1	35.95	1
26	3	3	2	1	2	39.42	1.35
27	3	3	2	1	3	41.89	1.91

Using Minitab software, the data were analyzed separately based on the PV temperature response and the TEG temperature difference response. This is because the PV temperature has the lower is better condition, while the TEG temperature difference has the higher is better condition.

2.2.1. PV Temperature Response

Taguchi analysis using Minitab software with the data shown in Table 2 generated main effect plot based on signal to noise ratio as shown in Fig 6.

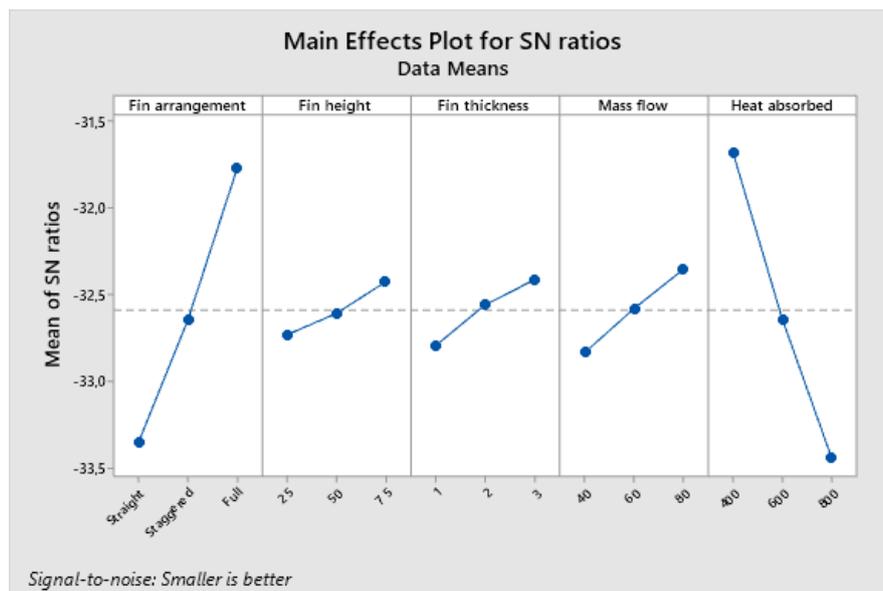


Fig. 6. Main effect plot based on SN ratio for PV temperature response

SNR (Signal to Noise Ratio) analysis describes the ratio between signal to noise. The advantage of analysis using the Taguchi method is that noise, or invalid data signals are taken into account so that the experimental design becomes robust. Based on the data in Fig 6, the optimal value is the level with the highest value in the plot with the condition smaller is better.

The optimal combination to get the optimal response are full TEG arrangement, 75mm fin height, 3mm fin thickness, 80 gr/s air mass flow rate, and 400 W/m² of heat absorbed. Fig 6 shows that the plot on the SNR analysis shows that heat absorbed and fin arrangement has a much larger range of values than the other three factors: fin height, fin thickness, and mass flow. Thus, heat absorbed and fin arrangement has a more significant influence than the other three factors.

2.2.2. TEG Temperature Difference Response

Taguchi analysis using Minitab software with the data shown in Table 2 generated main effect plot based on signal to noise ratio as shown in Fig 7.

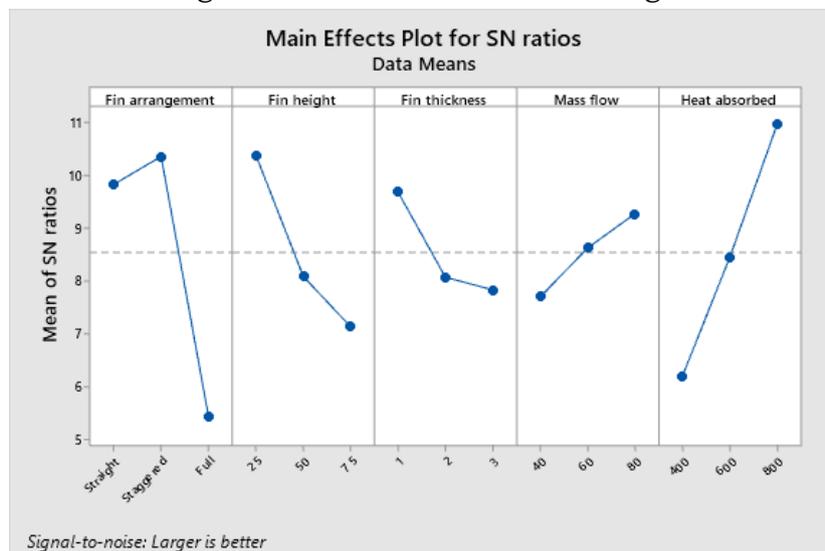


Fig. 7. Main effect plot based on SN ratio for TEG temperature difference response

Based on the SNR analysis in Fig 7, the optimal combination to obtain the optimal TEG temperature difference are the staggered TEG arrangement, 25mm fin height, 1mm fin thickness, 80 gr/s air mass flow rate, and 800 W/m² heat absorbed. Based on Fig 5, it can be seen that the plot of the SNR analysis shows that heat absorbed, fin height, and fin arrangement has a larger range of values than fin thickness and mass flow. Thus, heat absorbed, fin height, and fin arrangement has a greater influence than the other two factors.

2.3. Analysis of Variance

Analysis of variance (ANOVA) was used to determine the significance of the factors on the observed responses. ANOVA was carried out using Minitab software based on the data generated using the Taguchi design of experiment. ANOVA was carried out in

two separate parts. Those are the response of the PV temperature and the response of the temperature difference between the hot and cold sides of TEG.

2.3.1. PV Temperature Response

Analysis of variation using Minitab software with fin configuration, fin height, fin thickness, air mass flow, and heat absorbed as factors and the response in the form of PV surface temperature generated values as shown in Table 5.

Table 5. ANOVA for PV temperature response

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fin arrangement	2	287,18	143,588	68,27	0,000
Fin height	2	12,97	6,484	3,08	0,074
Fin thickness	2	19,43	9,713	4,62	0,026
Mass flow	2	29,26	14,632	6,96	0,007
Heat absorbed	2	347,07	173,533	82,51	0,000
Error	16	33,65	2,103		
Total	26	729,55			

Based on the data in Table 5, fin configuration, fin thickness, air mass flow, and heat absorbed have a significant effect on PV temperature. The most contributing factor to changes in PV temperature is the heat absorbed by PV, with a contribution of 47.57%. Furthermore, the fin configuration, mass flow, and fin thickness contributed to the PV temperature by 39.36%, 4.01%, 2.66%.

The high contribution of heat absorbed to PV temperature is caused by the more heat received by PV, the higher the PV temperature. The change in PV temperature due to the configuration of the fins is caused by the distribution of heat absorption by conduction by TEG. The change in PV temperature by the thickness of the fin is caused by the greater conduction heat transfer between the TEG and the fin. The change in PV temperature by the mass flow rate is caused by the increase in the convective heat transfer coefficient as the air mass flow rate increases.

Heat absorbed and fin arrangement has much more influence on the change in PV temperature than other factors because heat absorbed by PV is directly converted into temperature increment while fin configuration is responsible for the form of fluid flow pattern and the effective area of heat transfer turbulence in the channel. The more turbulence the flow, the bigger heat transfer occurs. Mass flow has a significant effect but not as much as heat absorbed and fin arrangement. It occurs because mass flow affects the convective heat transfer coefficient linearly, not drastically as the fin arrangement effect. Fin thickness also has a significant effect but not as much as the two dominant factors because fin thickness only slightly affects the conductive heat transfer. Fin thickness has no significant effect because the higher the fins, the bigger the cross-sectional area of fluid flow. While constant mass flow was applied, the velocity reduced as the cross-sectional area increased.

2.3.2. TEG Temperature Difference Response

Analysis of variation using Minitab software with fin configuration, fin height, fin thickness, air mass flow, and heat absorbed as factors and the response in the form of TEG temperature difference generated values as shown in Table 5.

Table 6. ANOVA for TEG temperature difference response

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Fin arrangement	2	12,7485	6,3742	22,86	0,000
Fin height	2	6,0535	3,0267	10,85	0,001
Fin thickness	2	2,1372	1,0686	3,83	0,044
Mass flow	2	0,6380	0,3190	1,14	0,343
Heat absorbed	2	12,2318	6,1159	21,93	0,000
Error	16	4,4620	0,2789		
Total	26	38,2710			

Based on the data in Table 6, fin configuration, fin height, fin thickness, and heat absorbed have a significant effect on different TEG temperatures. The most contributing factor to changes in PV temperature is the fin arrangement, with a contribution of 33.31%. Furthermore, heat absorbed, mass flow, and fin thickness contributed to the PV temperature by 31.96%, 15.82%, 5.58%.

The temperature distribution in the PV causes the big influence of the fin arrangement on the TEG temperature difference. The effect of the height of the fins on the TEG temperature difference is caused by the increasing rate of forced convection by the TEG fin. The effect of fin thickness on the TEG temperature difference is caused by changes in the heat transfer rate by conduction from the TEG to the fin. The effect of heat absorbed on the TEG temperature difference is caused by the greater the heat received by the PV, the higher the temperature of the hot side of the TEG. Different from the effect on PV temperature, fin height has a significant effect on TEG temperature difference response because it affects the conductive and convective heat transfer on the cool side of the TEG. The higher the fins, the lower the temperature of the cool side of TEG. Fin thickness also has a significant effect but is smaller than the effect of fin height because fin thickness only affects the conductive heat transfer of the cool side of TEG. Mass flow has no significant effect on the TEG temperature difference because it affects the heat transfer rate from the whole system. The change of mass flow affects both the hot side of TEG and the cool side of TEG, resulting in no change in the temperature difference between the hot side and the cool side of the TEG.

3. Conclusion

Based on the combination of factors and levels studied in this paper, the combination to obtain the optimal PV temperature is full TEG configuration, fin height 75 mm, fin thickness 3mm, mass flow rate 80 g/s, and heat absorbed 400 W/m². Meanwhile, the combination to obtain the optimal TEG temperature difference is the staggered TEG configuration, 25mm fin height, 1mm fin thickness, 80 g/s mass flow

rate, and 800 W/m² heat absorbed. Factors that significantly influence PV temperature response are TEG configuration, fin thickness, mass flow rate, and heat absorbed. While, factors that significantly influence TEG temperature difference response are TEG configuration, fin height, fin thickness, and heat absorbed.

Acknowledgement

The work presented in this paper is a part of master degree scholarship program University of Lampung.

References

- W. P. Nel and C. J. Cooper, "Implications of fossil fuel constraints on economic growth and global warming," *Energy Policy*, vol. 37, pp. 166-180, 2009.
- A. Zecca, L. Chiari, "Fossil-fuel constraints on global warming," *Energy Policy*, vol. 38, no. 1, pp. 1-3, 2010.
- N. Kannan, D. Vakeesan, "Solar energy for future world: - A review," *Renewable and Sustainable Energy Reviews*, vol. 62, pp. 1092-1105, 2016.
- M. R. Shaikh, S. Shaikh, S. Waghmare, S. Labade, and A. Tekale, "A Review Paper on Electricity Generation from Solar Energy," *International Journal for Research in Applied Science and Engineering Technology (IJRASET)*, vol. 5, no. 9, pp. 1883-1889, 2017.
- W. C. Sinke, "Cost effective cooling of photovoltaic modules to improve efficiency," *Case Studies in Thermal Engineering*, vol. 14, 2019.
- U. Sajjad, M. Amer, H. M. Ali, A. Dahiya, and N. Abbas, "Cost effective cooling of photovoltaic modules to improve efficiency," *Case Studies in Thermal Engineering*, vol. 14, 2019.
- S. Tiwari, S. Agrawal, and G. N. Tiwari, "PVT air collector integrated greenhouse dryers," *Renewable and Sustainable Energy Reviews*, vol. 90, pp. 142-159, 2018.
- N. Jaziri, A. Boughamoura, J. Müller, B. Mezghani, F. Tounsi, M. Ismail, "A comprehensive review of Thermoelectric Generators: Technologies and common applications," *Energy Reports*, vol. 6, pp. 264-287, 2020
- C. Wei, H. Wu, P. Wang, X. Dong, and L. Yu-Li, "Power output and efficiency of a thermoelectric generator under temperature control," *Energy Conversion and Management*, vol. 127, pp. 404-415, 2016.
- B. Challa, and P. Ponnambalam, "The theoretical performance evaluation of hybrid PV-TEG system," *Energy Conversion and Management*, vol. 173, pp. 450-460, 2018.
- A. M. A. Soliman, H. Hassan, and S. Ookawara, "An experimental study of the performance of the solar cell with heat sink cooling system," *Energy Procedia*, vol. 162, pp. 127-135, 2019.
- M. Mokhtari, M. B. Gerdroodbary, R. Yeganeh, and K. Fallah, "Numerical study of mixed convection heat transfer of various fin arrangements in a horizontal channel," *Engineering Science and Technology*, vol. 20, pp. 1106-1114, 2017.

- H. Ambarita, M. R. Siregar, K Kishinami, M Daimaruya and H Kawai, "Application of CFD in Indonesian Research: A review," *Journal of Physics Conference Series*, vol. 1005, pp. 27-29, 2017.
- A. Özakin and F. Kaya, "Experimental thermodynamic analysis of air-based PVT system using fins indifferent materials: Optimization of control parameters by Taguchi method and ANOVA," *Solar Energy*, vol. 197, pp. 199-211, 2020.
- Yakoob. Kolioak, M. Radhakrishna, A.M.K. Prasad,. "Optimization of Heat Energy Based on Phase Change Materials used in Solar Collector using Taguchi Method", *Materials Today*, vol. 22, pp. 2404-2411, 2020.
- D. Ji, S. Hu, Y. Feng, J. Qin, Z. Yin, A. Romagnoli, J. Zhao, H. Qian, "Geometry optimization of solar thermoelectric generator under different operating conditions via Taguchi method", *Energy Conversion and Management*, vol. 238, pp. 0196-0204, 2021.
- F. Bayrak, H. F. Oztop, and F. Selimefendigil, "Effects of different fin parameters on temperature and efficiency for cooling of photovoltaic panels under natural convection," *Solar Energy*, vol. 188, pp. 484-494, 2019.
- A. Kasaeian, Y. Khanjari, S. Golzari, O. Mahian, and S. Wongwises, "Effects of forced convection on the performance of a photovoltaic thermal system: An experimental study," *Experimental Thermal and Fluid Science*, vol. 85, 13-21, 2017.
- P. Sidi and M. T. Wahyudi, "Aplikasi metoda Taguchi untuk mengetahui optimasi kebulatan proses bubut CNC," *Jurnal Rekayasa Mesin*, vol. 4, no. 2, pp. 101-108, 2013.
- S. Armstrong and W.G. Hurley, "A Thermal Photovoltaic Panels under Varying Atmospheric Conditions," *Applied Thermal Engineering*, vol. 30, pp. 1488-1495, 2010.
- Amrizal, Amrul, A. Yonanda, and Zulfa, "Comparison Study of Solar Flat Plate Collector With Two Different Absorber Materials" in the 1st Faculty of Industrial Technology International Congress International Conference., Bandung, 2017, pp. 17-22.
- E. Yazdanshenas, A. Rezania, M. K. Rad, and L. Rosendahl, "Electrical response of thermoelectric generator to geometry variation under transient thermal boundary condition," *Journal of Renewable and Sustainable Energy*, vol. 10, no. 064705, 2018.
- M. Dogan and M. Sivrioglu, "Experimental investigation of mixed convection heat transfer from longitudinal fins in a horizontal rectangular channel," *International Journal of Heat and Mass Transfer*, vol 53, pp. 2149-2158, 2010.



Angga Darma Prabowo was born in Bandar Lampung City, Lampung, Indonesia in 1996. He received the S.T. degrees in mechanical engineering from the University of Lampung, Bandar Lampung, in 2019. From 2019 to 2021, he was a master degree student in mechanical engineering major, he has been research assistant with thermodynamics laboratory since 2019, he is a practitioner of mechanical engineering in waste recycling industry since 2019.



Amrizar was born in Sawahlunto City, West Sumatera, Indonesia. She received the B.S. and M.S. degrees in Mechanical Engineering from the University of Andalas, Padang, in 2001 and the Ph.D. degree in Engineering from Lleida University, Catalunya, Spain, in 2012.

From 2001 to 2004, she was a Research Assistant with the Princeton Plasma Physics Laboratory. Since 2009, she has been an Assistant Professor with the Mechanical Engineering Department, Texas A&M University, College Station. She is the author of three books, more than 150 articles, and more than 70 inventions. Her research interests include high-pressure and high-density nonthermal plasma discharge processes and applications, microscale plasma discharges, discharges in liquids, spectroscopic diagnostics, plasma propulsion, and innovation plasma applications. She is an Associate Editor of the journal Earth, Moon, Planets, and holds two patents.

Dr. Amrizar was a recipient of the International Association of Geomagnetism and Aeronomy Young Scientist Award for Excellence in 2008, and the IEEE Electromagnetic Compatibility Society Best Symposium Paper Award in 2011.



Gusri Akhyar Ibrahim had obtained his bachelor degree in Mechanical Engineering from University of Sriwijaya Palembang in 1997. Then followed by his Master of Mechanical Engineering from Universitas of GadjahMadaYogyakarta in 2005. His specialization was in sputtering method to produce thin layer on cutting tool. Completed research for doctor philosophy program at National University of Malaysia in area of machining process for super alloy materials namely titanium and Inconel. Currently active as a lecturer at University of Lampung in Mechanical Engineering Department. Some research activities are focusing in machining super alloy material for implant or biomedical engineering.

Correlation Of Rainfall Data TRMM and BMKG in Kalimantan Island

Budi Setiyawan^{1*}, Ahmad Zakaria², and Endro P. Wahono²

¹Student of Master Study Program of Civil Engineering, University of Lampung, Lampung, Indonesia

²Master Study Program of Civil Engineering, University of Lampung, Lampung, Indonesia

*Email: budisetya82@ymail.com

Abstract

The island of Kalimantan, especially the East Kalimantan area, has been included in the discourse on the development of the State Capital of the Republic of Indonesia. It is necessary to carry out further scientific studies from various aspects, one of which is rainfall. The Meteorology and Geophysics Agency (BMKG) and NASA's The Tropical Rainfall Measuring Mission (TRMM) are agencies for measuring rainfall in Indonesia. The BMKG ground rainfall data recording still leaves a void given the limitations of recording at rain observation stations, while the TRMM satellite rainfall data can provide complete data. The purpose of the study was to analyze the equations and correlations of ground rainfall data BMKG and TRMM satellite rainfall data and analyze the feasibility level of TRMM satellite rainfall data to be able to represent BMKG ground rainfall data that is missing or out of reach of rainfall observation stations. Rainfall data was used for 20 years (1998-2019) at rain stations on the island of Borneo. Data were analyzed in the form of daily, 7 daily, monthly and yearly. The results of the correlation analysis showed that the greater the cumulative number, the greater the similarity of the BMKG and TRMM patterns, with the highest correlation value in the annual cumulative (0.661-0.909). TRMM rainfall data is considered capable and feasible as an alternative in filling in missing BMKG rainfall data, especially as a substitute for certain area data that is difficult to measure.

Keywords: Rainfall, Correlation, BMKG, TRMM, Kalimantan

Introduction

The island of Kalimantan, especially in the East Kalimantan area, has been included in the discourse on planning the development of the State Capital of the Republic of Indonesia, there is still much that needs to be studied scientifically from various aspects of climate and weather, one of which is rainfall. In the application of scientific calculations, rainfall is determined in mm/time which can be interpreted as the height of the surface inundation caused by the rain itself within hours, daily, weekly or annual time units [1]. Until now, the official rainfall data in Indonesia has been issued by the Meteorology, Climatology and Geophysics Agency (BMKG). The Tropical Rainfall Measuring Mission (TRMM) is a National Aeronautics and Space Administration (NASA)

space mission in the form of satellites to improve understanding of the distribution of rain in tropical and sub-tropical areas of the earth, including the provision of information related to rain and its release about global climate formation and information others have to do with rain and climate. This TRMM collaboration project is a joint project between Japan and the United States for tropical and sub-tropical rain research, from the official NASA website - the *Precipitation Measurement Mission*, you can see a variety of data presentations on climate and rain research results with hourly and daily data updates [2].

There are still very few studies that produce similarities and relationships between TRMM satellite data and BMKG *ground* data, so it demands the need to find a correlation between the two rainfall data. The recording of BMKG *ground* rainfall data still leaves data gaps given the limitations of recording at rain observation stations, while the TRMM satellite rainfall data provides complete data due to the ability of recording by satellite. By obtaining the equation and correlation relationship between the two rainfall data, it can provide additional information about whether or not the TRMM satellite rainfall data is appropriate to represent the missing rainfall data filling in the BMKG *ground* rainfall data, the lack of information reinforces the importance of conducting Bulk Data Correlation. TRMM and BMKG Rain in the Kalimantan Island Region.

Materials and Methods

The study areas in this research are several BMKG Rainfall Observation Stations located on the island of Kalimantan, namely the Paloh rain station. The data used is secondary data with data collection methods from two sources, namely BMKG *ground* rainfall and TRMM satellite rainfall data. A comparison is made to see the magnitude of the similarity or similarity between data from BMKG and TRMM data. The first comparative analysis performed was the *Pearson* correlation analysis. In the correlation analysis, *Curve Comparative* is also carried out as a comparison of BMKG and TRMM rainfall data so that a comparison of rainfall data is obtained in graphical form. The next analysis is Linear Regression analysis, to see how big the relationship is between the two rainfall data between BMKG data and TRMM data and get the coefficient of determination.

Results and Discussions

TRMM and BMKG rainfall data at each station were compared to see the linear equation and correlation value. The compared rainfall data is divided into daily, 30 daily (monthly), and annual data.

1. Daily Data

The results of the correlation of daily BMKG and TRMM rainfall data are presented in Table 1 below:

Table 1. Daily Cumulative Correlation Value

Stasiun Hujan	Nilai Koefisien Korelasi
Nangapinoh	0,0609
Paloh	0,4147
Pangsuma	0,0824
Rahadi Oesman	0,0955
Siantan	0,0758
Supadio	0,3398
Susilo	0,4691

The results of the correlation analysis, it was found that from the seven rain stations analyzed in Kalimantan, the correlation value was from 0.06 to 0.47. From these results, it is stated that the uniformity of rainfall patterns between BMKG data and TRMM data on the same day shows a correlation with a low scale and a very low scale. Comparative data in graphical form is presented in the following graphic images (Figures 1):

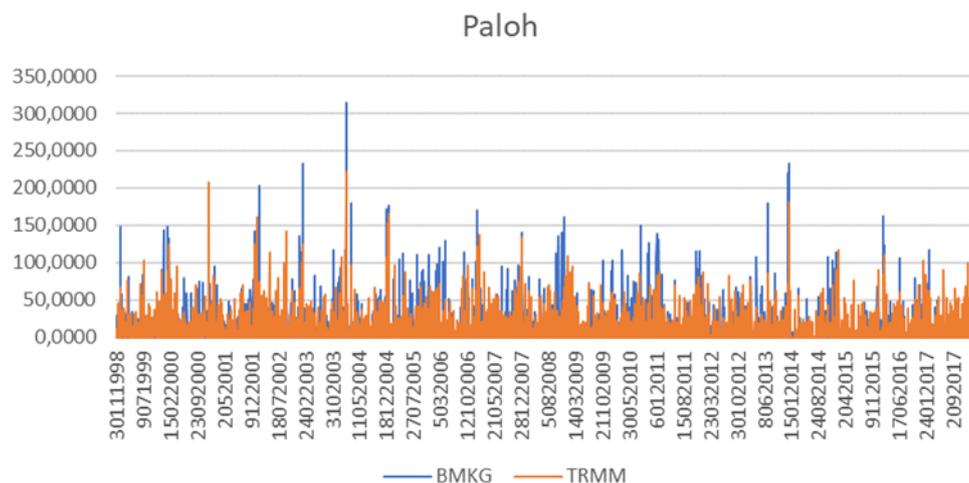


Figure 1. Comparison of Daily Cumulative Paloh Station Rain Data

From the results of the comparison of the daily cumulative data graph of BMKG and TRMM shows that the data graph for each pattern has similarities, this is inversely proportional to the maximum value of each data which shows a significant difference, so that the value shows a small correlation value.

The next analysis is Linear Regression analysis. This analysis was conducted to see how big the relationship between the two rainfall data was between the BMKG data and the TRMM data. The results of the Linear Regression analysis are presented as follows:

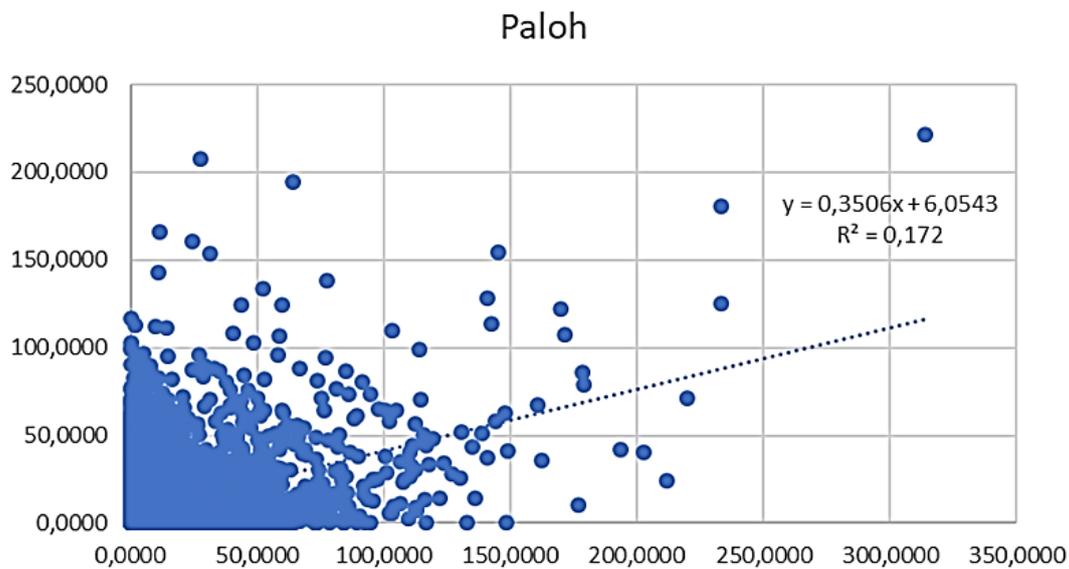


Figure 2. Daily Cumulative Paloh Station Linear Regression Graph

The results of the regression analysis show that the coefficient of determination or ability of a regression function can model the value of BMKG rainfall data from TRMM rainfall data which has a very low scale. From this it can be concluded that the daily rainfall data value of TRMM can only predict the BMKG value with an accuracy rate of 0.17.

2. Data 30 daily (Monthly)

The results of the correlation analysis of BMKG rainfall data on TRMM rainfall data with cumulative 30 daily rainfall data are presented in Table 2 as follows:

Table 2. Correlation Value of 30 Daily Data

Stasiun Hujan	Nilai Koefisien Korelasi
Nangapinoh	0,7659
Paloh	0,8284
Pangsuma	0,3585
Rahadi Oesman	0,3918
Siantan	0,6855
Supadio	0,6855
Susilo	0,7150

From the results of the correlation analysis, it shows that the correlation value which shows success is much better than the daily cumulative correlation value. The results of the 30-day cumulative correlation analysis have a low scale with a value of 0.35 – 0.82. The next data is a graphical comparison of rainfall data presented as follows (Figures 3):

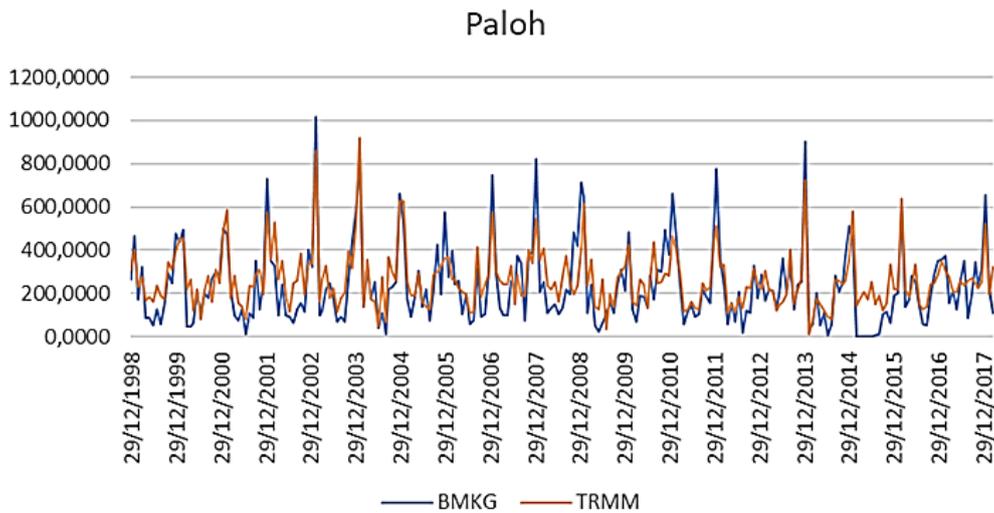


Figure 3. Comparison of 30-Day Paloh Station Rain Data

From the results of the comparison of the data graphs, it can be stated that the values of the BMKG and TRMM rainfall data have the same pattern, but the maximum value of the BMKG rainfall data has a higher tendency than the TRMM data. So this is considered to affect the 30 daily correlation value between BMKG and TRMM.

The next analysis is Linear Regression analysis are presented as follows (Figure 4). From the results of the analysis that has been produced, it is stated that the coefficient of determination or the model's ability to predict BMKG rainfall data is with a value of 0.68 with a low to very high scale.

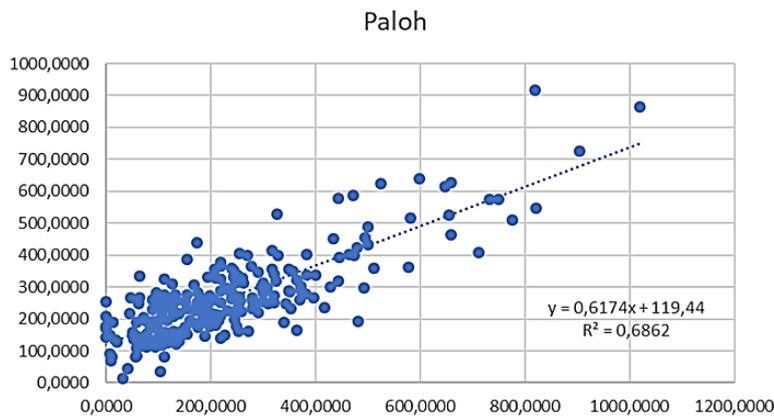


Figure 4. Linear Regression Graph Paloh Station Cumulative 30 Days

3. Annual Data

The results of the correlation analysis of BMKG rainfall data against TRMM rainfall data with cumulative annual rainfall data are presented in Table 3 as follows:

Table 3. Annual Data Correlation Value

Stasiun Hujan	Nilai Koefisien Korelasi
Nangapinoh	0,8865
Paloh	0,8811
Pangsuma	0,7017
Rahadi Oesman	0,6609
Siantan	0,9092
Supadio	0,8435
Susilo	0,8784

From the results of the correlation analysis, it shows that the correlation value which shows success is much better than the daily cumulative correlation value. The results of the annual cumulative correlation analysis have a low scale with a value of 0.661-0.909. So it is stated that the value of the results of the annual correlation analysis is much better than the results of the daily cumulative value. A comparison of the graphs of rainfall data is presented as follows (figures 5):

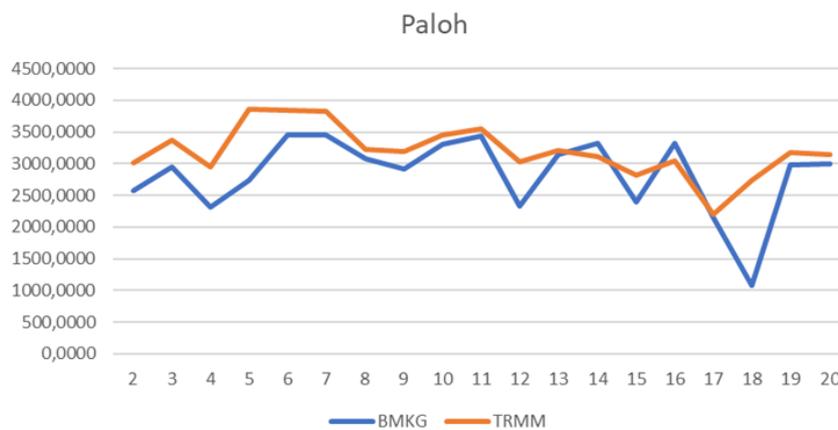


Figure 5. Comparison of Annual Paloh Station Rainfall Data

From the results of the comparison of the data graphs, it can be stated that the values of the BMKG and TRMM rainfall data have the same pattern, but the maximum value of the BMKG rainfall data has a higher tendency than the TRMM data. So this is considered to be able to affect the value of the Annual correlation between BMKG and TRMM.

The next analysis is Linear Regression analysis. This analysis was conducted to see how big the relationship between the two rainfall data was between the BMKG data and the TRMM data. The results of the Linear Regression analysis are presented as follows:

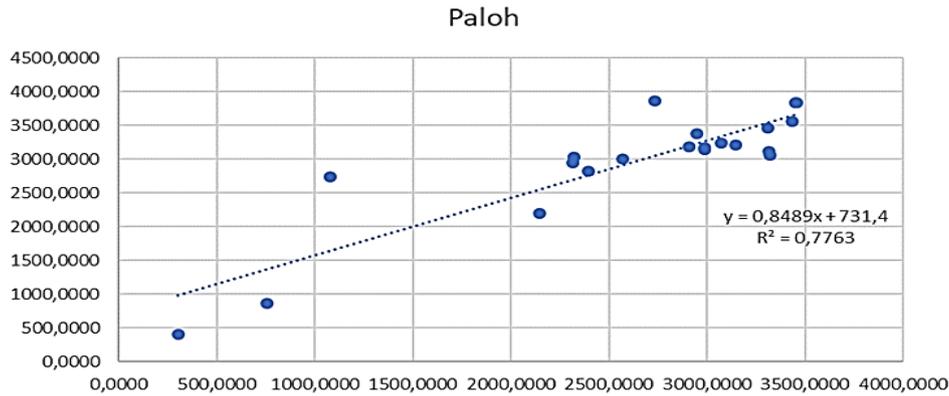


Figure 6. Annual Cumulative Paloh Station Linear Regression Graph

From the results of the analysis that has been produced, it is stated that the coefficient of determination or the model's ability to predict BMKG rainfall data is with a value of 0.77 with a high scale.

To strengthen a conclusion in a study, it is considered necessary to compare the results of this study with the results of previous studies that have been carried out. Through the results of the analysis and observations in this study, there is a similar pattern of the level of correlation between the BMKG and TRMM rainfall data, namely the correlation level at the higher rainfall level results in a very high correlation level. In this study, the density level in the annual rainfall data increases the correlation between BMKG and TRMM rainfall data is very high, ranging from 0.661-0.909. The pattern of the same level of correlation can be seen in the comparison chart which can be described as follows (Figure 7, 8, 9):

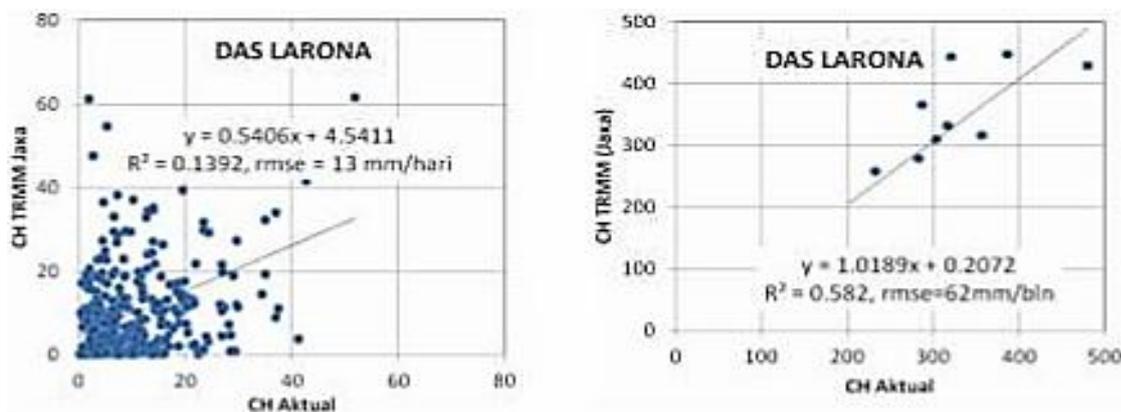


Figure 7. Correlation of TRMM data for daily rainfall data (left) and monthly rainfall data (right) [3]

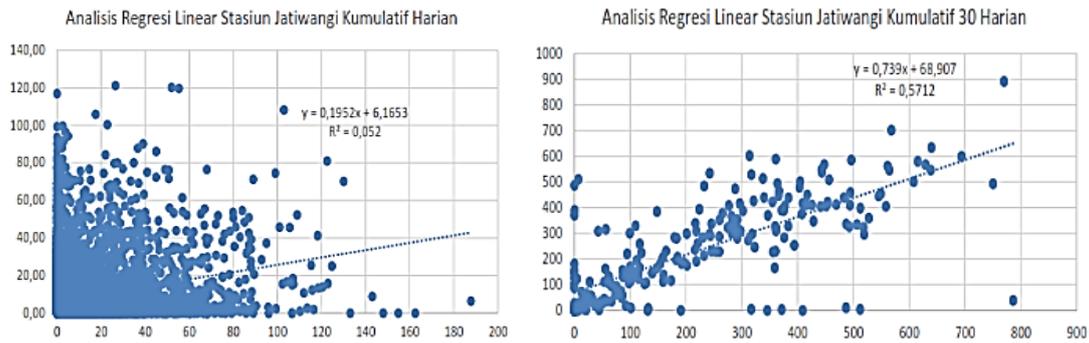


Figure 8. Correlation of BMKG and TRMM data for daily rainfall data (left) and monthly rainfall data (right) [4]

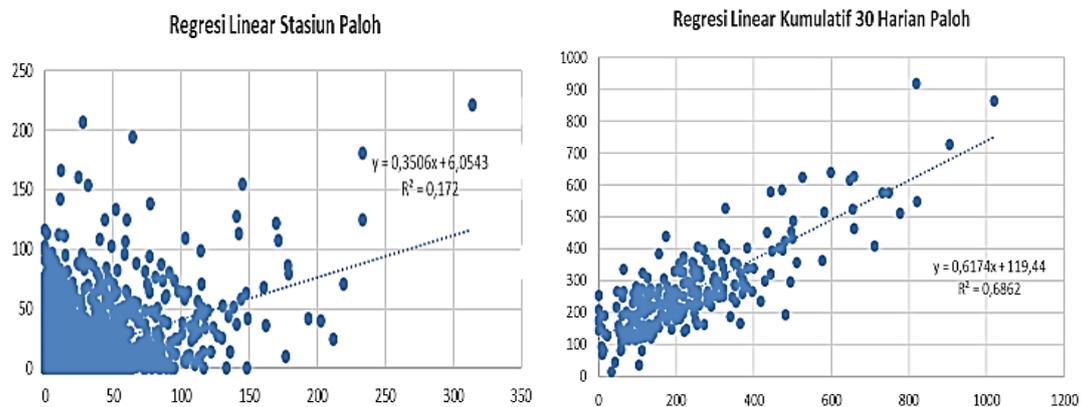


Figure 9. Correlation of BMKG and TRMM data for daily rainfall data (left) and monthly rainfall data (right) in this study.

Conclusions

The results of the analysis carried out are that the greater the rainfall, the greater the correlation between BMKG and TRMM. It is expressed as the highest value basically with 0.66 - 0.90, to create 30 daily is 0.35 - 0.82 and created daily with value 0.06 - 0.47. The Paloh rain station in the artwork has a moderate correlation. So it can be stated that this station has a good correlation value. The results of the analysis of 30 daily and annual rainfall data have a better correlation, this is very helpful considering the large amount of rainfall to collect missing rainfall data in daily rainfall data. Based on this, the TRMM rainfall data is considered feasible to fill in the missing rainfall data at the BMKG.

References

- Soemarto, CD. (1986). *Hidrologi Teknik*. Surabaya: Usaha Nasional. 515 halaman.
- Prasetya, Rakhmat. As-syakur, Abd.Rahman. Osawa, Takahiro. (2013). *Validation of TRMM Precipitation Radar satellite data over Indonesian region*. *Theor Appl Climatol* 112:575-587.
- Syaifullah, M.Djazim. (2014). *Validasi Data TRMM Terhadap Data Curah Hujan Aktual di Tiga DAS di Indonesia*. *Jurnal Meteorologi dan Geofisika* Vol.15 No.2.
- Alfian, Rian. (2021). *Analisis Korelasi Data Curah Hujan BMKG dan TRMM di Provinsi Jawa Barat*. Tesis. Universitas Lampung. Bandar Lampung.

DAMPAK MEKANIS DARI BATU LEMPUNG YANG DISEBABKAN OLEH SLAKING

Dian Triyanto¹, Andius Dasa Putra², Endro Prasetyo Wahono³

¹Mahasiswa Magister Teknik Sipil, Universitas Lampung; Jl. Soemantri Brojonegoro No 1 Bandar Lampung; 35145

^{2,3} Teknik Sipil, Universitas Lampung; Jl. Soemantri Brojonegoro No 1 Bandar Lampung; 35145

Abstrak.

Penelitian ini dilakukan untuk mengetahui pengaruh fenomena slaking yang memengaruhi deformasi pada batu lempung. Batu lempung yang terbentuk dari lapisan lempung, lumpur, kapur, dan rombakan batu lainnya mengalami kompaksi dan suhu yang tinggi sehingga material tersebut menjadi padat, dan memiliki pori yang sangat kecil akibat keseragaman partikelnya. Pengujian yang dilakukan adalah analisis X-Ray Diffraction, Accelerated Slaking Test, serta One Dimensional Compression Test. Berdasarkan penelitian ini menunjukkan bahwa jenis batu lempung Lemong mengalami deformasi akibat fenomena slaking yang sangat rendah, karena dipengaruhi adanya ukuran pori-pori butiran dalam partikel yang sangat kecil, sehingga peneliti mendapatkan data dan solusi untuk mengetahui tingkat kemampuan batu lempung Lemong untuk pembangunan infrastruktur.

Abstract.

This research was conducted to determine the effect of the slaking phenomenon on the deformation of claystone. Claystone formed from layers of clay, mud, lime, and other rock debris undergoes compaction and high temperatures so that the material becomes dense, and has very small pores due to the uniformity of the particles. The tests carried out were the analysis of X-Ray Diffraction, Accelerated Slaking Test, and OneDimensional Compression Test. Based on this research, it shows that the type of Lemong clay is deformed due to the very low slaking phenomenon, because it is influenced by the size of the grain pores in very small particles, so researchers get data and solutions to determine the level of ability of Lemong clay for infrastructure development.

PENDAHULUAN

Bumi memiliki beberapa lapisan terdiri dari lapisan inti bumi, mantel, dan kerak bumi. Penyusun kerak bumi terdiri dari beberapa batuan yaitu batuan beku, sedimen, dan metamorf. Batuan sedimen merupakan batuan yang tersusun akibat pengendapan material hancuran dari batuan atau material lain yang memadat akibat proses kompaksi dan pemanasan. Batuan sedimen terdiri dari beberapa jenis batu salah satunya adalah batu lempung. Batu lempung terbentuk dari lumpur yang tanah lempung yang mengalami kompaksi akibat tekanan dan suhu yang sangat tinggi sehingga material tanah lempung memadat dan menjadi keras seperti batu, akan tetapi batu lempung pada

saat ini di Indonesia penggunaannya dalam bidang konstruksi belum banyak, karena batu lempung Ketika digunakan untuk material konstruksi akan mengalami deformasi yang cukup besar, salah satunya adalah fenomena slaking. Fenomena *Slaking* merupakan ketahanan batuan lemah terhadap aktivitas air yang ada di batuan tersebut (Putra, dkk, 2019). Fenomena *Slaking* dari bahan yang berasal dari batuan lemah seperti batu lumpur atau lempung dapat menyebabkan deformasi struktur bumi. Oleh karena itu harus benar dipertimbangkan dalam proses desain dan konstruksi. penelitian sebelumnya menunjukkan bahwa *Slaking* merupakan penyebab dalam distribusi ukuran partikel dan perubahan sifat mekanik. Batuan yang mengalami pelapukan cenderung hancur dan berubah menjadi partikel kecil yang diakibatkan adanya proses pembasahan dan pengeringan.

Dengan meningkatnya pembangunan infrastruktur terutama jalan raya, beberapa titik pembangunan melewati daerah dengan keadaan geologi tersusun oleh batu lempung. Hal tersebut mengakibatkan pembangunan tersebut membutuhkan material selain batu lempung dari lokasi yang jauh, dan batu lempung di daerah pembangunan tidak digunakan, karena dengan alasan memiliki mutu yang tidak baik. Dengan dengan beberapa pengujian peneliti membahas tentang fenomena slaking yang mempengaruhi deformasi batu lempung, sehingga batu tersebut dapat atau tidak direkomendasikan untuk digunakan sebagai material konstruksi.

Penelitian ini membahas tentang deformasi batu lempung akibat fenomena slaking, sehingga batu lempung mengalami tingkat deformasi yang akan mempengaruhi kemampuan batu lempung sebagai bahan konstruksi dalam pembangunan infrastruktur khususnya jalan yang dapat dijadikan sebagai acuan awal pembangunan terutama di Provinsi Lampung. Beberapa pengujian yang dilakukan meliputi pengujian *X-Ray Diffraction*, *1D Compression Test*, *Accelerated Slaking Test*. Sehingga dengan dilakukan penelitian ini diketahui metode yang akan digunakan untuk meningkatkan daya dukung batuan ketika daerah tersebut dilakukan pembangunan infrastruktur, dan materialnya menggunakan material dari lingkungan sekitar.

TINJAUAN PUSTAKA

Slaking adalah proses penghancuran batuan akibat air melalui pembasahan dan pengeringan. Perilaku batuan lapuk telah dipelajari berupa eksperimen (Dhakal, dkk, 2002; Liu & Zhang, 2015; Santi, 1998) melalui uji *slake durability* dimana diterapkan siklus pembasahan dan pengeringan untuk mengevaluasi ketahanan batuan lapuk seperti batu serpih, batu lempung dan batu lanau. Hal ini menunjukkan bahwa siklus *slaking* secara signifikan mempengaruhi proses degradasi dan distribusi perubahan ukuran partikel (Putra & Kikumoto, 2017; Putra & Kikumoto, 2016; Putra, dkk, 2019; Vallejo & Murphy, 1999). Uji *slake durability* digunakan secara luas untuk menilai perubahan fisik perilaku *slaking* sebagai hasil dari proses pembasahan dan pengeringan (*wetting-drying processes*) (Putra, dkk, 2019). Batuan sedimen adalah batuan yang terbentuk dari hasil pengendapan (sedimentasi), hasil erosi atau batuan yang terjadi dari akumulasi mineral dari hasil perombakan batuan yang sudah ada sebelumnya atau hasil aktifitas kimia maupun organisme yang diendapkan lapis demi lapis pada permukaan bumi yang

kemudian mengalami pematangan (litifikasi) dan diagenesa (Nurdin, 2009). *Breakage Parameter (Br)* merupakan metode yang digunakan untuk melihat besar kerusakan batuan akibat mekanisme *Slaking* dengan mencari luasan berdasarkan grafik uji *Accelerated Slaking Test* dengan persamaan ABCDE dan ABCD maka didapatkan nilai Br sebesar 0-1. Semakin besar nilai Br menunjukkan bahwa kerusakan batuan akibat mekanisme *Slaking* semakin besar (Putra, 2016)

METODE PENELITIAN

Penelitian ini mengambil lokasi penelitian di kecamatan Lemong, Kabupaten Peisir barat, Provinsi Lampung, karena pada lokasi tersebut keadaan struktur geologi didominasi oleh batu lempung dan pembangunan infrastruktur tepat di atas struktur tersebut.

Data

Data yang digunakan pada penelitian ini merupakan sampel batu lempung yang diuji menggunakan beberapa metode. Pengambilan sampel dilakukan beberapa tahapan seperti Mencari lokasi terjadinya kerusakan konstruksi akibat perilaku batuan penopang dan material yang digunakan. Kemudian plotting di peta geologi sesuai lokasi terjadinya kerusakan konstruksi. Kemudian mendatangi lokasi dan mengambil sampel batuan dengan menggunakan palu geologi, dan melihat kemenerusan sebaran batuan tersebut. Sampel diambil dengan ukuran acak berdiameter 20 – 30 cm dan dimasukkan ke kantong sampel dan dibawa ke laboratorium mekanika tanah.

Metode

Metode yang digunakan pada penelitian ini dilakukan pengujian XRD, Analisis Geologi, *1D Compression Slaking Test*, dan *Accelerated Slaking Test*.

3.2.1. Pengujian XRD

Pengujian XRD pada beberapa sampel yang bertujuan mengetahui kandungan pada setiap batuan yang diuji. Pengujian ini dilakukan di Laboratorium Yokohama University, Jepang.

3.2.2. Analisis Geologi

Analisis ini digunakan untuk mendukung analisis mineralogi, jenis batuan, dan sebaran batuan, dengan beberapa analisis seperti membuat plotting pada peta geologi, kemudian membaca jenis batuan, dan sebaran batuan, sesuai stratigrafi geologinya, lalu mendeskripsikan mineralogi batuan sesuai dengan jenis batuan penyusun dan data hasil pengujian *X-Ray Diffraction*.

Pengujian Accelerated Slaking Test

Pengujian ini merupakan pengujian pada batuan dalam bentuk pengamatan perilaku batuan yang digunakan untuk menyelidiki proses dan mekanisme *slaking* dari batuan lapukan dengan lebih detail dan tidak diberikan tekanan pada sampel uji, dengan langkah-langkah sebagai berikut :

Pecahkan batuan sampel dengan menggunakan palu, kemudian disaring menggunakan saringan dan ambil sampel yang lolos saringan dengan ukuran 37,5 mm dan tertahan pada saringan dengan ukuran 9,5 mm. lalu susun batuan sampel secara rapih pada wadah dan dipastikan sampel tidak dapat berubah posisi saat direndam oleh air, selanjutnya foto sampel yang telah disusun, lalu rendam sampel dengan air hingga sampel terendam secara penuh. Simpan sampel yang telah direndam pada tempat yang memiliki suhu ruangan selama 24 jam, setelah 24 jam, keluarkan air sampel yang terdapat pada loyang atau wadah menggunakan suntikan secara hati-hati agar posisi batuan sampel tidak ada yang berubah, kemudian masukkan sampel kedalam oven, lalu nyalakan oven dengan suhu 100° C selama 24 jam, setelah 24 jam, sampel dikeluarkan dan difoto, kemudian sampel direndam kembali dengan air, lakukan kembali proses pengulangan diatas, sebanyak 5 kali. Setelah pengulangan kemudian dilakukan perhitungan dengan melakukan analisis saringan terhadap sampel pada siklus ketiga dan siklus kelima. Membuat grafik perubahan ukuran partikel pada setiap sampel perbandingan antara presentase kelolosan dengan ukuran partikel. Kemudian gabungkan grafik dari siklus ketiga dan kelima pada sampel, Kemudian menghitung *Breakage Parameter* berdasarkan grafik yang didapatkan.

Pengujian 1D Compression Slaking

Test

Untuk mengevaluasi adanya *slaking*, maka uji *1D Compression Slaking Test* cocok digunakan untuk mengetahui perilaku deformasi batuan lapuk dengan menggabungkan proses pembasahan dan pengeringan. Sama halnya dengan alat uji konsolidasi, uji *1D Compression Slaking Test* digunakan untuk mengetahui perbandingan antara waktu dan deformasi. Wadah spesimen yang digunakan yaitu silinder baja (cincin penahan) berukuran diameter 60 mm dan tinggi 50 mm dengan batu pori masing-masing dipasang di bagian atas dan bawah pada benda uji.

Langkah-langkah pengujian *1D Compression Slaking Test* yaitu Pemilihan sampel batuan yang lolos saringan no. 10 dan tertahan di saringan no. 20. Siapkan alat uji *1D Compression Slaking Test*, kemudian letakkan batu pori bagian bawah pada dasar sel konsolidasi dan lapis dengan kertas saringan dan letakkan cincin penahan di atas cincin cetak, kemudian memasukkan sampel batuan ke dalam cincin penahan kira-kira 1/3 kemudian tumbuk benda uji sebanyak 100×, masukkan lagi benda uji 2/3 lalu tumbuk 100×, kemudian masukkan benda uji sampai penuh lalu tumbuk 100×. Setelah itu ratakan menggunakan spatula, lalu letakkan batu pori bagian atas benda uji dan lapis dengan kertas saringan. Pembebanan dilakukan secara bertahap yaitu (9,8 , 19,6 , 39,2 , 78,5 , 157 , 314 kPa). Waktu untk setiap pembebanan yaitu 30 menit, setelah pembebanan dilakukan proses pembasahan selama 24 jam kemudian dilakukan proses pengeringan selama 6 jam. lakukan proses pembasahan dan pengeringan selama 3× pengulangan. Pada proses pengeringan akhir, oven benda uji selama 24 jam lalu diayak dengan gerakan memutar horizontal tanpa mengoyak secara vertikal.

HASIL DAN PEMBAHASAN

Pengujian XRD

Pengujian ini dilakukan untuk mengetahui komposisi penyusun batuan, sehingga dapat digunakan untuk mendukung uji Slaking. Fenomena slaking sangat dipengaruhi oleh komposisi penyusun batuan, karena komposisi ini yang membuat batuan itu memiliki kekerasan, dan ketahanan terhadap pengaruh slaking, sehingga tingkat deformasi batu lempung dapat diketahui.

Hasil dari pengujian XRD sampel batu lempung daerah Lemongn Gambar 1. Diketahui bahwa jenis mineral yang menyusun batuan Daerah Lemong yaitu: *Dolomite*, *Boron Nitride*, *3-Nitro-nitromethyl-1 H-1,2,4-triazole*, dan *Praseodymium*. Berdasarkan hasil uji XRD tersebut dapat diketahui rata-rata penyusun batuan yang dijadikan sampel tersusun oleh mineral Kapur (*dolomite*), memiliki tekstur yang keras ketika padat.

Hasil Analisis saringan pengujian

Accelerated Slaking Test

Hasil analisis saringan pengujian *Accelerated Slaking Test* pada batu lempung lemong dapat diketahui pada Gambar 2 yang dilakukan sebanyak 5 siklus pembasahan dan pengeringan sehingga dapat diketahui tingkat batuan dapat mempertahankan bentuknya akibat fenomena slaking dan analisis saringan pada siklus ketiga dan kelima maka didapatkan grafik uji sebagai berikut gambar 2. Setelah dilakukan analisis saringan kemudian dilakukan analisis Breakage Parameter untuk mengetahui tingkat kehancuran batuan yang diuji. Perhitungan ini dilakukan dengan mencari luasan pada setiap grafik hasil *Accelerated Slaking Test* menggunakan persamaan ABCDE dan ABCD maka didapatkan nilai *Br* sebesar 0-1. Semakin besar nilai *Br* yang didapat maka semakin besar pula tingkat kerusakan atau kehancuran batuan akibat proses *slaking*.

Berdasarkan hasil perhitungan nilai *Br* pada gambar 3 diketahui nilai *Br* batu lempung lemong sebesar 0,0093, dapat diketahui bahwa batuan Lemong memiliki tingkat deformasi yang sangat rendah sehingga dapat dikategorikan batu lempung lemong memiliki tingkat kemampuan batu mengalami kehancuran yang sangat rendah akibat fenomena *slaking*.

1D Compression Slaking Test

Sama halnya dengan alat uji konsolidasi, uji *1D Compression Slaking Test* digunakan untuk mengetahui perbandingan antara waktu dan deformasi. Maka uji *1D Compression Slaking Test* sangat cocok digunakan untuk mengetahui perilaku deformasi batu lempung dengan menggabungkan proses pembasahan dan pengeringan.

Berdasarkan hasil uji *1D Compression Slaking Test* gambar 4, Batu lempung Lemong mengalami deformasi tidak terlalu signifikan setelah dilakukan proses pembebanan dengan ketinggian 5 cm dan dibebani sampai 314 kPa. Angka pori awal batuan Pemancar ($e_0 = 0.759$) kemudian Sampel menunjukkan deformasi akibat *crushing* dengan penurunan sebesar ($\Delta e_1 = 0.074$), kemudian dilakukan proses pembasahan dan pengeringan berulang atau *slaking* yang mengakibatkan kekakuan dan kekuatan material mengalami penurunan dan terjadi ketidakstabilan. Angka pori awal pada batu

lempung Lemong yaitu ($e_0 = 0.759$). Dengan angka pori awal yang kecil pada batu lempung Lemong mengakibatkan sulitnya air memasuki ruang pori- pori tersebut. Hal ini dapat dilihat saat fenomena *slaking* yang terjadi, dengan sedikit terjadi kehancuran dan kehilangan kekuatan material dari batuan tersebut akibat sedikitnya air yang masuk pada pori batuan.

Deformasi yang terjadi setelah 3 siklus pengulangan fenomena *slaking* sampel mengalami penurunan sebesar ($\Delta e_2 = 0.022$), diketahui nilai ($\Delta e_1 > \Delta e_2$) menunjukkan bahwa deformasi akibat fenomena *crushing* lebih besar daripada fenomena *slaking*. Tabel 1. Merupakan hasil perbandingan nilai antara besarnya perubahan angka pori akibat *crushing* (Δe_1) dan akibat *slaking* (Δe_2).

Setelah dilakukan pengujian 1D *Compression Slaking Test* kemudian dilakukan analisis saringan untuk mengetahui distribusi partikel, yang menyusun batuan dengan cara disaring untuk memisahkan partikel sesuai dengan ukuran saringan masing-masing.

Pada sampel batu lempung lemong kemudian dilakukan pengujian analisis saringan (*sieve analysis*). Berat awal sampel batuan (w_s) yang digunakan adalah sebesar 216 gram. Berdasarkan grafik gambar 5, sampel batuan Lemong memiliki tingkat kehancuran yang sangat rendah setelah dilakukan 3 kali pengulangan tekanan dan proses *slaking*. Persentase lolos saringan (%) batuan Lemong dapat dilihat pada tabel 2.

Analisa Perubahan sifat tekan dan ukuran partikel

Dari perilaku batuan sedimen daerah Lemong yang ditunjukkan pada Gambar 6, terlihat jelas bahwa nilai B_r (Gambar 6(c)) meningkat menjadi 0,009 pada 314 kPa, yang konsisten dengan penghancuran partikel setelah siklus pembasahan dan pengeringan, berupa garis tekanan di plot semi-logaritmik e dan $\log v'$ yang menjadi lebih curam, dan benda uji mengalami tekanan yang cukup signifikan, sehingga terjadi penurunan *void ratio* lebih besar dari 0,7. Dapat diketahui bahwa *slaking* disebabkan oleh siklus pembasahan dan pengeringan sehingga menyebabkan angka *void ratio* (e) menurun.

Analisa Persebaran Batuan Sedimen dan Lapuk

Berdasarkan peta geologi regional dan survey langsung di lapangan dapat diketahui beberapa persebaran batuan sedimen dan lapuk di provinsi lampung. Persebaran tersebut digolongkan menjadi beberapa formasi dan litologi batuan sesuai gambar 7. Formasi dan litologi batuan di provinsi lampung bagian permukaan lebih banyak didominasi oleh batuan sedimen dan lapuk yang sebagian besar merupakan perubahan dari batuan gunung api berupa pasir andesit, tufa, lanau, breksi, sisa tumbuhan, lempung dan serpih. Sehingga pada pembangunan infrastruktur, sangat membutuhkan material selain batuan sedimen, tetapi setelah dilakukan beberapa pengujian dan analisis pada batuan sedimen khususnya batu lempung, batu lempung dapat dijadikan sebagai material pengganti batuan lain dan dapat diambil dari daerah sekitar lokasi pembangunan infrastruktur.

KESIMPULAN

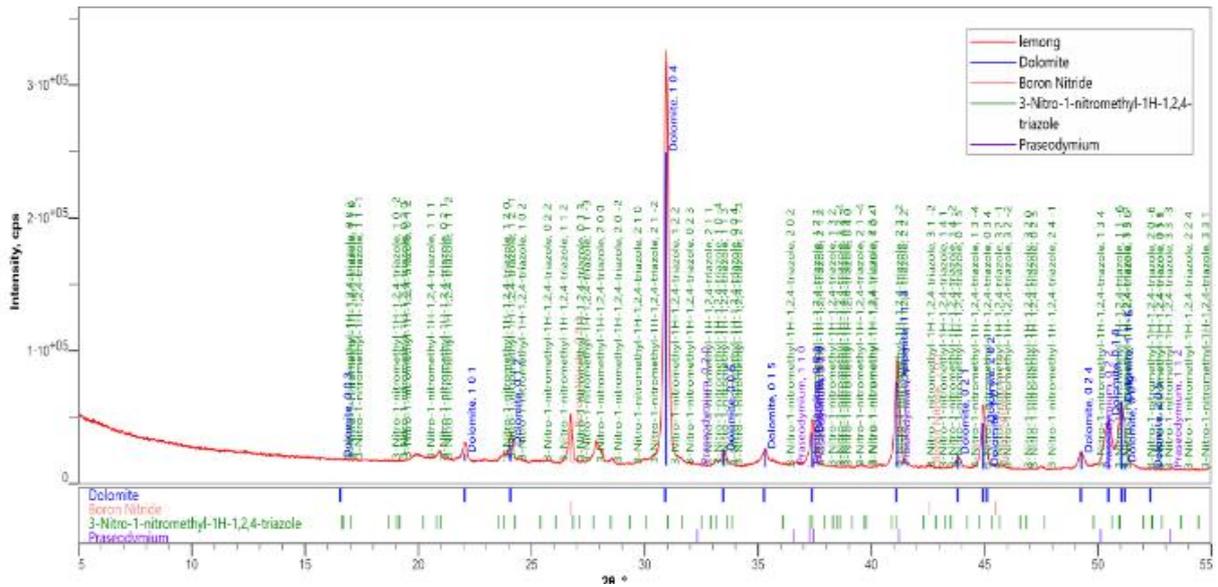
- a. Deformasi sedimen akibat mekanisme *crushing* dan *slaking* sangat dipengaruhi oleh distribusi partikel batuan berupa mineral penyusun yang berbeda-beda, Sebagian besar mineral penyusun batu lempung Lemong berupa Kapur (Dolomite) memiliki tingkat ketahanan terhadap aktivitas air dalam batuan, pada kondisi padat. Diketahui dari hasil pengujian *Accelerated Slaking Test* dan *1D Compression Slaking Test* bahwa deformasi batu lempung Lemong akibat pengaruh mekanisme *crushing* (Δe_1) pada batuan Lemong sebesar 0,074, dan pengaruh dari fenomena *slaking* (Δe_2) pada batuan Lemong sebesar 0,022.
- b. Batu lempung Lemong direkomendasikan sebagai bahan konstruksi terutama untuk timbunan seperti *Subbase* karena memiliki nilai (Δe_1) > (Δe_2) atau memiliki tingkat deformasi batuan yang sangat rendah, sehingga penggunaan material yang selama ini menggunakan material selain batuan sedimen dapat menggunakan batuan sedimen terutama lempung di daerah Lemong, dan dapat diketahui sebaran batuan tersebut sesuai formasi penyusun batuan tersebut dilihat dari peta geologi.

UCAPAN TERIMA KASIH

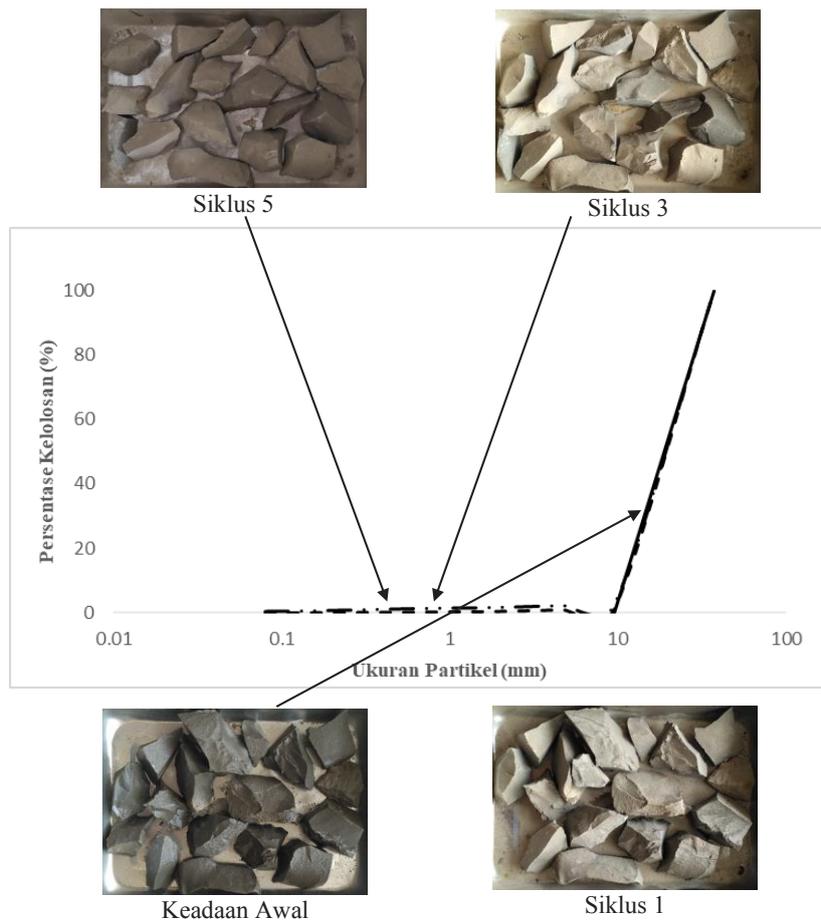
Penulis mengucapkan terima kasih kepada Fakultas Teknik, Jurusan Teknik Sipil, Program Studi Magister Teknik Sipil Universitas Lampung yang telah memberi dukungan terhadap penelitian ini.

DAFTAR PUSTAKA

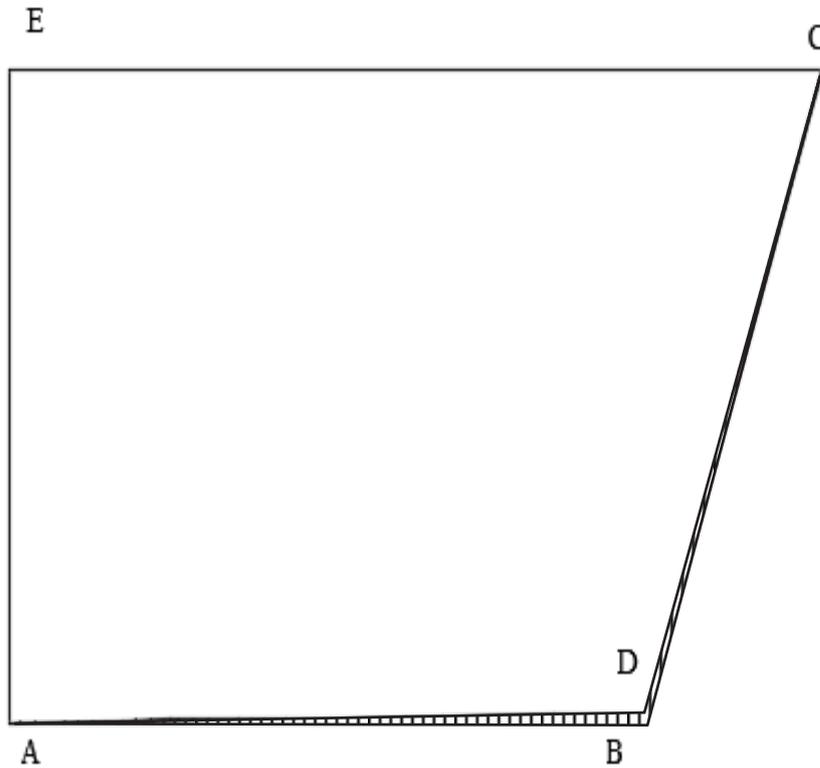
- Nurdin, Ade Akhyar. 2009. *Tugas Mata Kuliah Mikropaleontologi Dasar-Dasar Mikropaleontologi (Batuan, Stratigrafi, Sedimentologi)*. Fakultas Sains dan Teknik Universitas Jenderal Soedirman. Purbalingga.
- Putra, A.D., Kikonomoto M., Takashi M. 2019. *Weathering induced deformation for crushed weak rocks and it's countermeasure*. *Geoteknik.*, 92: 09-003.
- Putra, A.D., Kikumoto M. 2016. *Slaking of Mudstone and its Mechanical Consequences in 1D Compression Condition*. *ARMA*: 16-116.
- Putra, A.D., Kikumoto, M. 2017. *Pelapukan-Induksi Ofgeomaterials Deformasi Hasil Weakrocks*. *ARNP Jurnal Teknik dan Ilmu Pengetahuan Terapan*. Vol 12-12.
- Putra, A.D. 2018. *Slaking and Deformation Behavior of Mudstone*. *Thesis*. Yokohama National University. Japan.
- Qi, J., Sui, W., Liu, Y., & Zhang, D. 2015. *Slaking Process and Mechanisms Under Static Wetting and Drying Cycles Slaking Tests in a Red Strata Mudstone*. *Geotechnical and Geological Engineering*, 33(4), 959-972.
- Sadisun, I. A., dkk. (2010). *Physical Disintegration Characterization of Mudrocks Subjected to Slaking Exposure and Immersion Tests*. *Indonesian Journal on Geoscience*, 5(4), 219-225.
- Sartono, A. 2006. *Difraksi Sinar-X (XRD)*. Tugas Akhir Matakuliah Proyek Laboratorium. Departemen Fisika, Fakultas Matematika dan Ilmu Pengetahuan Alam. Universitas Indonesia.



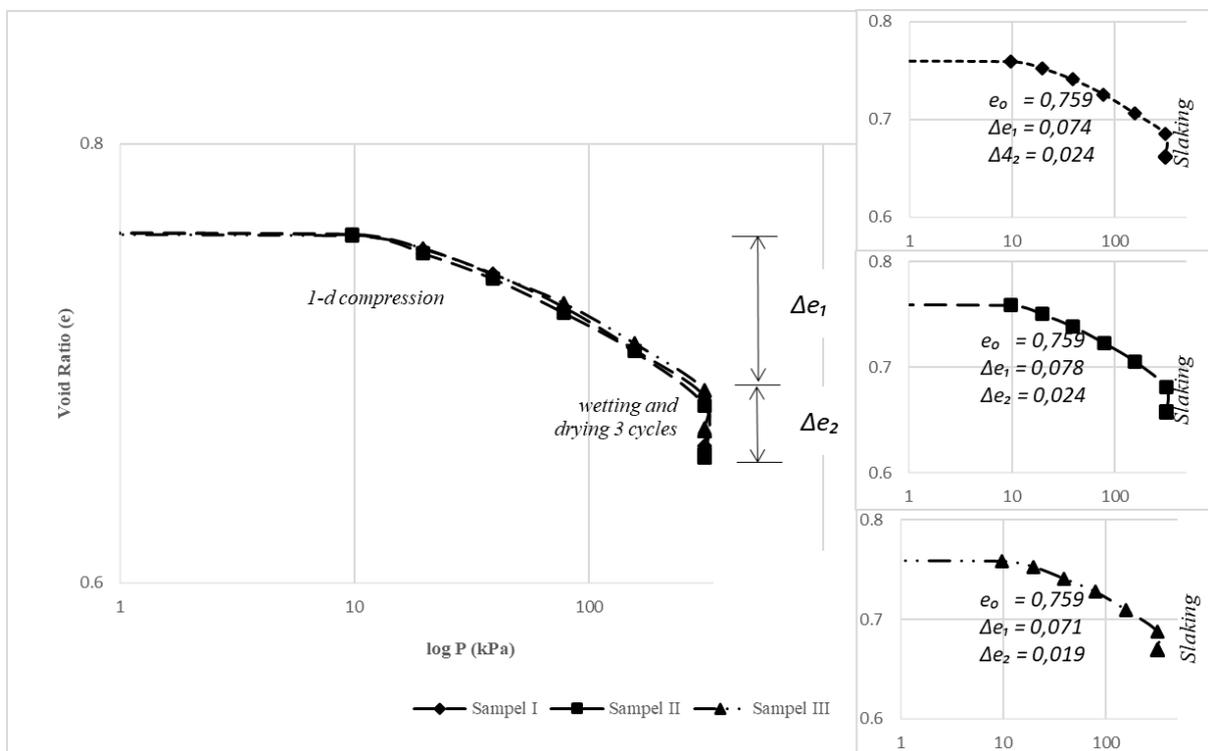
Gambar 1. Hasil Uji XRD Sampel Batuan Lemong



Gambar 2. Hasil Analisis Saringan Uji Accelerated Slaking Test sampel batuan Lemong



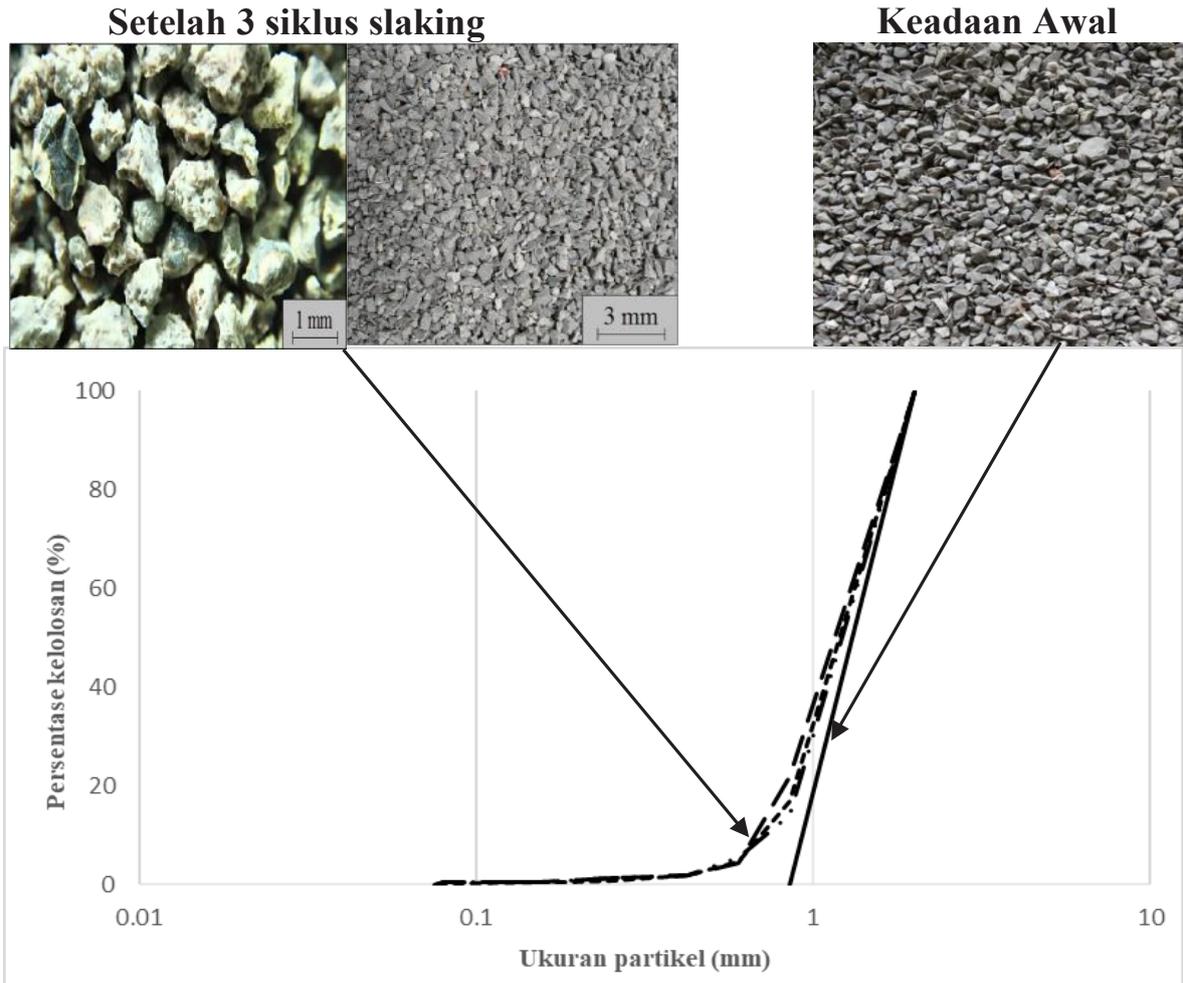
Gambar 3. Breakage Parameter siklus ketiga batuan Lemong



Gambar 4. Hubungan void ratio (e) dan log p (kPa) pada batuan Lemong

Tabel 1. Perbandingan nilai Δe_1 dan Δe_2 Lemong

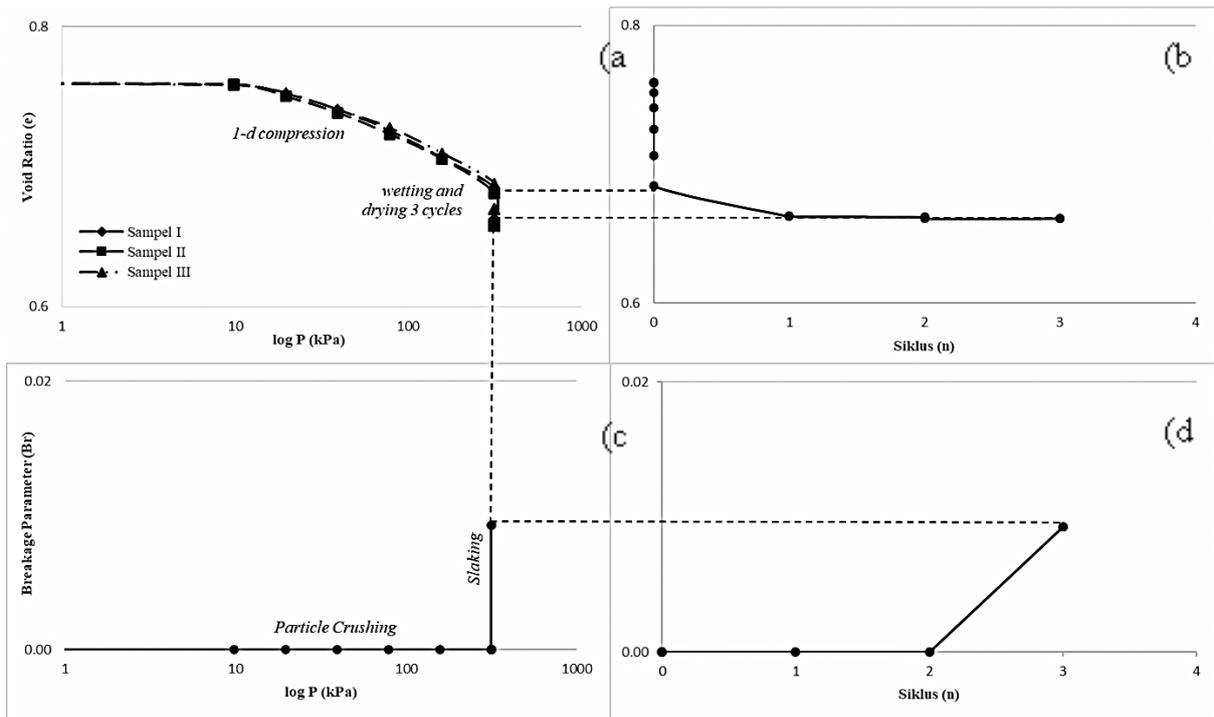
Sampel	e_0	Δe_1		Δe_2		Selisih	Keterangan
I	0.759	0.074	0.074	0.024	0.022	$\Delta e_1 > \Delta e_2$	Direkomendasikan sebagai bahan konstruksi berupa batu belah dan split, subbase untuk timbunan
II		0.078		0.024			
III		0.071		0.019			



Gambar 5. Distribusi ukuran partikel batuan Lemong

Tabel 2. Persentase lolos saringan (%) batuan Lemong, Pemancar, dan Semaka

Sampel	Sebelum uji		Setelah uji		Keterangan
	Lolos Saringan no. 10 (%)	Lolos Saringan no. 20 (%)	Lolos Saringan no. 10 (%)	Lolos Saringan no. 20 (%)	
Lemong	100.00	0.00	100.00	30.84	Tidak terjadi penghancuran yang signifikan



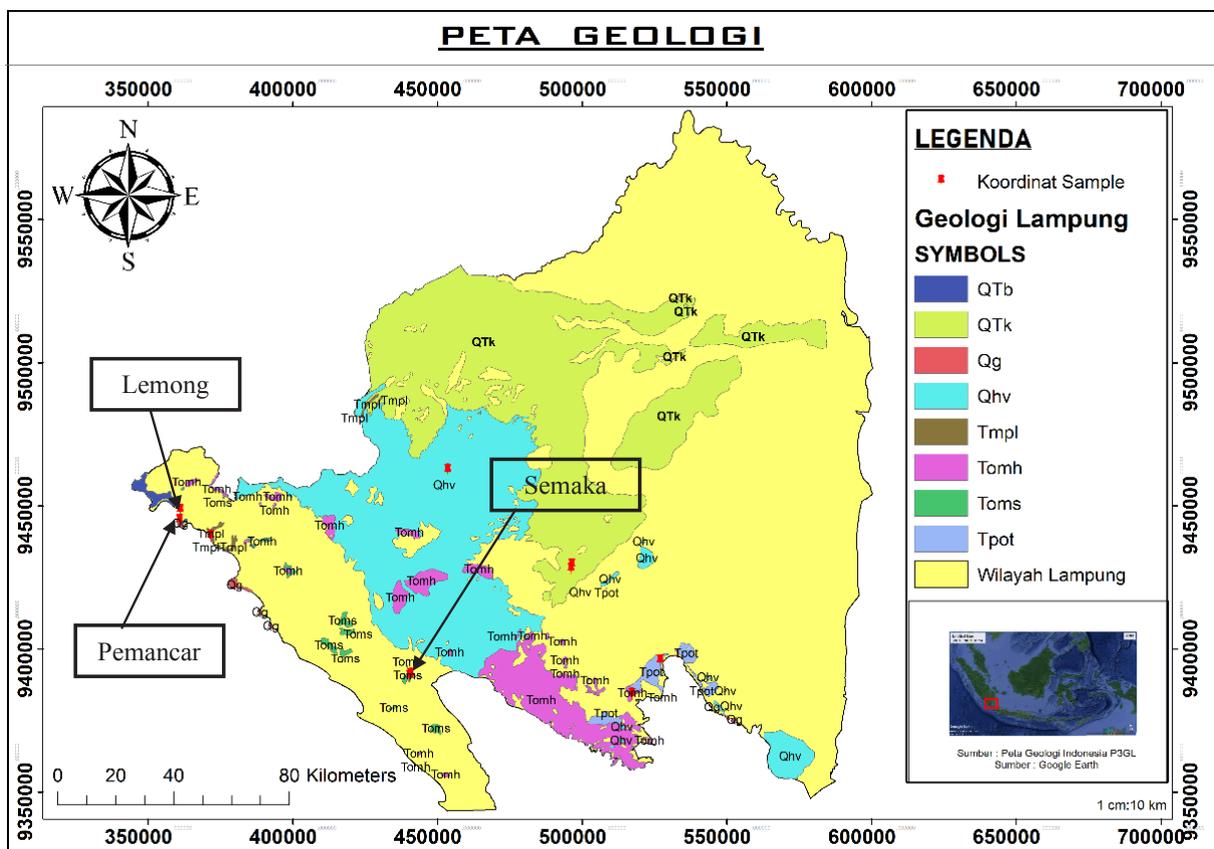
Gambar 6. Perubahan sifat tekan dan ukuran partikel batuan Lemong selama pengujian 1D Compression Slaking Test



Gambar 7. Lokasi Sampel batuan Sedimen dan lapuk Kec. Lemong



Gambar 8. Sampel batuan Sedimen dan lapuk Kec. Lemong



Gambar 9. Peta Geologi Regional Provinsi Lampung

VALIDASI DATA CURAH HUJAN POS PENAKAR HUJAN DENGAN DATA CURAH HUJAN TRMM

Hary Wijanarko^{*}, Ahmad Zakaria^b, Endro Prasetyo Wahono^c

*Mahasiswa Magister Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1
Bandar Lampung, 35145, Indonesia*

*Jurusan Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1 Bandar
Lampung, 35145, Indonesia*

*Jurusan Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1 Bandar
Lampung, 35145, Indonesia*

ABSTRAK

Data hujan merupakan salah satu data hidrologi yang sangat penting untuk digunakan dalam perencanaan bangunan air dan manajemen air serta proyek-proyek pengembangan sumber daya air. Data hujan diperoleh dari pengukuran pos penakar hujan dan satelit pengukur hujan yaitu TRMM (Tropical Rainfall Measuring Mission). Prediksi data hujan yang hilang dapat dimodelkan melalui perilaku data serial data TRMM. Data TRMM dan data pos penakar hujan akan dibuat permodelan statistik sebagai suatu sebab dan akibat. Ketika permodelan yang dimaksud menghasilkan persamaan yang menggambarkan hubungan antara data TRMM dan pos hujan tersebut maka seluruh lokasi yang berada di sekitar stasiun tersebut dapat diprediksi dengan tepat. Terdapat tiga stasiun yang menjadi objek penelitian yaitu PH 006, PH 026 dan R 219. validasi data merupakan model yang dihasilkan akan berupa persamaan hubungan variable yang terdiri dari data pos hujan sebagai variable independen dan data hujan TRMM sebagai variable dependen. Hasil analisis menunjukkan bahwa hasil validasi data memiliki nilai korelasi yang paling kuat adalah pada periode bulanan dan 2 mingguan dengan nilai yang paling tinggi ada pada stasiun PH 026 yaitu 0,892 untuk periode bulanan dan 0,702 untuk periode 2 mingguan. periode bulanan, dua mingguan dan mingguan data curah hujan TRMM yang menjadi objek validasi pada setiap stasiun memiliki pola yang sudah dapat dikatakan mengikuti pola curah hujan pos penakar.

1. Pendahuluan

Data hujan biasanya merupakan hasil pencatatan data hujan harian dari suatu lokasi di dalam suatu daerah aliran sungai. Biasanya terdapat satu atau beberapa stasiun hujan dalam suatu daerah aliran sungai. Data hujan dapat dicatat dengan alat pencatat hujan manual atau alat pencatat hujan otomatis. [5].

Data hujan berfungsi sebagai data sekunder untuk menghitung suatu besaran debit pada suatu badan air, baik itu debit rancangan maupun debit andalan. Data hujan

dapat tidak dipakai apabila tersedia data debit yang mencukupi pada suatu sungai atau badan air yang lain [7].

Stasiun-stasiun penakar hujan di Propinsi Lampung merupakan stasiun-stasiun yang mempunyai serial data curah hujan yang cukup lengkap di pulau Sumatera. Stasiun hujan yang ada di Provonsi Lampung dikelola oleh beberapa isntitusi yaitu Badan Meterologi, Klimatologi dan Geofisika (BMKG), Balai Besar Wilayah Sungai Mesuji Sekampung (BBWSMS) dan Dinas Pengelolaan Sumber Daya Air (PSDA) Provinsi Lampung. Tahun awal pencatatan data bervariasi satu dengan lainnya. Dinas PSDA Provinsi Lampung mengelola 11 pos hujan yang tersebar di beberapa Kabupaten. Sejauh ini data - data yang terdapat pada pos hujan yang dikelola tersebut masih mempunyai beberapa kekurangan yaitu titik data hujan hilang baik harian, bulanan maupun tahunan sehingga perlu divalidasi untuk menjamin akurasi data hujan. Keakuratan data hidrologi termasuk data hujan akan sangat membantu Dinas PSDA Provinsi Lampung dalam mengelola daerah irigasi yang menjadi kewenangan Provinsi Lampung.

Dalam penelitian ini data TRMM dan data pos penakar hujan akan dibuat permodelan statistik sebagai suatu sebab dan akibat. Data pos hujan yang akan dipakai dalam permodelan statistik ini adalah data dari stasiun pos hujan dibawah pengelolaan Dinas PSDA Provinsi Lampung. Data dari stasiun hujan tersebut di percaya merupakan data yang akurat. Oleh karena itu data ini dipakai sebagai data acuan dalam melakukan permodelan statistik. Ketika permodelan yang dimaksud menghasilkan persamaan yang menggambarkan hubungan antara data TRMM dan pos hujan tersebut maka seluruh lokasi yang berada di sekitar stasiun tersebut dapat diprediksi dengan tepat.

2. Metode Penelitian

2.1 Hujan

Indonesia memiliki daerah yang dilalui garis khatulistiwa dan sebagian besar daerah di Indonesia merupakan daerah tropis, walaupun demikian beberapa daerah di Indonesia memiliki intensitas hujan yang cukup besar [7].

Hujan adalah suatu proses fisis yang dihasilkan dari fenomena cuaca. Cuaca sendiri adalah suatu sistem yang kompleks sehingga bisa dimaklumi apabila para “modeler cuaca” atau “peramal cuaca” kadang meleset prakiraannya. [12].

Curah hujan (precipitation) merupakan salah satu unsur iklim yang memiliki variasi tinggi dalam skala ruang maupun waktu sehingga sulit untuk diprediksi [1].

Data curah hujan sangat dibutuhkan dalam suatu perencanaan bangunan air atau perhitungan kebutuhan air. Data hujan memberikan masukan langsung sebagai data utama dalam pemodelan hujan lebat, banjir, dan tanah longsor [10].

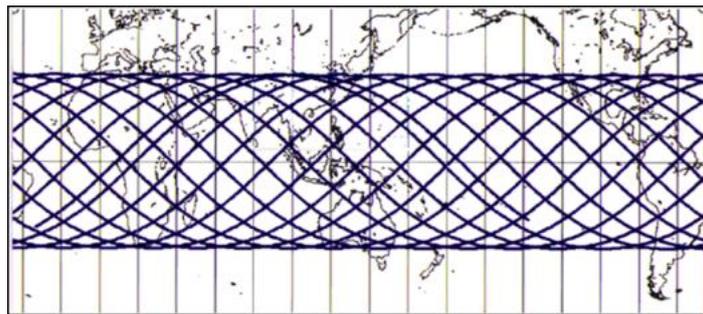
2.1.1 Pengukuran Data Hujan

Data curah dapat diperoleh dari pengukuran di permukaan bumi (Ground Data) atau pengukuran melalui penginderaan jauh seperti satelit dan radar. Satuan ukur untuk presipitasi adalah Inch, millimetres (volume/area), atau kg/m² (mass/area) untuk precipitation bentuk cair. 1 mm hujan artinya adalah ketinggian air hujan dalam radius 1 m² adalah setinggi 1 mm [7].

2.2 Tropical Rainfall Measuring Mission (TRMM)

Tropical Rainfall Measuring Mission (TRMM) adalah proyek bersama antara NASA dan badan antariksa Jepang, JAXA. Yang diluncurkan pada tanggal 27 November 1997 dan terus memberikan komunitas riset dan operasional informasi curah hujan yang unik dari luar angkasa hingga tahun 2011. Penggunaan pertama kali dari kedua instrumen gelombang mikro aktif dan pasif, dengan orbit inklinasi rendah (35°) membuat TRMM menjadi satelit terdepan di dunia untuk studi curah hujan dan proses iklim di daerah tropis [8].

Satelit TRMM pertama kali diluncurkan pada tanggal 27 November 1997 di Jepang dan dibawa oleh roket H-II di pusat stasiun peluncuran roket milik JAXA di Tanegashima-Jepang, berorbit polar (non-sunsynchronous) dengan sudut inklinasi sebesar 35° terhadap ekuator, berada pada ketinggian orbit 350 km (pada saat-saat awal diluncurkan), dan diubah ketinggian orbitnya menjadi 403 km sejak 24 Agustus 2001 sampai sekarang. Pengoperasian satelit TRMM pada ketinggian orbit 403 km ini dikenal dengan istilah TRMM boost [4].



Gambar 1. Orbit Satelit TRMM

Sumber: [6]

Data hujan yang dihasilkan oleh TRMM memiliki tipe dan bentuk yang cukup beragam yang dimulai dari level 1 sampai level 3. Level 1 merupakan data yang masih dalam bentuk raw dan telah dikalibrasi dan dikoreksi geometrik, Level 2 merupakan data yang telah memiliki gambaran parameter geofisik hujan pada resolusi spasial yang sama akan tetapi masih dalam kondisi asli keadaan hujan saat satelit tersebut melewati daerah yang direkam, sedangkan level 3 merupakan data yang telah memiliki nilai-nilai hujan, khususnya kondisi hujan bulanan yang merupakan penggabungan dari kondisi hujan dari level 2 [11].

2.3 Analisa Kesesuaian Metode

2.3.1 Kalibrasi

Metode kalibrasi yang banyak digunakan untuk pemodelan hidrologi berupa metode coba-coba dengan alasan proses perhitungan yang relatif sederhana. Perbedaan cara kalibrasi terletak pada pemakaian teknologi yang digunakan, misalnya

menggunakan perhitungan komputer yang dapat melakukan perhitungan algoritma dengan cepat dan akurat [3].

Suatu analisis yang membahas hubungan antara dua variabel atau lebih disebut dengan analisis regresi. Apabila dalam analisis regresi telah dapat ditentukan model persamaan matematik yang cocok, persoalan berikutnya adalah menentukan berapa kuat hubungan anatara variabel-variabel tersebut. [9].

Model yang sangat banyak digunakan dalam analisis hidrologi adalah analisis regresi. Analisis regresi merupakan persamaan yang menghubungkan dua (atau lebih) variabel. Persamaan ini memberikan distribusi frekuensi dari satu variabel, apabila variabel lain ditetapkan dalam satu nilai tertentu atau dapat digunakan untuk memperkirakan nilai suatu variabel bila nilai variabel lain diketahui. Derajat asosiasi (association level) sampel dari dua (atau lebih) variabel dinyatakan dalam koefisien korelasi (*correlation coefficient*) [2].

Beberapa alternatif analisis persamaan regresi yang pada umumnya digunakan dalam analisis data hidrologi diantaranya adalah model regresi [9]

1. Regresi Linear Sederhana (Linear Regression)
2. Regresi Eksponensial (Exponential Regression)
3. Regresi Logaritma (Logarithmic Regression)
4. Regresi Polinomial (Polynomial Regression)
5. Regresi Berpangkat (Power Regression)

2.3.2 Validasi Data

Validasi (validation) adalah proses evaluasi terhadap model untuk mendapatkan gambaran tentang tingkat ketidakpastian yang dimiliki oleh suatu model dalam memprediksi proses hidrologi. Pada umumnya validasi dilakukan dengan menggunakan data, diluar periode data yang digunakan untuk kalibrasi [3]. Adapun beberapa metode validasi yang digunakan dalam studi ini, yaitu :

1. Root Squared Error (RMSE)

Indikator yang dibutuhkan pada metode ini ialah berupa kesalahan yang didasarkan pada total kuadratis dari simpangan antara hasil model dengan observasi yang dapat didefinisikan sebagai persamaan berikut :

$$RMSE = \sqrt{\left(\sum_{i=1}^n (Y_i - \hat{Y}_i)^2\right) / n}$$

Keterangan:

- Y_i = data observasi (data sebenarnya)
 Ŷ_i = data perkiraan (data hasil estimasi)
 n = jumlah data

2. Koefisien Korelasi

Koefisien Korelasi adalah suatu analisis yang membahas tentang derajat asosiasi dalam analisis regresi yang memiliki hubungan sebab akibat. Nilai Koefisien Korelasi berkisar antara $0,0 \leq r \leq 1,0$. Dalam analisis hidrologi, hubungan antara fenomena berdasarkan nilai koefisien korelasi dapat dinyatakan sebagai berikut [4] :

$0,00 < r < 0,19$: Sangat rendah

$0,20 < r < 0,39$: Rendah

$0,40 < r < 0,59$: Sedang

$0,60 < r < 0,79$: Kuat

$0,80 < r < 1,00$: Sangat Kuat

Besarnya koefisien korelasi yang menunjukkan derajat hubungan antara variable X dan Y.

3. Hasil dan Pembahasan

3.1 Data Curah Hujan

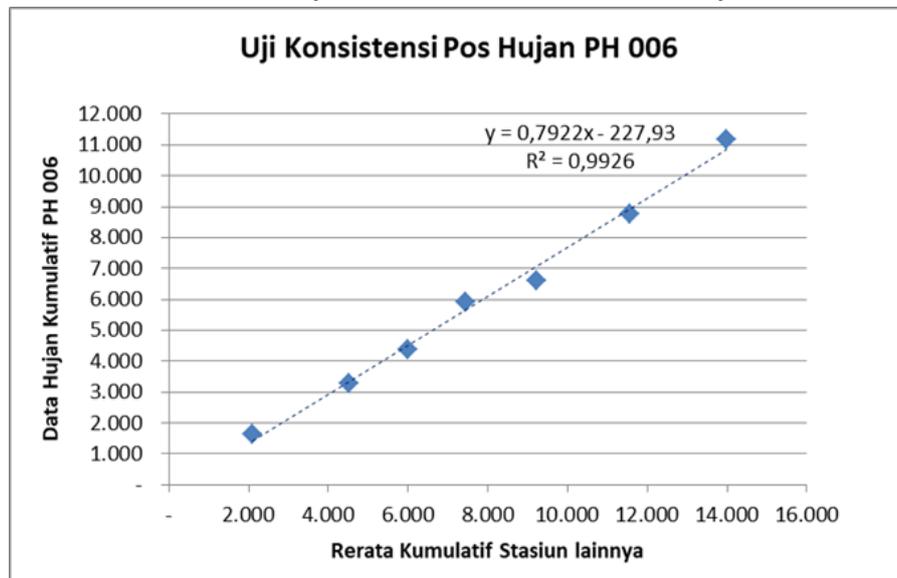
Pada penelitian ini, pengumpulan data curah hujan dilakukan untuk memenuhi parameter-parameter yang diperlukan untuk analisa. Kebutuhan data curah hujan yang dikumpulkan berdasarkan metode pengumpulan data sesuai sumber data yang diperoleh. Data curah hujan bersumber pada data sekunder.

3.2 Uji Konsistensi

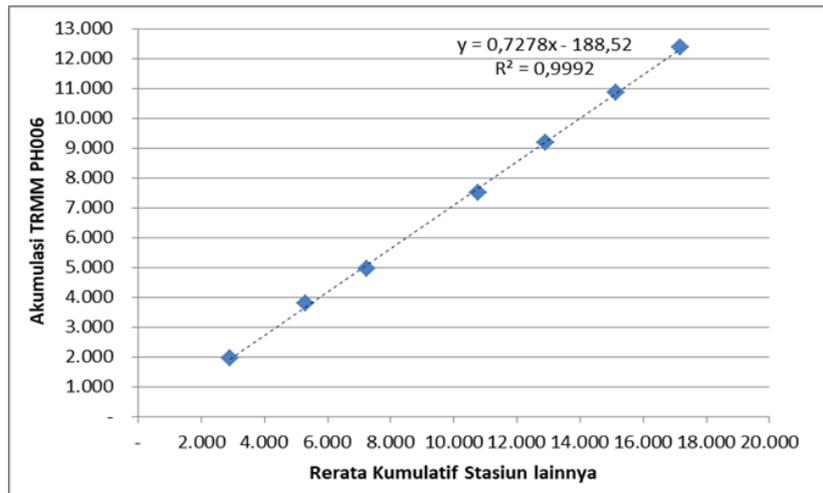
Uji konsistensi data curah hujan merupakan metode analisa data curah hujan yang dilakukan untuk menguji data hujan yang didapat konsisten atau tidak. Data curah hujan yang dipakai dalam uji konsistensi ini adalah data curah hujan maksimum tahunan dengan melakukan analisa regresi dengan mendapatkan koefisien determinan yang mendekati 1.

Berikut adalah contoh hasil uji konsistensi di stasiun PH 006 :

Gambar 1 Uji Konsistensi Pos Penakar Hujan



Gambar 2 Uji Konsistensi TRMM



Tabel 1 hasil Uji Konsistensi

No	Pos Hujan	R ²	
		Pos Penakar Hujan	TRMM
1	PH 006	0,9926	0,9992
2	PH 026	0,9883	0,9984
3	R 219	0,9789	0,9992

Hasil perhitungan

Dari hasil uji konsistensi yang telah dilakukan di seluruh pos stasiun hujan dan TRMM yang digunakan dalam penelitian ini memiliki nilai R² mendekati 1, sehingga data pos penakar hujan dan data TRMM digunakan atau konsisten.

3.2 Analisa Validasi

Pada penelitian ini periode data yang digunakan pada tahap perbandingan dan validasi adalah periode curah hujan bulanan, periode curah hujan 2 mingguan, periode curah hujan mingguan dan periode curah hujan harian, dengan rentang data yang sama.

3.2.1 Analisa Validasi data periode bulanan

Dalam penelitian ini data curah hujan yang dipakai sebanyak 7 tahun yaitu dari tahun 2013 sampai dengan tahun 2019.

Perhitungan analisa validasi data curah hujan ini diawali dengan mendapatkan persamaan dari hasil regresi kedua data curah hujan dari regresi linier dan polinomial. Dengan mengacu pada nilai koefisien determinan (R²) yang dihasilkan pada tiap persamaan regresi. Nilai R² terbesar akan dipilih sebagai persamaan untuk koreksi data hujan TRMM.

Tabel 2. Hasil Regresi Periode Bulanan

Stasiun	Regresi	
	Persamaan	R ²
PH006	$-0.0007x^2 + 0.5211x + 14.167$	0,2446
PH026	$-0.0003x^2 + 0.3521x + 183.34$	0,0149
R219	$-0,0019x^2 + 1,1787x$	0,1793

Hasil perhitungan

Langkah selanjutnya dari proses validasi ini adalah Mengkoreksi data curah hujan TRMM dengan menggunakan persamaan yang dipilih sesuai Koefisien Determinan yang paling besar. Dari proses validasi periode Bulanan ini didapatkan nilai dari beberapa metode validasi sebagai berikut :

Tabel 3. Hasil Perhitungan Validasi Periode Bulanan

Stasiun	Metode Validasi	Periode Bulanan
PH 006	RMSE	119,022
	KR	0,444
	R	0,340
PH 026	RMSE	126,055
	KR	0,184
	R	0,892
R 219	RMSE	73,267
	KR	0,486
	R	0,494

Hasil perhitungan

3.2.2 Analisa Validasi data periode 2 Minggu

Hasil regresi untuk periode 2 minggu adalah sebagai berikut :

Tabel 4. Hasil Regresi Periode 2 Minggu

Stasiun	Regresi	
	Persamaan	R ²
PH006	$-0.0007x^2 + 0.5211x + 14.167$	0,2446
PH026	$-0.0003x^2 + 0.3521x + 183.34$	0,0149
R219	$-0,0005x^2 + 0,3308x + 15,701$	0,202

Dari proses validasi periode 2 minggu didapatkan nilai dari beberapa metode validasi sebagai berikut :

Tabel 5. Hasil Perhitungan Validasi Periode 2 Mingguan

Stasiun	Metode Validasi	Periode 2 Mingguan
PH 006	RMSE	71,296
	KR	0,488
	R	0,324
PH 026	RMSE	79,933
	KR	0,179
	R	0,702
R 219	RMSE	38,212
	KR	0,410
	R	0,297

Hasil perhitungan

3.2.3 Analisa Validasi data periode Mingguan

Hasil regresi untuk periode mingguan adalah sebagai berikut :

Tabel 6. Hasil Regresi Periode Mingguan

Stasiun	Regresi	
	Persamaan	R ²
PH006	$-0,0011x^2 + 0,4651x + 16,367$	0,108
PH026	$-0,0013x^2 + 0,6325x + 33,462$	0,067
R219	$-0,0006x^2 + 0,2721x + 10,411$	0,16

Hasil perhitungan

Dari proses validasi periode mingguan didapatkan nilai dari beberapa metode validasi sebagai berikut :

Tabel 7. Hasil Perhitungan Validasi Periode Mingguan

Stasiun	Metode Validasi	Periode Mingguan
PH 006	RMSE	45,083
	KR	0,454
	R	0,238
PH 026	RMSE	63,175
	KR	0,217
	R	0,537
R 219	RMSE	18,645
	KR	0,091
	R	0,264

Hasil perhitungan

3.2.4 Analisa Validasi data periode Harian

Hasil regresi untuk periode harian adalah sebagai berikut :

Tabel 8. Hasil Regresi Periode Harian

Stasiun	Regresi	
	Persamaan	R ²
PH006	$2E-06x^2 - 0.0052x + 5.9397$	0,010
PH026	$-0,0018x^2 + 0,2287x + 5,9362$	0,010
R219	$-0,001x^2 + 0,1015x + 2,4495$	0,014

Hasil perhitungan

Dari proses validasi periode harian didapatkan nilai dari beberapa metode validasi sebagai berikut :

Tabel 9. Hasil Perhitungan Validasi Periode Harian

Stasiun	Metode Validasi	Periode Harian
PH 006	RMSE	12,860
	KR	0,102
	R	0,057
PH 026	RMSE	25,161
	KR	0,300
	R	0,154
R 219	RMSE	5,851
	KR	0,027
	R	0,081

Hasil perhitungan

Untuk nilai dari hasil uji validasi pada stasiun dan periode berbeda memiliki hasil yang beragam, dimana nilai pada seluruh metode penelitian mengalami perbaikan nilai di setiap perubahan periode. Pada penelitian ini menunjukkan dimana nilai pada periode bulanan memiliki nilai korelasi yang lebih besar dari periode waktu lainnya.

4. Kesimpulan

Nilai koefisien korelasi antara data curah hujan TRMM dan data curah hujan pos penakar akan lebih baik dilakukan pada periode atau menggunakan data bulanan. Hal ini terlihat dari hasil perhitungan dimana nilai korelasi bulanan memiliki hasil hubungan yang lebih kuat dibandingkan periode dua mingguan, mingguan dan harian. Untuk hasil koefisien korelasi antara data curah hujan TRMM dan Pos Penakar yang memiliki hubungan yang sangat kuat terdapat pada stasiun PH 026 periode bulanan.

Hasil penelitian ini pada periode bulanan, dua mingguan dan mingguan data curah hujan TRMM yang menjadi objek validasi pada setiap stasiun memiliki pola yang sudah dapat dikatakan mengikuti pola curah hujan pos penakar meskipun nilainya masih

dibawah perkiraan. Untuk periode harian pola data curah hujan TRMM yang tervalidasi masih belum dapat dikatakan mengikuti pola curah hujan pos penakar.

Untuk mendapatkan hasil validasi dengan nilai korelasi dan pola hujan yang memiliki hubungan yang kuat maka data yang sebaiknya digunakan adalah data curah hujan yang berada pada suatu batasan wilayah seperti Daerah Aliran Sungai (DAS) dengan perhitungan statistik yang lebih tepat.

Daftar Pustaka

- Dasanto, Dwi Bambang dkk. 2014., *Evaluasi Curah Hujan TRMM Menggunakan Pendekatan Koreksi Bias Statistik.*, Bogor: Departemen Geofisika, Fakultas Matematika, Institut Pertanian Bogor, *Jurnal Tanah Dan Iklim* 38: 15–24.
- Harto S., 2010. *Hidrologi: Teori, Masalah, Penyelesaian.* Yogyakarta: Nafiri Offset.
- Indarto., 2012. *Hidrologi Dasar Teori dan Contoh Aplikasi Model Hidrologi.* Jember: Bumi Aksara
- I Nyoman Yoga Patria. et al., 2019 *Permodelan Hubungan Antara Hujan Dengan Debit (Inflow) Pada Waduk Way Rarem Dengan Menggunakan Data Curah Hujan Trmm (Tropical Rainfall Measuring Mission)* Skripsi, Teknik Pengairan UNIBRAW, Malang.
- Kurniawan, A. (2020). *Evaluasi Pengukuran Curah Hujan Antara Hasil Pengukuran Permukaan (AWS, HELLMAN, OBS) dan Hasil Estimasi (Citra Satelit=GSMaP) Di Stasiun Klimatologi Mlati Tahun 2018* *Jurnal Geografi, Edukasi dan Lingkungan (JGEL)* Vol. 4, Yogyakarta.
- Pakoksung, Kwanchai., 2001. *Satellite Data Application for Flood Simulation.* <https://www.researchgate.net/figure/TRMM-Orbit-NASDA-2001>. (Diakses pada 14 September 2018).
- Perdana, Damar Adi, dan Ahmad Zakaria., 2015. *Studi Pemodelan Curah Hujan Sintetik Dari Beberapa Stasiun Di Wilayah Pringsewu.* Bandar Lampung: JRSDD Vol. 3, No. 1 hal 45–56.
- Proposal S R., 2011. *Tropical Rainfall Measuring Mission.*
- Soewarno., 2015. *Analisis Data Hidrologi Menggunakan Metode Statistika dan Stokastik.* Yogyakarta: Graha Ilmu.
- Sungmin, O., U. Foelsche, dkk., 2018. *Validation and Correction of Rainfall Data from the WegenerNet High Density Network in Southeast Austria.* *Journal of Hydrology* 556., 2018: 1110–22.
- Syaifullah, M. Djazim. 2014 *Validasi Data TRMM Terhadap Data Curah Hujan Aktual Di Tiga DAS Di Indonesia.* *Jurnal Meteorologi Dan Geofisika*, vol. 15, no. 2, pp. 109–18.
- Tukidi., 2010. *Karakter curah hujan di indonesia.* Semarang: FIS UNNES *Jurnal Geografi.*

THE DEVELOPMENT OF TANJUNG KARANG TRAIN STATION AREA BASED ON TRANSIT ORIENTED DEVELOPMENT (TOD)

Heby Rakasiwi^{1,*}, Citra Persada¹, Rahayu Sulistyorini¹.

¹Department of Civil Engineering, Faculty of Engineering, Lampung University, Jl. Prof. Dr. Sumantri Brojonegoro No. 1 Bandar Lampung, 35145, Indonesia

Abstract

One of the planning concept to overcome urban problems such as urban sprawl, traffic congestion, and community transportation fee to workplace is to implement area development based on Transit Oriented Development (TOD) with transit service that is capable to reduce people's dependence towards private vehicles. In addition, the integration between mixed land use and transit nodes can increase people's desire to use mass transportation. One city that will implement TOD concept is Bandar Lampung with the set up of Tanjung Karang Train Station Area in Bandar Lampung Spatial Planning Regulation as a Transit Oriented Development (TOD) area. However, an area with a high density of high-rise buildings and variety of activities as well as the increasing usage of public transportation should have been visible by now.

This study is trying to present recommendation in developing the area of Tanjung Karang Train Station Area with the knowledge of TOD typology in accordance with the planning of area development direction, TOD existing characteristics, and concept of the strategy that would be developed. This study uses scoring analysis method to decide TOD typology, GAP analysis to find out existing achievement, and SWOT analysis to formulate the strategy in developing TOD area. The results of the research in typology based on the policy direction of the Bandar Lampung city development plan show the TOD development criteria in the Tanjung Karang Station area. The development strategy implemented in accordance with the TOD principle is to increase the principles of density, design, destination accessibility, and distance to transit whose planning concepts are contained in the regional block plan.

Keywords: TOD, Urban Typology, TOD Development Concept.

1. Introduction

Land use in urban areas is always a discussion in the infrastructure provision sector in each administrative area, whether national, provincial, or district/city. This is related to problems that still occur throughout the year that are recurred and unresolved, namely urban sprawl, slums, reduced catchment area, and traffic congestion as well as increased travel time and public transportation costs to work so that it has an impact on investment issued by the government to the provision of

unsustainable infrastructure. These problems arise when they are not based on sustainable development planning. A good and sustainable planning system has an influence on the direction of good urban space utilization and then the accessibility factor resulting from a good transportation system that will encourage the formation of ideal and compact urban spaces (Hansen, 2004). The principle of sustainable development (sustainable development) is a development that creates a balance between social, environmental and economic elements that can be realized through the transformation of transit points and land use (WCED, 1987). In line with this, according to Abdullah & Mazlan (2016) planning that is considered good and most effective in terms of realizing these efforts is by applying the concept of Transit Oriented Development (TOD) which is a strategy of sustainable development of a city in ensuring environmental protection and ecological balance as well as activities. and social interactions in it, providing an overview of the shape of urban space which is very important in the sustainability of the city in the future.

The development approach of the TOD concept was introduced by Peter Calthorpe (1993) where TOD is an effort to respond to the declining quality of the environment which then causes the phenomenon of sprawl city development and the increasing dependence of city residents on the use of motorized vehicles (private), thus TOD is defined as a concept that uses spatial patterns mix-used that encourage people to live close to transit services and to reduce people's dependence on driving private vehicles. One of the good precedents in implementing the TOD concept is the Singapore Buangkok MRT Station which was built by integrating the subway with buses that serve city residents with comfortable pedestrian infrastructure and public space facilities which have a capacity of 30% of the total TOD area. As an example, many cities in Indonesia are planning to develop a TOD area with a transit system so that it has the potential to serve several modes of transportation quickly, these areas are usually the areas with rail-based transportation modes that are integrated to other passenger transportations.

One of the cities that will implement TOD development is Bandar Lampung City, which currently has Regional Regulation Number 10 of 2011 concerning Regional Spatial Planning for 2011-2030 which directs that to solve urban space utilization problems, it can be overcome through the concept of developing the TOD area which is located at Tanjung Karang Train Station area with the development of public transportation and terminals. Even though they already have public transportation modes in the area, currently they still have problems, namely high use of private vehicles, traffic jams, and the inconvenience of pedestrian users. So this study was conducted to determine the typology of the TOD area based on the direction of development of the Bandar Lampung City area, analyze the existing characteristics of TOD based on the typology that has been determined and analyze the strategy in implementing the TOD concept in the Tanjung Karang Train Station area.

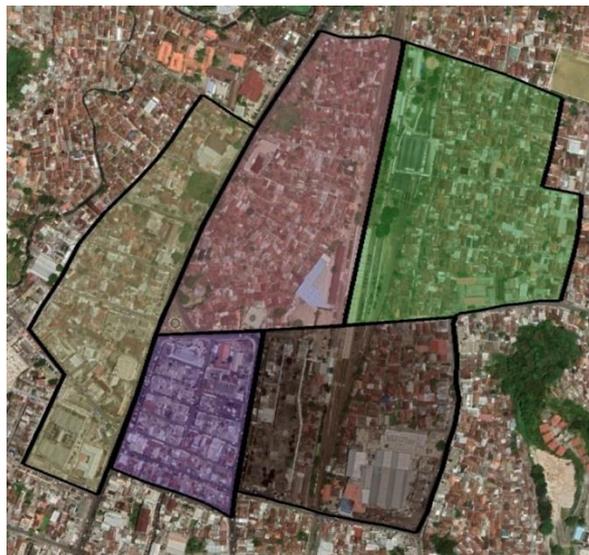
2. Research Method

2.1. Study Area

The research location is determined based on the TOD criteria from the Ministry of ATR/BPN, namely the area specified in the spatial plan as a centralized area for intermodal and intermodal integration, which is within a radius of 400-800 meters from the transit node. At a radius of 800 meters to identify the population of transit area users, while a radius of 400 meters to identify facilities and infrastructure that support the transit location.

At a radius of 800 meters, the population that will be used is based on the scope of the villages included in the Tanjung Karang Train Station area, namely Pasir Gintung Village, Tanjung Karang Pusat District, Penengahan Raya Village, Kedaton District, Sukajawa Baru Village, Tanjung Karang Barat District, Gunung Sari Village, Tanjung Karang, Pelita Enggal Sub-district, Brebes Sawah Village, Sawah Lama, and Kebon Jeruk Sub-district of Tanjung Karang Timur, and Jagabaya I Village, Way Halim District.

As for the delineation with a radius of 400 meters and the distribution of blocks based on physical boundaries such as roads, rivers, and building blocks. Here is a picture of a delineation with a radius of 400 meters.



source: Google Earth Imagery

Figure 1. TOD Area Delineation and Block Division

2.2. TOD Typology Technical Criteria

The technical criteria for TOD typology are the variables used to determine the typology based on the direction of development of the Tanjung Karang Train Station area, this typological criterion is sourced from the Ministry of ATR/BPN.

1. Urban TOD

The Urban TOD area is located in a city service center within a city area with a regional-scale service function or an urban area within a district designated as an activity center. The City TOD area has the following characteristics:

- a. Serves as an economic center for primary functions
- b. Served by a mass transportation system within the internal scope of the district/city, regional inter-regency/inter-city, and/or inter-provincial
- c. Located on the main line of high-capacity mass public transportation such as inter-district/inter-city and/or inter-provincial bus stops, train and light rail stations
- d. Served by high capacity transit systems, medium capacity transit systems, low capacity transit systems as feeders, and possible modes of water transportation
- e. It is an area with a mixed function of commercial, office and residential blocks with high intensity that is integrated with the mass transportation system.

2. Sub-Urban TOD

The Sub-Urban TOD area is located in a city service sub-center within a city area with a city-scale service function or part of a city or urban area within a district area designated as an activity center. The sub-urban TOD area has the following characteristics:

- a. Serves as an economic center for secondary functions
- b. Served by a mass transportation system within the internal scope of the district/city and/or inter-regency/inter-city within one province
- c. Located on circulation routes such as district/city internal bus stops, train and light rail stations;
- d. Served by high-capacity transit systems, medium-capacity transit systems, low-capacity transit systems as feeders, and possible modes of water transportation
- e. It is an area with a mixed function of commercial, office blocks, and residential areas with medium to high intensity integrated with the mass transportation system.

3. Neighborhood TOD

The Neighborhood TOD area is located in an environmental service center within a city area with a service function on an environmental scale or an urban area within a district area designated as an activity center. Neighborhood TOD area has the following characteristics:

- a. Serves as a local economic center
- b. Served by the mass transportation system within the internal scope of the district/city which is connected to the transportation system of the district/city area
- c. Located in a residential area with good access to the city center or sub-city center
- d. Served by a medium and low capacity transit system by Light Rail, BRT, local buses, and/or feeder buses
- e. It is an area with a mixed function of commercial, office blocks, and residential areas with moderate intensity integrated with the transportation system.

Table 1. Technical Criteria for TOD Area Typology

Technical Criteria	TOD Area Typology Indicators		
	Urban	Sub Urban	Neighborhood
Modes of transportation			
Type of Transportation Mode	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of light rail transit, Local Bus/ Bus Express
Headway	< 5 minutes	5-15 minutes	15-30 minutes
Densify			
Population	>750 people/ha	450-1500 people/ha	350-1000 people/ha
Land Use Intensity			
Floor Area Ratio (FAR)	>5	3-5	2-3
Building Covered Ratio (BCR)	80%	70%	70%
Building Density	High Rise	Mid-High Rise	Mid Rise
Residential Density	20-75 units/1.000 m ²	12-38 units/1.000 m ²	15-20 unit/1.000 m ²
Number of floors	> 11	3-15	3-8
Diversity			
Activity duration	18 hours	16 hours	14 hours
Residential : Non-Residential	20%-60% : 40%-60%	30%-60% : 40%-70%	60%-80% : 20%-40%
Type of activity	1. housing mix 2. commercial 3. office 4. culture/ entertainment center 5. other public facilities	1. housing mix 2. commercial 3. office 4. culture	1. housing mix 2. Housing support facilities
Commercial Characteristics	Regional	Regional	Community, local
Residential type	high-rise, midrise apartments, and condominium	Mid-Rise, low-rise, and a little high-rise	Mid-rise, low-rise, town-house

2.3. Analysis

The data analysis techniques used in this research are scoring analysis techniques, GAP analysis techniques, SWOT analysis techniques, and descriptive analysis techniques.

1. Analysis of Determination of TOD Area Typology Based on Regional Development Direction

The analysis of determining the typology of the TOD area based on the direction of development of this area uses a scoring analysis technique that aims to identify the suitability score for each research variable by applying the Guttman scale. According to Sugiyono (2014) the Guttman scale is a scale that used to get a firm answer. There are only two intervals such as "agree-disagree"; "Yes No"; "True False"; "positive-negative"; "never-never" and so on.

The statements used in this analysis are appropriate and not in accordance with the application in the scoring analysis using a score of "1" (one) to indicate "appropriate" and a score of "0" (zero) to indicate "not appropriate". This scoring is carried out on the technical criteria in each type of typology in the TOD area. Furthermore, a suitability analysis will be carried out for each type of typology by changing the results obtained in percentage form as follows:

$$\text{suitability value (\%)} = \frac{\text{total score}}{\text{maximum score}} \times 100\%$$

The total score is the total value of the analysis results in each TOD typology, while the maximum score is the number of possible scores that can be achieved in each typology. In this study, the total score obtained was 22 according to the typological criteria analyzed. After getting a score, the value is classified according to suitability, namely 0-49% (close to inappropriate), 50% (close to appropriate and not appropriate), and 51-100% (close to appropriate).

2. Identification of Existing TOD Characteristics

In identifying the existing characteristics of TOD, descriptive statistical analysis was used. According to Iqbal Hasan (2001) descriptive statistics is a part of statistics that studies how to collect data and present data so that they are easy to understand. Descriptive statistics only deals with describing or providing information about a data or situation. In other words, descriptive statistics function to explain conditions, symptoms, or problems. The objects studied in this target are the characteristics of the Tanjung Karang Train Station area based on a predetermined TOD typology which includes modes of transportation, density, diversity, intensity of land use, parking, and road network patterns.

3. Analysis of Transit-Based Development of Tanjung Karang Train Station Area

The analysis technique uses Gap analysis, referring to the opinion of Bens (2011), Gap Analysis has the meaning of identifying the missing steps, which are needed to achieve the goal. Gap Analysis is a planning tool that creates a shared view of what needs to be done to close the gap between the present state and the desired future. This analysis is used to see the extent to which the TOD concept has been applied based on the TOD typology that has been determined with existing conditions, so that achievements will be presented to form the expected typology in the Transit Oriented Development (TOD) based area in the Tanjung Karang Train Station area.

4. Strategy Analysis in Applying the TOD Concept

This analysis is used in order to develop a strategy for implementing the TOD concept after determining the typology, identifying the characteristics of the existing TOD, and examining the development of TOD so that potentials and problems will be found to implement the TOD concept.

The analysis technique at this stage will use a SWOT analysis, according to Sondang P. Siagian (2004) SWOT analysis is one of the most powerful analytical instruments when it is used properly and it is widely known that "SWOT is an acronym for the words strength, weakness, opportunities and threats".

3. Results and Discussion

3.1. Results

The results of this study is accordance with the results of the analysis that has been described in the previous discussion after collecting secondary and primary data.

1. Regional Development Direction Policy

The policy for the direction of regional development is based on the regional development plan in the Tanjung Karang Train Station Area. Policy directions and data sources are presented in table.

Table 2. Regional Development Policy

Technical Criteria	Regional Development Policy	Data Source
Modes of transportation		
Type of Transportation Mode	Train, Medium Bus, passenger car	<ul style="list-style-type: none"> Lampung Province Spatial Plan Perwali Bandar Lampung No. 22 Tahun 2018
Headway	Maximum 15-30 minutes	
Densify		
Population	183 people/ha	Population Projection
Land Use Intensity		
Floor Area Ratio (FAR)	32	Bandar Lampung Spatial Plan
Building Covered Ratio (BCR)	80%	
Building Density	High rise	
Residential Density	6-16 unit/1.000 m ²	
Number of floors	45	
Diversity		
Activity duration	-	Bandar Lampung Spatial Plan
Residential : Non-Residential	5% : 95%	
Type of activity	Housing, trade and services, public and social facilities, offices, transportation	
Commercial Characteristics	Regional	
Residential type	High-rise	

2. Typology of the TOD area of Tanjung Karang Train Station

Data below shows a study of several policies of the City of Bandar Lampung which are taken from several aspects with the technical criteria of the TOD indicator. In hence, what is produced is an overview of the direction of TOD development in accordance with the policies that have been arranged.

Table 3. Scoring Analysis of TOD Area Typology Determination

Technical Criteria	Results of the Study on Regional Development Directions	TOD Area Typology Indicator Scoring		
		Urban	Sub Urban	Neighborhood
Modes of transportation				
Type of Transportation Mode	Train, Medium Bus, passenger car	1	1	0
Headway	Maximum 15-30 minutes	1	1	1
Densify		Densify		
Population	183 people/ha	0	0	0
Land Use Intensity				
Floor Area Ratio (FAR)	32	1	0	0
Building Covered Ratio (BCR)	80%	1	0	0
Building Density	High	1	0	0
Residential Density	6-16 unit/1.000 m ²	0	1	1
Number of floors	45	1	0	0
Diversity				
Activity duration	-			
Residential : Non-Residential	5% : 95%	1	0	0
Type of activity	Housing, trade and services, public and social facilities, offices, transportation	1	0	0
Commercial Characteristics	Regional	1	1	0
Residential type	High-rise	1	0	0
Total Skor		10	5	2

From the results from the calculations above, the typology which is in accordance with the direction of the Bandar Lampung City area development policy is the Urban Typology.

3. Identification of Existing TOD Characteristics

The existing characteristics of TOD is identified by direct observation through field surveys and interpretation by using satellite imagery. This identification is used to determine the current characteristics of TOD, namely the currently available transportation modes, population density, intensity of land use, diversity, and road network patterns as presented in table 4.

Table 4. Identification of Existing Conditions

Technical Criteria	Existing Condition
Modes of transportation	
Type of Transportation Mode	Train and city transportation
Headway	> 5 menit
Densify	
Population	147 jiwa/ha
Land Use Intensity	
Floor Area Ratio (FAR)	1,1
Building Covered Ratio (BCR)	58%
Building Density	Medium
Residential Density	12 units/1.000 m ²
Number of floors	5
Diversity	
Activity duration	12 hours
Residential : Non-Residential	72% ; 28%
Type of activity	Residential, commercial, office, public facilities and social facilities
Commercial Characteristics	Regional
Residential type	Mid-Rise

4. Analysis on the Development of the Transit-Based Tanjung Karang Train Station Area.

This analysis of the Transit-Based Tanjung Karang Train Station Development Study uses GAP analysis by presenting a comparison between existing conditions and the TOD typology along with the recommendations to follow-up.

Table 5. Analysis on TOD Development for Tanjung Karang Station Area

Technical Criteria	Observation Results	Typology of Urban TOD	Analysis
Modes of transportation			
Type of Transportation Mode	Train and city transportation	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	<ul style="list-style-type: none"> • Improve transportation facilities and infrastructures • Reactivate BRT • Add a stop
Headway	> 5 minutes	< 5 minutes	Arrange public transportation schedules
Densify			
Population	147 people/ha	>750 people/ha	Provide housing to meet the density level
Land Use Intensity			
Floor Area Ratio (FAR)	1,1	>5	Maximize trade and service areas by providing buildings with high KLB and KDB intensity and integrate high-rise buildings and a mixture of commercial residential and office housing mixes with mid-rise buildings.
Building Covered Ratio (BCR)	58%	80%	
Building Density	Sedang	High Rise	
Residential Density	12 unit/1.000 m ²	20-75 units/1.000 m ²	
Number of floors	5	> 11	
Diversity			
Activity duration	12 hours	18 hours	Provide an area with 18 hours of activities including retail activities in Pasir Gantung and night culinary activities in the Central Market area
Residential : Non-Residential	72% ; 28%	20%-60% : 40%-60%	Build the concept of vertical housing in residential areas and maximizing commercial functions in trade and service areas
Type of activity	Residential, commercial, office, public facilities and social facilities	1. housing mix 2. commercial 3. office 4. culture/ entertainment center	Build a mixed residential-commercial and residential-office concept

Technical Criteria	Observation Results	Typology of Urban TOD	Analysis
		5. other public facilities	
Commercial Characteristics	Regional	Regional	Aim to Pasar Tengah and Pasir Gintung
Residential type	Mid-Rise	<i>high-rise, midrise apartments, and condominium</i>	Build a vertical residential concept with family facilities
Network Pattern			
Block dimension	It is located in the Pasar Tengah area, besides that it is more than 130 meters	70-130 meters	<ul style="list-style-type: none"> • form pedestrian-friendly blocks in commercial areas connected to other areas • build pedestrian paths to improve pedestrian accessibility and be friendly to persons with disabilities • apply the park and ride concept to the station and terminal parking pockets
Network Pattern	Tanjung Karang train station (transit station), Train (primary transit), Trans Bandar Lampung Bus (secondary transit), and city transportation (<i>feeder</i>)	Transit station, primary transit (1 mode), secondary transit (2 mode), and <i>feeder</i>	<ul style="list-style-type: none"> • Reactivate BRT • Add station services via Damri Bus to Jabodetabek destinations

5. Regional Development Strategy Concept.

The concept of a regional development strategy describes the implementation of the strategy to be implemented in the Tanjung Karang Train Station Area. The discussion lies in the description of the development location that can be implemented through the regional block plan.

a. Transportation Mode Development Strategy Concept

The strategies that will be applied to this concept are:

- 1) Provide park and ride in station and terminal parking pockets
- 2) Integrate transportation mode services through pedestrian paths that can access stations, terminals, and bus stops
- 3) The application of a paid system for private vehicles when entering the TOD area

- 4) Increase the number of bus stops on Jl teuku umar and Jl. Hayam Wuruk
 - 5) Reactivate BRT as main route
 - 6) Facilitate a special place for online transportation stops at the Pasar Bawah terminal
- b. Density Development Strategy Concept
- The strategy that will be applied to this concept is to provide housing for families with dense occupancy rates equipped with social facilities and public facilities as well as recreation areas or family entertainment centers.

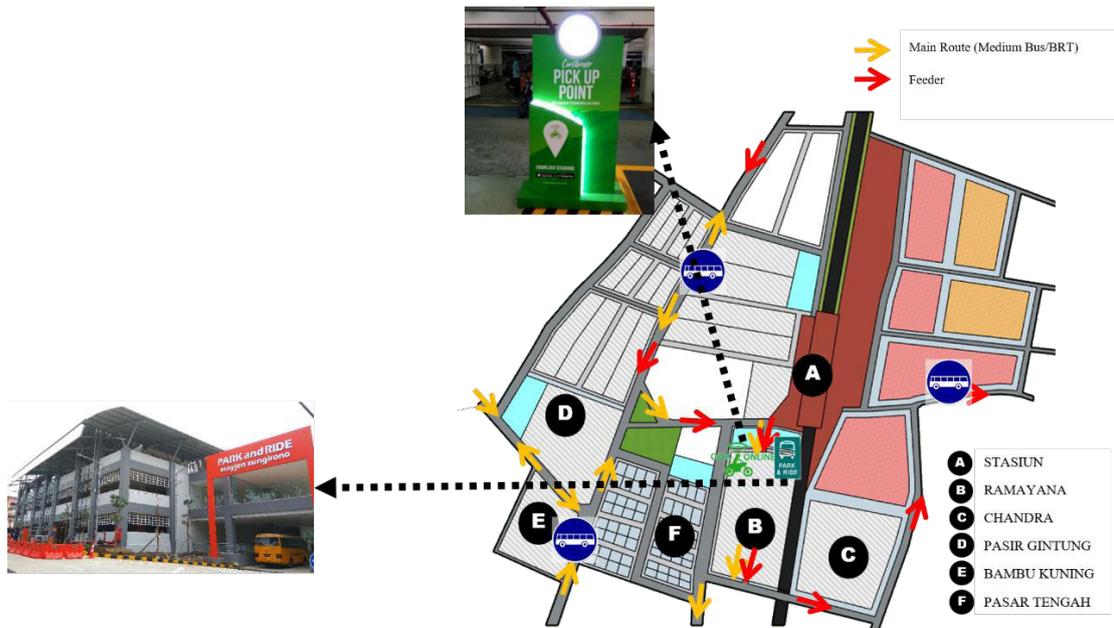


Figure 2. The Concept of Development Aspects of the Mode of Transportation



Figure 3. The Concept of Density Aspect Development

c. Concept of Land Use Intensity Development Strategy

The strategies that will be applied to this concept are:

- 1) Build high-rise buildings with commercial and office uses
- 2) Build high-rise buildings with residential and commercial purposes
- 3) Build high-rise apartments/condos/rusunami in residential areas

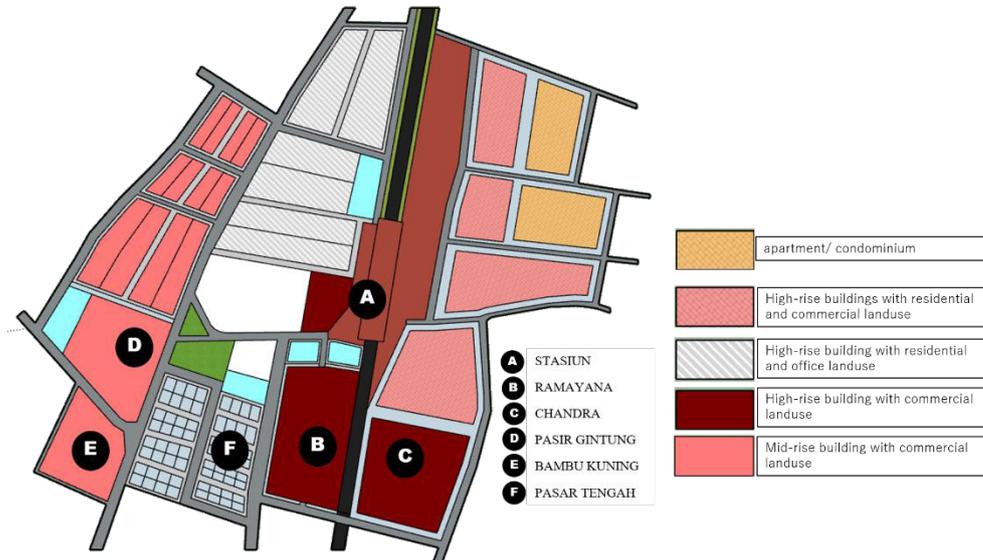


Figure 4. The Concept of Development of the Intensity of Land Use

d. Concept of Diversity Development Strategy

The strategies that will be applied to this concept are:

- 1) Direct retail trading activities with a duration of 18 hours in the Pasir Gintung area
- 2) Wholesale trade in The Pasar Tengah area and office commercial area
- 3) Make The Pasar Tengah area a night culinary with the concept of a city walk

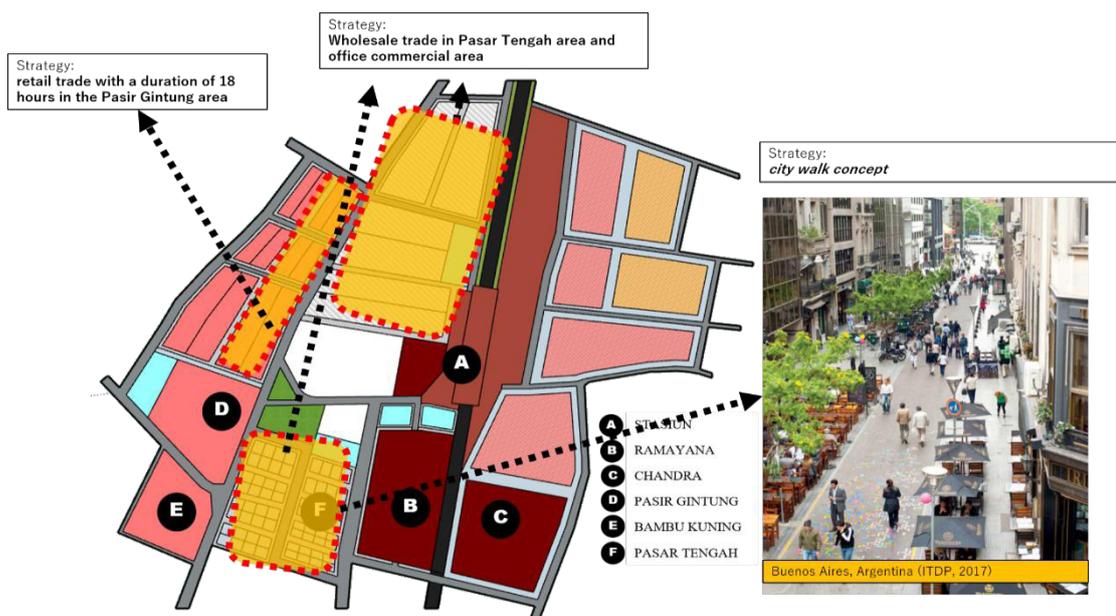


Figure 5. Concept of Diversity Development

e. Concept of Network Pattern Development Strategy

The strategies that will be applied to this concept are:

- 1) The dimensions of the block in the Pasar Tengah and Pasir Gintung are 70-130 meters
- 2) Intermodal integration between stations, terminals and bus stops through pedestrian accessibility with a maximum distance of 400 meters.
- 3) Create a pedestrian-friendly path for persons with disabilities
- 4) Add pedestrian bridges to facilitate pedestrian access to pass through the road network and the rail network.

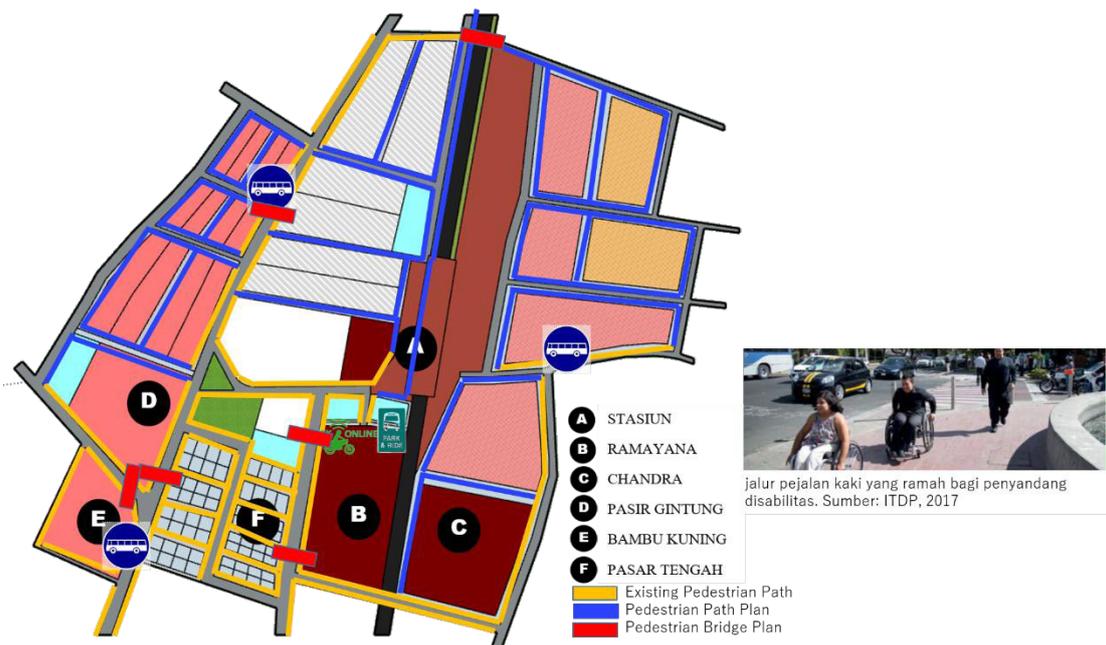


Figure 6. Concept of Network Pattern Development

3.2. Discussion

Based on the regional development on the previous discussion, it is obligatory to develop a development strategy by implementing the TOD concept. This strategy considers the existing condition of the area, which is mostly occupied in the form of buildings and the rest of area, green and non-green open spaces area designated for public facilities. This development strategy is in accordance with Permen ATR/BPN No. 16 of 2017 about Guidelines for the Development of Transit Oriented Areas that are appropriate to be implemented as the concept of a redevelopment site strategy by its rejuvenation by putting new functions and setting the environment by complementing transit facilities or TOD area facilities.

4. Conclusion

Determination of the typology of the TOD area in Tanjung Karang Train Station area is carried out by reviewing several regulations and policies about the direction of regional development at the research location. The data used are the revised technical material of Bandar Lampung City RTRW, Bandar Lampung Mayor Regulation Number 22

of 2018 about The Transportation of People and Goods and the ATR/BPN Ministerial Regulation about The Forming of RDTR. The technical criteria included in the study are modes of transportation, density, intensity of land use, diversity, and road network patterns. The results of the scoring, the suitability value for the urban typology is 76.92%, the sub-urban typology is 38.46%, and the neighborhood typology is 15.38%, so as the results, the typology for the development of the Tanjung Karang Train Station TOD area is UrbanTypology.

Urban Typology, as an analysis character of eksisting based on the predetermined TOD typology criteria, is compared with existing conditions. By using GAP analysis, the results of the comparison are achieved and unachieved conditions. From the results of the analysis, there are technical criteria for urban typology that have been achieved, which are the types of space utilization activities and commercial characteristics. While the existing characteristics that have not been achieved are the type of transportation mode, headway, population density, and the intensity of land use.

The implementation strategy on TOD concept in Tanjung Karang Train Station with urban typology is based on unachieved existing that with this strategy Tanjung Karang Train Station development based on TOD fits the technical criteria.

Acknowledgements

We would like to thanks the anonymous reviewers who provided a valuable comments and feedbacks on the early draft of this paper.

References

- Abdullah, J., & Mazlan, M. H. (2016). Characteristics of and Quality of Life in a Transit Oriented Development (TOD) of Bandar Sri Permaisuri, Kuala Lumpur. *Procedia-Social and Behavioral Sciences*. 234, 498-505.
- Bens, I. (2011). *Facilitating with Ease!: core skills for facilitators, team leaders, and members, managers, consultants, and trainers*. New York: JohnWiley & Sons, Inc.
- Calthorpe, P. (1993). *The Next American Metropolis: Ecology, Community, and the American Dreams*. New York: Princeton Architectural Press.
- Hansen, Walter G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*. 73-76.
- Hasan, M Iqbal. 2001. *Pokok-pokok Materi Statistik I (Statistik Deskriptif)*. Jakarta: Bumi Aksara.
- Institute for Transportation and Development Policy. (2017). *TOD Standard 3.0*. New York: ITDP.
- Kementerian Agaria dan Tata Ruang/Kepala Badan Pertanahan Nasional. (2018). *Peraturan Menteri ATR/BPN Nomor 16 Tahun 2017 tentang Pedoman Pengembangan Kawasan Berorientasi Transit*. Jakarta: Kemen. ATR/BPN.
- Pemerintah Kota Bandar Lampung. (2011). *Perda Nomor 10 Tahun 2011 tentang Rencana Tata Ruang Wilayah Tahun 2011-2030*. Bandar Lampung: Pemerintah Kota Bandar Lampung.

- Siagian, Sondang P. (2004). *Manajemen Strategik*. Jakarta: PT. Bumi Aksara
- Sugiyono. (2014). *Metode Penelitian Pendidikan Pendekatan Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta
- WCED. (1987). *Our Common Future*. Oxford : Oxford University Press.

THE DEVELOPMENT OF TANJUNG KARANG TRAIN STATION AREA BASED ON TRANSIT ORIENTED DEVELOPMENT (TOD)

Heby Rakasiwi^{1*}, Citra Persada¹, Rahayu Sulistyorini¹.

¹Department of Civil Engineering, Faculty of Engineering, Lampung University, Jl. Prof. Dr. Sumantri Brojonegoro No. 1 Bandar Lampung, 35145, Indonesia

Abstract

One of the planning concept to overcome urban problems such as urban sprawl, traffic congestion, and community transportation fee to workplace is to implement area development based on Transit Oriented Development (TOD) with transit service that is capable to reduce people's dependence towards private vehicles. In addition, the integration between mixed land use and transit nodes can increase people's desire to use mass transportation. One city that will implement TOD concept is Bandar Lampung with the set up of Tanjung Karang Train Station Area in Bandar Lampung Spatial Planning Regulation as a Transit Oriented Development (TOD) area. However, an area with a high density of high-rise buildings and variety of activities as well as the increasing usage of public transportation should have been visible by now.

This study is trying to present recommendation in developing the area of Tanjung Karang Train Station Area with the knowledge of TOD typology in accordance with the planning of area development direction, TOD existing characteristics, and concept of the strategy that would be developed. This study uses scoring analysis method to decide TOD typology, GAP analysis to find out existing achievement, and SWOT analysis to formulate the strategy in developing TOD area. The results of the research in typology based on the policy direction of the Bandar Lampung city development plan show the TOD development criteria in the Tanjung Karang Station area. The development strategy implemented in accordance with the TOD principle is to increase the principles of density, design, destination accessibility, and distance to transit whose planning concepts are contained in the regional block plan.

Keywords: TOD, Urban Typology, TOD Development Concept.

1. Introduction

Land use in urban areas is always a discussion in the infrastructure provision sector in each administrative area, whether national, provincial, or district/city. This is related to problems that still occur throughout the year that are recurred and unresolved, namely urban sprawl, slums, reduced catchment area, and traffic congestion as well as increased travel time and public transportation costs to work so that it has an impact on investment issued by the government to the provision of unsustainable infrastructure. These problems arise when they are not based on sustainable development planning. A good and sustainable planning system has an

influence on the direction of good urban space utilization and then the accessibility factor resulting from a good transportation system that will encourage the formation of ideal and compact urban spaces (Hansen, 2004). The principle of sustainable development (sustainable development) is a development that creates a balance between social, environmental and economic elements that can be realized through the transformation of transit points and land use (WCED, 1987). In line with this, according to Abdullah & Mazlan (2016) planning that is considered good and most effective in terms of realizing these efforts is by applying the concept of Transit Oriented Development (TOD) which is a strategy of sustainable development of a city in ensuring environmental protection and ecological balance as well as activities. and social interactions in it, providing an overview of the shape of urban space which is very important in the sustainability of the city in the future.

The development approach of the TOD concept was introduced by Peter Calthorpe (1993) where TOD is an effort to respond to the declining quality of the environment which then causes the phenomenon of sprawl city development and the increasing dependence of city residents on the use of motorized vehicles (private), thus TOD is defined as a concept that uses spatial patterns mix-used that encourage people to live close to transit services and to reduce people's dependence on driving private vehicles. One of the good precedents in implementing the TOD concept is the Singapore Buangkok MRT Station which was built by integrating the subway with buses that serve city residents with comfortable pedestrian infrastructure and public space facilities which have a capacity of 30% of the total TOD area. As an example, many cities in Indonesia are planning to develop a TOD area with a transit system so that it has the potential to serve several modes of transportation quickly, these areas are usually the areas with rail-based transportation modes that are integrated to other passenger transportations.

One of the cities that will implement TOD development is Bandar Lampung City, which currently has Regional Regulation Number 10 of 2011 concerning Regional Spatial Planning for 2011-2030 which directs that to solve urban space utilization problems, it can be overcome through the concept of developing the TOD area which is located at Tanjung Karang Train Station area with the development of public transportation and terminals. Even though they already have public transportation modes in the area, currently they still have problems, namely high use of private vehicles, traffic jams, and the inconvenience of pedestrian users. So this study was conducted to determine the typology of the TOD area based on the direction of development of the Bandar Lampung City area, analyze the existing characteristics of TOD based on the typology that has been determined and analyze the strategy in implementing the TOD concept in the Tanjung Karang Train Station area.

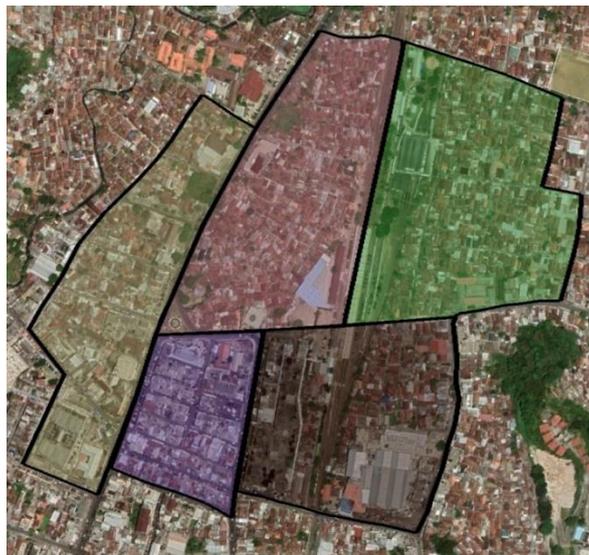
2. Research Method

2.1. Study Area

The research location is determined based on the TOD criteria from the Ministry of ATR/BPN, namely the area specified in the spatial plan as a centralized area for intermodal and intermodal integration, which is within a radius of 400-800 meters from the transit node. At a radius of 800 meters to identify the population of transit area users, while a radius of 400 meters to identify facilities and infrastructure that support the transit location.

At a radius of 800 meters, the population that will be used is based on the scope of the villages included in the Tanjung Karang Train Station area, namely Pasir Gintung Village, Tanjung Karang Pusat District, Penengahan Raya Village, Kedaton District, Sukajawa Baru Village, Tanjung Karang Barat District, Gunung Sari Village, Tanjung Karang, Pelita Enggal Sub-district, Brebes Sawah Village, Sawah Lama, and Kebon Jeruk Sub-district of Tanjung Karang Timur, and Jagabaya I Village, Way Halim District.

As for the delineation with a radius of 400 meters and the distribution of blocks based on physical boundaries such as roads, rivers, and building blocks. Here is a picture of a delineation with a radius of 400 meters.



source: Google Earth Imagery

Figure 7. TOD Area Delineation and Block Division

2.2. TOD Typology Technical Criteria

The technical criteria for TOD typology are the variables used to determine the typology based on the direction of development of the Tanjung Karang Train Station area, this typological criterion is sourced from the Ministry of ATR/BPN.

4. Urban TOD

The Urban TOD area is located in a city service center within a city area with a regional-scale service function or an urban area within a district designated as an activity center. The City TOD area has the following characteristics:

- f. Serves as an economic center for primary functions
- g. Served by a mass transportation system within the internal scope of the district/city, regional inter-regency/inter-city, and/or inter-provincial
- h. Located on the main line of high-capacity mass public transportation such as inter-district/inter-city and/or inter-provincial bus stops, train and light rail stations
- i. Served by high capacity transit systems, medium capacity transit systems, low capacity transit systems as feeders, and possible modes of water transportation
- j. It is an area with a mixed function of commercial, office and residential blocks with high intensity that is integrated with the mass transportation system.

5. Sub-Urban TOD

The Sub-Urban TOD area is located in a city service sub-center within a city area with a city-scale service function or part of a city or urban area within a district area designated as an activity center. The sub-urban TOD area has the following characteristics:

- f. Serves as an economic center for secondary functions
- g. Served by a mass transportation system within the internal scope of the district/city and/or inter-regency/inter-city within one province
- h. Located on circulation routes such as district/city internal bus stops, train and light rail stations;
- i. Served by high-capacity transit systems, medium-capacity transit systems, low-capacity transit systems as feeders, and possible modes of water transportation
- j. It is an area with a mixed function of commercial, office blocks, and residential areas with medium to high intensity integrated with the mass transportation system.

6. Neighborhood TOD

The Neighborhood TOD area is located in an environmental service center within a city area with a service function on an environmental scale or an urban area within a district area designated as an activity center. Neighborhood TOD area has the following characteristics:

- f. Serves as a local economic center
- g. Served by the mass transportation system within the internal scope of the district/city which is connected to the transportation system of the district/city area
- h. Located in a residential area with good access to the city center or sub-city center
- i. Served by a medium and low capacity transit system by Light Rail, BRT, local buses, and/or feeder buses
- j. It is an area with a mixed function of commercial, office blocks, and residential areas with moderate intensity integrated with the transportation system.

Table 6. Technical Criteria for TOD Area Typology

Technical Criteria	TOD Area Typology Indicators		
	Urban	Sub Urban	Neighborhood
Modes of transportation			
Type of Transportation Mode	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of light rail transit, Local Bus/ Bus Express
Headway	< 5 minutes	5-15 minutes	15-30 minutes
Densify			
Population	>750 people/ha	450-1500 people/ha	350-1000 people/ha
Land Use Intensity			
Floor Area Ratio (FAR)	>5	3-5	2-3
Building Covered Ratio (BCR)	80%	70%	70%
Building Density	High Rise	Mid-High Rise	Mid Rise
Residential Density	20-75 units/1.000 m ²	12-38 units/1.000 m ²	15-20 unit/1.000 m ²
Number of floors	> 11	3-15	3-8
Diversity			
Activity duration	18 hours	16 hours	14 hours
Residential : Non-Residential	20%-60% : 40%-60%	30%-60% : 40%-70%	60%-80% : 20%-40%
Type of activity	6. housing mix 7. commercial 8. office 9. culture/ entertainment center 10. other public facilities	5. housing mix 6. commercial 7. office 8. culture	3. housing mix 4. Housing support facilities
Commercial Characteristics	Regional	Regional	Community, local
Residential type	high-rise, midrise apartments, and condominium	Mid-Rise, low-rise, and a little high-rise	Mid-rise, low-rise, town-house

2.3. Analysis

The data analysis techniques used in this research are scoring analysis techniques, GAP analysis techniques, SWOT analysis techniques, and descriptive analysis techniques.

5. Analysis of Determination of TOD Area Typology Based on Regional Development Direction

The analysis of determining the typology of the TOD area based on the direction of development of this area uses a scoring analysis technique that aims to identify the suitability score for each research variable by applying the Guttman scale. According to Sugiyono (2014) the Guttman scale is a scale that used to get a firm answer. There are only two intervals such as "agree-disagree"; "Yes No"; "True False"; "positive-negative"; "never-never" and so on.

The statements used in this analysis are appropriate and not in accordance with the application in the scoring analysis using a score of "1" (one) to indicate "appropriate" and a score of "0" (zero) to indicate "not appropriate". This scoring is carried out on the technical criteria in each type of typology in the TOD area. Furthermore, a suitability analysis will be carried out for each type of typology by changing the results obtained in percentage form as follows:

$$\text{suitability value (\%)} = \frac{\text{total score}}{\text{maximum score}} \times 100\%$$

The total score is the total value of the analysis results in each TOD typology, while the maximum score is the number of possible scores that can be achieved in each typology. In this study, the total score obtained was 22 according to the typological criteria analyzed. After getting a score, the value is classified according to suitability, namely 0-49% (close to inappropriate), 50% (close to appropriate and not appropriate), and 51-100% (close to appropriate).

6. Identification of Existing TOD Characteristics

In identifying the existing characteristics of TOD, descriptive statistical analysis was used. According to Iqbal Hasan (2001) descriptive statistics is a part of statistics that studies how to collect data and present data so that they are easy to understand. Descriptive statistics only deals with describing or providing information about a data or situation. In other words, descriptive statistics function to explain conditions, symptoms, or problems. The objects studied in this target are the characteristics of the Tanjung Karang Train Station area based on a predetermined TOD typology which includes modes of transportation, density, diversity, intensity of land use, parking, and road network patterns.

7. Analysis of Transit-Based Development of Tanjung Karang Train Station Area

The analysis technique uses Gap analysis, referring to the opinion of Bens (2011), Gap Analysis has the meaning of identifying the missing steps, which are needed to achieve the goal. Gap Analysis is a planning tool that creates a shared view of what needs to be done to close the gap between the present state and the desired future.

This analysis is used to see the extent to which the TOD concept has been applied based on the TOD typology that has been determined with existing conditions, so that achievements will be presented to form the expected typology in the Transit Oriented Development (TOD) based area in the Tanjung Karang Train Station area.

8. Strategy Analysis in Applying the TOD Concept

This analysis is used in order to develop a strategy for implementing the TOD concept after determining the typology, identifying the characteristics of the existing TOD, and examining the development of TOD so that potentials and problems will be found to implement the TOD concept.

The analysis technique at this stage will use a SWOT analysis, according to Sondang P. Siagian (2004) SWOT analysis is one of the most powerful analytical instruments when it is used properly and it is widely known that "SWOT is an acronym for the words strenght, weakness, opportunities and threats".

3. Results and Discussion

3.1. Results

The results of this study is accordance with the results of the analysis that has been described in the previous discussion after collecting secondary and primary data.

6. Regional Development Direction Policy

The policy for the direction of regional development is based on the regional development plan in the Tanjung Karang Train Station Area. Policy directions and data sources are presented in table.

Table 7. Regional Development Policy

Technical Criteria	Regional Development Policy	Data Source
Modes of transportation		
Type of Transportation Mode	Train, Medium Bus, passenger car	<ul style="list-style-type: none"> Lampung Province Spatial Plan Perwali Bandar Lampung No. 22 Tahun 2018
Headway	Maximum 15-30 minutes	
Densify		
Population	183 people/ha	Population Projection
Land Use Intensity		
Floor Area Ratio (FAR)	32	Bandar Lampung Spatial Plan
Building Covered Ratio (BCR)	80%	
Building Density	High rise	
Residential Density	6-16 unit/1.000 m ²	
Number of floors	45	
Diversity		
Activity duration	-	Bandar Lampung Spatial Plan
Residential : Non-Residential	5% : 95%	
Type of activity	Housing, trade and services, public and social facilities, offices, transportation	
Commercial Characteristics	Regional	
Residential type	High-rise	

7. Typology of the TOD area of Tanjung Karang Train Station

Data below shows a study of several policies of the City of Bandar Lampung which are taken from several aspects with the technical criteria of the TOD indicator. In hence, what is produced is an overview of the direction of TOD development in accordance with the policies that have been arranged.

Table 8. Scoring Analysis of TOD Area Typology Determination

Technical Criteria	Results of the Study on Regional Development Directions	TOD Area Typology Indicator Scoring		
		Urban	Sub Urban	Neighborhood
Modes of transportation				
Type of Transportation Mode	Train, Medium Bus, passenger car	1	1	0
Headway	Maximum 15-30 minutes	1	1	1
Densify		Densify		
Population	183 people/ha	0	0	0
Land Use Intensity				
Floor Area Ratio (FAR)	32	1	0	0
Building Covered Ratio (BCR)	80%	1	0	0
Building Density	High	1	0	0
Residential Density	6-16 unit/1.000 m ²	0	1	1
Number of floors	45	1	0	0
Diversity				
Activity duration	-			
Residential : Non-Residential	5% : 95%	1	0	0
Type of activity	Housing, trade and services, public and social facilities, offices, transportation	1	0	0
Commercial Characteristics	Regional	1	1	0
Residential type	High-rise	1	0	0
Total Skor		10	5	2

From the results from the calculations above, the typology which is in accordance with the direction of the Bandar Lampung City area development policy is the Urban Typology.

8. Identification of Existing TOD Characteristics

The existing characteristics of TOD is identified by direct observation through field surveys and interpretation by using satellite imagery. This identification is used to determine the current characteristics of TOD, namely the currently available transportation modes, population density, intensity of land use, diversity, and road network patterns as presented in table 4.

Table 9. Identification of Existing Conditions

Technical Criteria	Existing Condition
Modes of transportation	
Type of Transportation Mode	Train and city transportation
Headway	> 5 menit
Densify	
Population	147 jiwa/ha
Land Use Intensity	
Floor Area Ratio (FAR)	1,1
Building Covered Ratio (BCR)	58%
Building Density	Medium
Residential Density	12 units/1.000 m ²
Number of floors	5
Diversity	
Activity duration	12 hours
Residential : Non-Residential	72% ; 28%
Type of activity	Residential, commercial, office, public facilities and social facilities
Commercial Characteristics	Regional
Residential type	Mid-Rise

9. Analysis on the Development of the Transit-Based Tanjung Karang Train Station Area.

This analysis of the Transit-Based Tanjung Karang Train Station Development Study uses GAP analysis by presenting a comparison between existing conditions and the TOD typology along with the recommendations to follow-up.

Table 10. Anlysis on TOD Development for Tanjung Karang Station Area

Technical Criteria	Observation Results	Typology of Urban TOD	Analysis
Modes of transportation			
Type of Transportation Mode	Train and city transportation	1 (one) short-distance transit mode and 1 (one) long-distance transit mode in the form of heavy rail, light rail transit, BRT, Local Bus/ Bus Express	<ul style="list-style-type: none"> • Improve transportation facilities and infrastructures • Reactivate BRT • Add a stop
Headway	> 5 minutes	< 5 minutes	Arrange public transportation schedules
Densify			
Population	147 people/ha	>750 people/ha	Provide housing to meet the density level
Land Use Intensity			
Floor Area Ratio (FAR)	1,1	>5	Maximize trade and service areas by providing buildings with high KLB and KDB
Building	58%	80%	

Technical Criteria	Observation Results	Typology of Urban TOD	Analysis
Covered Ratio (BCR)			intensity and integrate high-rise buildings and a mixture of commercial residential and office housing mixes with mid-rise buildings.
Building Density	Sedang	High Rise	
Residential Density	12 unit/1.000 m ²	20-75 units/1.000 m ²	
Number of floors	5	> 11	
Diversity			
Activity duration	12 hours	8 hours	Provide an area with 18 hours of activities including retail activities in Pasir Gintung and night culinary activities in the Central Market area
Residential : Non-Residential	72% ; 28%	20%-60% : 40%-60%	Build the concept of vertical housing in residential areas and maximizing commercial functions in trade and service areas
Type of activity	Residential, commercial, office, public facilities and social facilities	6. housing mix 7. commercial 8. office 9. culture/ entertainment center 10. other public facilities	Build a mixed residential-commercial and residential-office concept
Commercial Characteristics	Regional	Regional	Aim to Pasar Tengah and Pasir Gintung
Residential type	Mid-Rise	high-rise, midrise apartments, and condominium	Build a vertical residential concept with family facilities
Network Pattern			
Block dimension	It is located in the Pasar Tengah area, besides that it is more than 130 meters	70-130 meters	<ul style="list-style-type: none"> • form pedestrian-friendly blocks in commercial areas connected to other areas • build pedestrian paths to improve pedestrian accessibility and be friendly to persons with disabilities • apply the park and ride concept to the station and terminal parking pockets
Network Pattern	Tanjung Karang train station (transit station), Train (primary transit), Trans Bandar Lampung Bus (secondary transit), and city transportation (<i>feeder</i>)	Transit station, primary transit (1 mode), secondary transit (2 mode), and <i>feeder</i>	<ul style="list-style-type: none"> • Reactivate BRT • Add station services via Damri Bus to Jabodetabek destinations

10. Regional Development Strategy Concept.

The concept of a regional development strategy describes the implementation of the strategy to be implemented in the Tanjung Karang Train Station Area. The discussion lies in the description of the development location that can be implemented through the regional block plan.

f. Transportation Mode Development Strategy Concept

The strategies that will be applied to this concept are:

- 7) Provide park and ride in station and terminal parking pockets
- 8) Integrate transportation mode services through pedestrian paths that can access stations, terminals, and bus stops
- 9) The application of a paid system for private vehicles when entering the TOD area
- 10) Increase the number of bus stops on Jl teuku umar and Jl. Hayam Wuruk
- 11) Reactivate BRT as main route
- 12) Facilitate a special place for online transportation stops at the Pasar Bawah terminal

g. Density Development Strategy Concept

The strategy that will be applied to this concept is to provide housing for families with dense occupancy rates equipped with social facilities and public facilities as well as recreation areas or family entertainment centers.

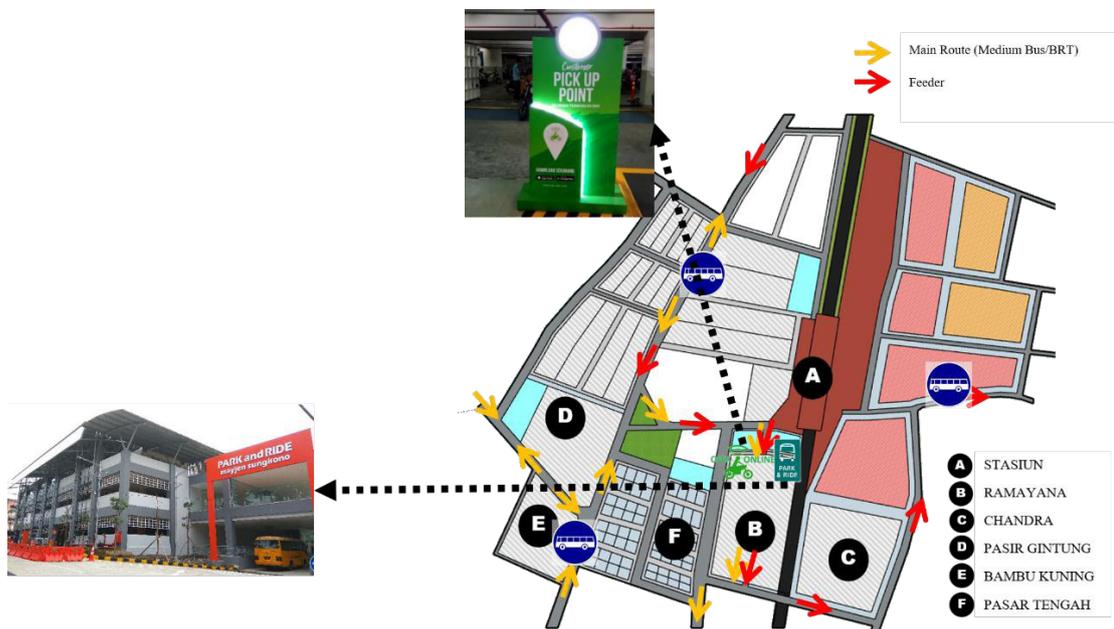


Figure 8. The Concept of Development Aspects of the Mode of Transportation

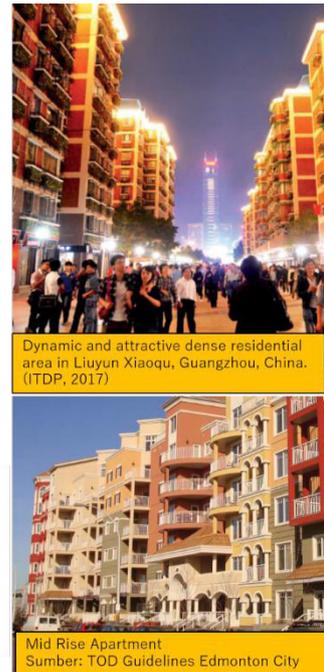
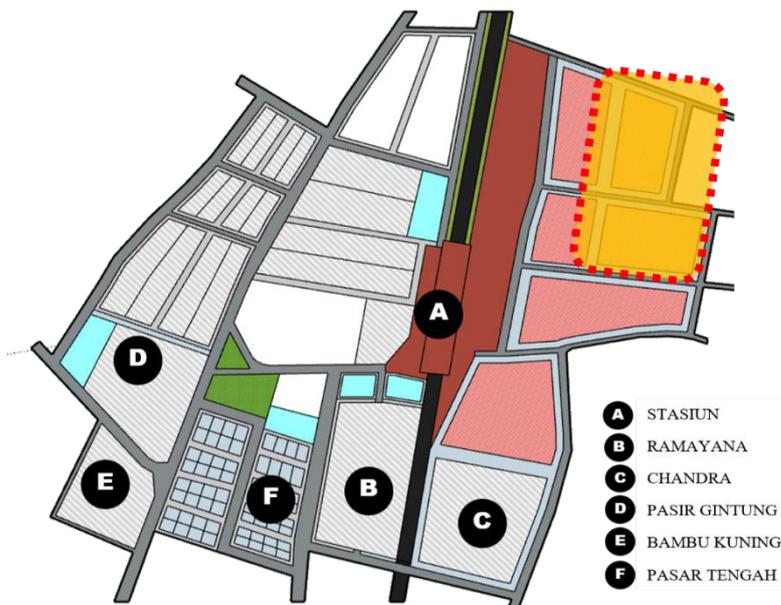


Figure 9. The Concept of Density Aspect Development

h. Concept of Land Use Intensity Development Strategy

The strategies that will be applied to this concept are:

- 4) Build high-rise buildings with commercial and office uses
- 5) Build high-rise buildings with residential and commercial purposes
- 6) Build high-rise apartments/condos/rusunami in residential areas

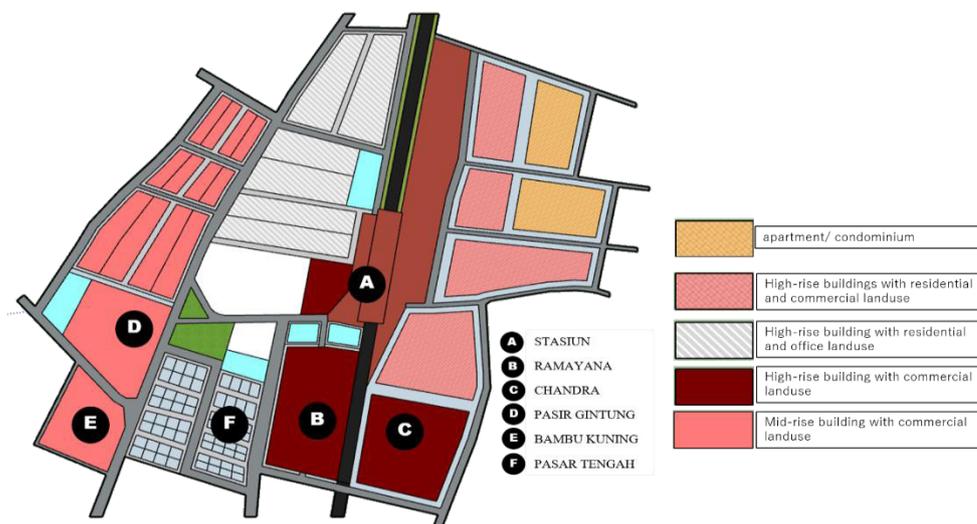


Figure 10. The Concept of Development of the Intensity of Land Use

i. Concept of Diversity Development Strategy

The strategies that will be applied to this concept are:

- 4) Direct retail trading activities with a duration of 18 hours in the Pasir Gintung area
- 5) Wholesale trade in The Pasar Tengah area and office commercial area
- 6) Make The Pasar Tengah area a night culinary with the concept of a city walk

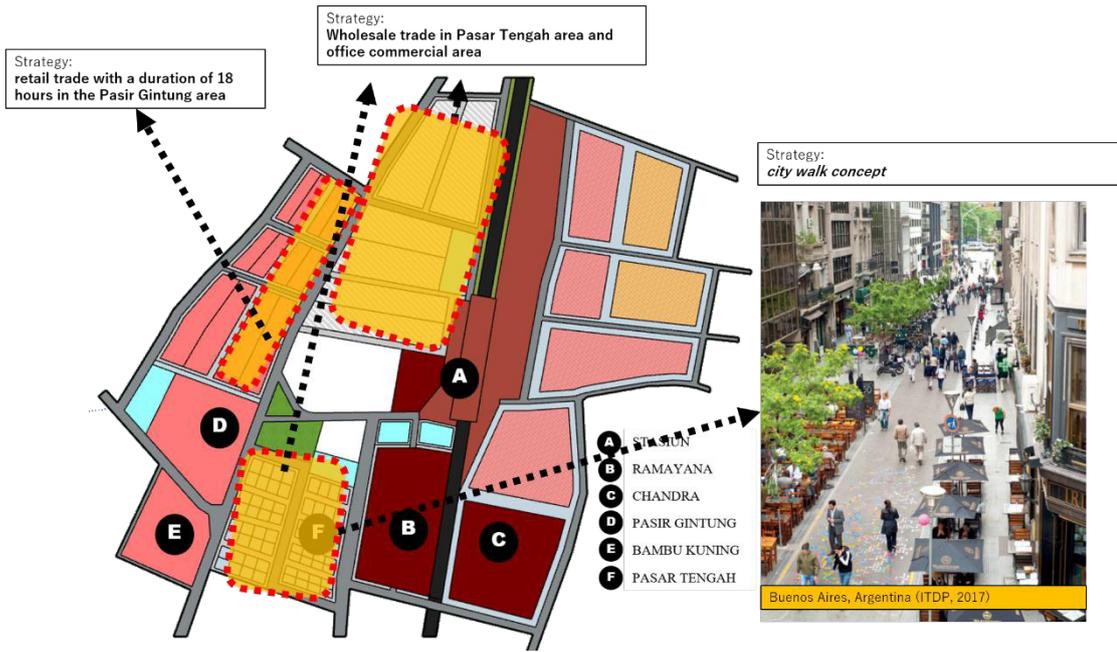


Figure 11. Concept of Diversity Development

j. Concept of Network Pattern Development Strategy

The strategies that will be applied to this concept are:

- 5) The dimensions of the block in the Pasar Tengah and Pasir Gintung are 70-130 meters
- 6) Intermodal integration between stations, terminals and bus stops through pedestrian accessibility with a maximum distance of 400 meters.
- 7) Create a pedestrian-friendly path for persons with disabilities
- 8) Add pedestrian bridges to facilitate pedestrian access to pass through the road network and the rail network.

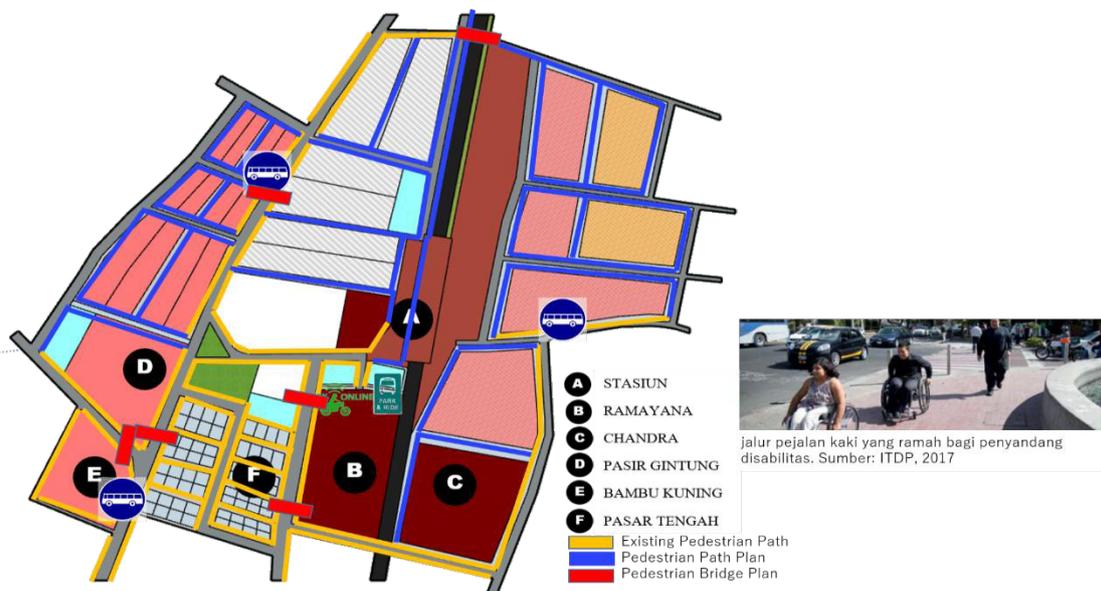


Figure 12. Concept of Network Pattern Development

3.2. Discussion

Based on the regional development on the previous discussion, it is obligatory to develop a development strategy by implementing the TOD concept. This strategy considers the existing condition of the area, which is mostly occupied in the form of buildings and the rest of area, green and non-green open spaces area designated for public facilities. This development strategy is in accordance with Permen ATR/BPN No. 16 of 2017 about Guidelines for the Development of Transit Oriented Areas that are appropriate to be implemented as the concept of a redevelopment site strategy by its rejuvenation by putting new functions and setting the environment by complementing transit facilities or TOD area facilities.

4. Conclusion

Determination of the typology of the TOD area in Tanjung Karang Train Station area is carried out by reviewing several regulations and policies about the direction of regional development at the research location. The data used are the revised technical material of Bandar Lampung City RTRW, Bandar Lampung Mayor Regulation Number 22 of 2018 about The Transportation of People and Goods and the ATR/BPN Ministerial Regulation about The Forming of RDTR. The technical criteria included in the study are modes of transportation, density, intensity of land use, diversity, and road network patterns. The results of the scoring, the suitability value for the urban typology is 76.92%, the sub-urban typology is 38.46%, and the neighborhood typology is 15.38%, so as the results, the typology for the development of the Tanjung Karang Train Station TOD area is UrbanTypology.

Urban Typology, as an analysis character of eksisting based on the predetermined TOD typology criteria, is compared with existing conditions. By using GAP analysis, the results of the comparison are achieved and unachieved conditions. From the results of the analysis, there are technical criteria for urban typology that have been achieved, which are the types of space utilization activities and commercial characteristics. While the existing characteristics that have not been achieved are the type of transportation mode, headway, population density, and the intensity of land use.

The implementation strategy on TOD concept in Tanjung Karang Train Station with urban typology is based on unachieved existing that with this strategy Tanjung Karang Train Station development based on TOD fits the technical criteria.

Acknowledgements

We would like to thanks the anonymous reviewers who provided a valuable comments and feedbacks on the early draft of this paper.

References

- Abdullah, J., & Mazlan, M. H. (2016). Characteristics of and Quality of Life in a Transit Oriented Development (TOD) of Bandar Sri Permaisuri, Kuala Lumpur. *Procedia-Social and Behavioral Sciences*. 234, 498-505.
- Bens, I. (2011). *Facilitating with Ease!: core skills for facilitators, team leaders, and members, managers, consultants, and trainers*. New York: JohnWiley & Sons, Inc.
- Calthorpe, P. (1993). *The Next American Metropolis: Ecology, Community, and the American Dreams*. New York: Princeton Architectural Press.
- Hansen, Walter G. (1959). How Accessibility Shapes Land Use. *Journal of the American Institute of Planners*. 73-76.
- Hasan, M Iqbal. 2001. *Pokok-pokok Materi Statistik I (Statistik Deskriptif)*. Jakarta: Bumi Aksara.
- Institute for Transportation and Development Policy. (2017). *TOD Standard 3.0*. New York: ITDP.
- Kementerian Agaria dan Tata Ruang/Kepala Badan Pertanahan Nasional. (2018). *Peraturan Menteri ATR/BPN Nomor 16 Tahun 2017 tentang Pedoman Pengembangan Kawasan Berorientasi Transit*. Jakarta: Kemen. ATR/BPN.
- Pemerintah Kota Bandar Lampung. (2011). *Perda Nomor 10 Tahun 2011 tentang Rencana Tata Ruang Wilayah Tahun 2011-2030*. Bandar Lampung: Pemerintah Kota Bandar Lampung.
- Siagian, Sondang P. (2004). *Manajemen Strategik*. Jakarta: PT. Bumi Aksara
- Sugiyono. (2014). *Metode Penelitian Pendidikan Pendekatan Kuantitatif, Kualitatif, dan R&D*. Bandung: Alfabeta
- WCED. (1987). *Our Common Future*. Oxford : Oxford University Press.

THE RATIO OF BMKG AND TRMM RAINFALL DATA IN WEST JAVA PROVINCE BY USING STATISTICAL PARAMETER AND CORRELATION ANALYSIS

Rian Alfian¹, Ahmad Zakaria¹, Endro Prasetyo Wahono¹, Dyah Indriana Kusumastuti¹,
Ahmad Herison¹

¹Departement of Civil Engineering, Faculty of Engineering, Universitas Lampung,
Lampung, Indonesia

*Email: rian19922017@gmail.com

Abstract

Weather observations can be done in two ways, namely weather observations based on weather stations and based on remote sensing such as satellites. One of these weather study data is rainfall measured from the BMKG rain observation post and TRMM satellite observations. To see the pattern of the distribution of rain that has occurred, the two weather observations can be connected as a reference for the distribution of rain. The purpose of this study was to analyze the correlation value of rainfall data between BMKG and TRMM by looking at the comparison graph and analyzing the comparison of statistical parameters. This research was conducted using daily rainfall data from 1998-2018 at four rain stations in West Java Province and taking descriptive decisions in the form of pictures and graphs in the form of daily, monthly and annual data. Based on the analysis results, the largest correlation value is in the annual cumulative with a value of 0,88-0,94, the smaller the number of days, the smaller the correlation value. The BMKG and TRMM rainfall data have relatively the same pattern, but the maximum data have differences so that it reduces the correlation value. In the Statistical Parameter analysis, it can be stated that the difference in the values of the statistical parameters is directly proportional to the daily cumulative, that the difference in the median and mean values in the BMKG and TRMM data is greater in the data with a larger cumulative. Meanwhile, for linear regression analysis, it was found that the greatest value was the cumulative 1-year value with a coefficient of determination from 0,78 - 0,89.

Keywords: BMKG; Correlation; Rainfall; Regression Analysis; TRMM

Introduction

Rainfall that occurs in the tropics, namely Indonesia, has influential elements such as meteorology compared to other factors. The variation of rainfall in the territory of Indonesia is very large both spatially and temporally (Gunawan, 2014). In general, to know accurate rainfall and can be used in engineering planning, rainfall data is needed to support information in the form of temporal (time series) and spatial (spatial) (Syaifullah, 2014). The amount of rain as a result of measurements with a rain gauge for some time years can be used to determine the nature (characteristics) of rainfall in a place (Hadi et al, 2006). However, there is also the concept of probability where the characteristics of rain based on time are ignored and the calculation will only be profitable if the data processing is long enough (Zakaria, 2010).

Good rainfall data can be obtained from recordings that are maintained and always monitored. Whether recording or observations can be done in two ways, namely weather observations based on weather stations and weather observations based on remote sensing such as satellites. As well as rainfall data originating from the meteorological observation post owned by the Meteorology, Climatology and Geophysics Agency (BMKG) it can predict weather conditions in areas such as West Java Province with a maximum average temperature of 32,2°C and a minimum temperature of 18.2°C.

West Java Province is geographically located between 5°50' – 7°50' South Latitude and 104°48' – 108°48' East Longitude (Badan Pusat Statistik, 2021). West Java Province is a land area that is distinguished by steep mountainous areas, gently sloping hillsides, broad plains, and watersheds. Rainfall measurements were carried out at rain observation posts in the West Java Province. The area consists of several rain observation points, but not all rain observation points are used in this study.

The distribution of rain is not only seen from the measured rainfall data from the BMKG rain observation post but also satellite observations are needed to see the pattern of rain distribution that has occurred, namely by looking at the data from the TRMM. NASA's Tropical Rainfall Measurement Mission (TRMM) was the first coordinated international effort to provide reliable rainfall measurements from space (Wong & Chiu, 2008). TRMM data is precipitation data (rain) obtained from the TRMM meteorological satellite with several sensors in it. Based on this, several studies have been obtained using TRMM satellite data which can verify rainfall data from the TRMM satellite and at the BMKG rain observation post in West Java Province.

Several studies have shown that monthly rainfall predictions in the western part of Java are still in areas with low accuracy, especially in the mountains (Apriyanal and Lindawati, 2015). This also affects the suitability of the rain pattern between the observed rainfall data and the estimated TRMM rainfall (Wiratri, 2012). In this study, we will present the relationship or correlation between the rainfall data from the BMKG rain observation post and the TRMM data which is usually used as a reference for the distribution of rain. The rainfall for each rain observation post in the area is then summed and averaged to get the average rainfall value for the area. The purpose of this study is to analyze the correlation value of BMKG rainfall data and TRMM data and

analyze the comparison of statistical parameters and the ability of the rainfall data.

Materials and Methods

The stages of this research consist of the initial preparation stage, the data processing stage, and the data analysis stage. The research flow chart is shown in Figure 1. This study uses secondary data from related parties such as BMKG and TRMM West Java Province at four stations namely Jatiwangi Station, Citeko Station, Bandung Geophysics Station, and Bogor Station. The data used is rainfall data with a span of 20 years, the data range from 1998 - 2018 which is downloaded from the official website of BMKG and TRMM West Java Province.

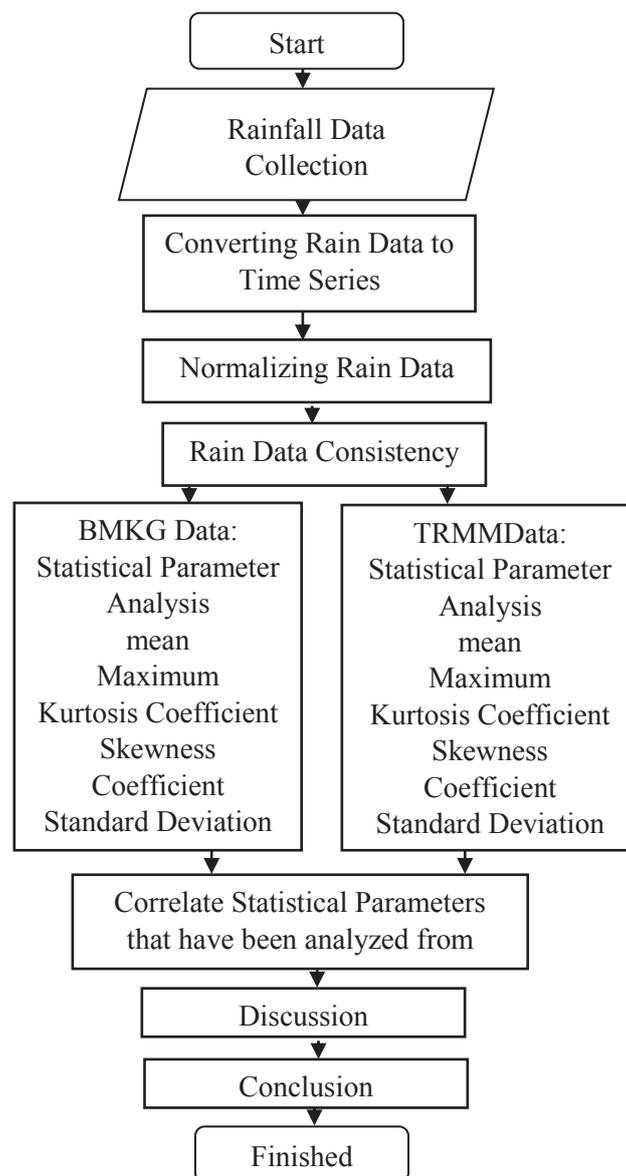


Figure 1. Research Flowchart

Procedure

Processing data in this study has several stages, including changing the BMKG station rainfall data and TRMM data into time series data, Normalizing rainfall data from

the Meteorology, Climatology, and Geophysics Agency, Conducting a consistency test for rain data that has been done searching for missing data. To find out whether this data is suitable for use as research data, Classify daily cumulative rainfall data, 7 daily, 15 daily, monthly, annual average, annual maximum, Analyzing rainfall data with statistical parameters namely Mean, Variance, Standard Deviation, Coefficient Skewness, and Kurtosis Coefficient, Correlate rainfall data from two different sources from different classifications, Correlate statistical parameters of rainfall data from two different rainfall data, Perform rainfall data modeling with regression analysis for BMKG and TRMM data.

Analysis

The analysis of the research results is in the form of correlation values and also descriptive decision-making according to the results of the analysis. The results are pictures and graphs from each rain station and also from different methods in West Java Province. After obtaining the results of this study, a discussion was carried out to draw conclusions based on the research rules Results and Discussions

Converting Rain Data Into Time Series

Precipitation data from the BMKG before being used in the study was still in the form of a time series with many empty days. In transforming rain data that are experiencing shortages, a program is used so that the process of filling in days that are not recorded and empty data can be processed much faster. The program used in this research is a program created using Force. This program is used to transform BMKG rainfall data that can be correlated well and by TRMM rainfall data.

Consistency Test Data

This test is used as one of the parameters that the rain data used is good data by looking at the possibilities of the data that is owned has a value that is far from its value in general. The consistency Test is carried out by adding up each existing daily data for a year or annual cumulative. Consistency tests were also carried out on the TRMM rainfall data, this was done to ensure that the TRMM rainfall data values did not have significant errors. The analyzed annual cumulative is used in determining the consistency test. This test is carried out by doing the cumulative last year compared to the cumulative of other stations. This annual cumulative value is the value used in linear regression analysis.

Correlation Analysis of BMKG Rainfall Data and Daily of TRMM

Correlation analysis of daily rainfall data was carried out using daily cumulative data. This comparison is used to see how much the pattern similarity value between BMKG data and TRMM data. This analysis was compared with 3 stages, namely Pearson correlation analysis, statistical data comparison, Curve Fitting, and linear regression analysis. The results of Pearson's correlation analysis show that from 4 rain stations in West Java, the correlation value is from 0,08 – 0,22. This states that the similarity of

rainfall patterns between BMKG data and TRMM data on the same day has a low-scale correlation. This was also stated by the researcher where the results of the analysis obtained if the rainfall data measured by TRMM had the same temporal distribution pattern of rainfall as that measured by BMKG (Pangestu, 2019).

Analyzing the correlation, Curve Fitting was also carried out to see the comparison of the BMKG and TRMM rainfall data, for this reason, a comparison of the rain data was carried out in the graphical form. The results of the graph comparisons carried out show that the data graphs have similar patterns, but the maximum value of each data has a significant difference so that these values have a small correlation value.

In addition, for statistical parameter analysis, it was found that the mean value or average value of the BMKG and TRMM rainfall data has a difference with a scale of 0,35 - 1,44, for the median value of BMKG and TRMM data has a difference with a scale of 0.05 to 1.91 states that the average value and the daily mean value of the BMKG and TRMM results have a small difference. the results of statistical parameter analysis can also be seen that the characteristics of the data have the same tendency, namely that the distribution of the data when viewed through the value of the skewness coefficient that all data has a positive distribution graph. As for the results of the kurtosis coefficient, all rain data has a Leptokurtic curve steepness level. The value of variance and standard deviation states that the data has a level of dispersion away from the zero value. It states that data values have dynamic variations in the amount of data. So that the analyzed rain data tends to move away from the average value of rainfall.

The results of the regression analysis show that the coefficient of determination or the ability of the regression function to model the BMKG rainfall data value from the TRMM rainfall data has a very low scale, it can be concluded that the TRMM daily rainfall data value can only predict the BMKG value with an accuracy rate of 1% - 5%. The results can be seen in the following figure 1 - 4.

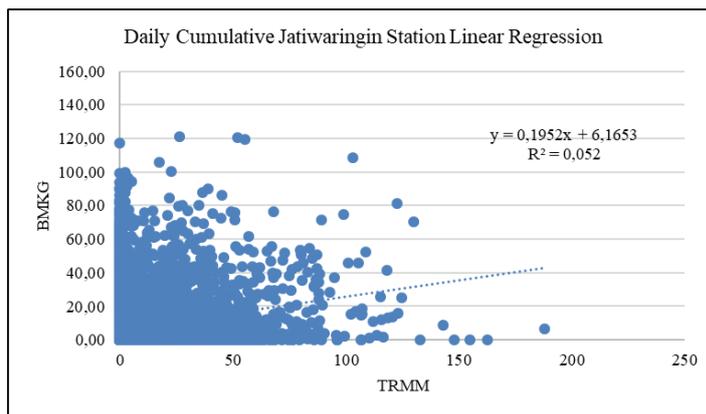


Figure 1. Daily Cumulative Jatiwaringin Station Linear Regression Chart.

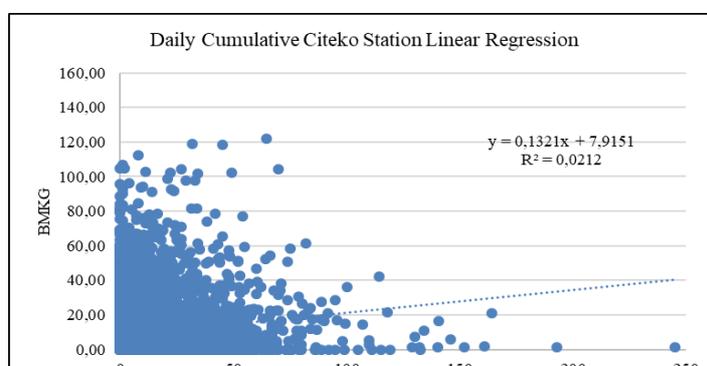


Figure 2. Daily Cumulative Citeko Station Linear Regression Chart.

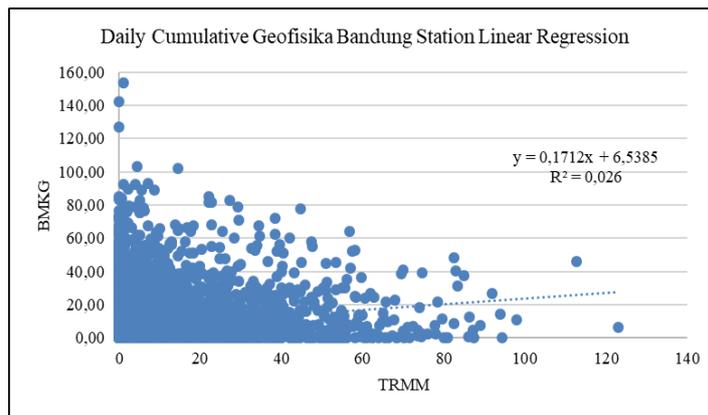


Figure 3. Daily Cumulative Geofisika Bandung Station Linear Regression Chart.

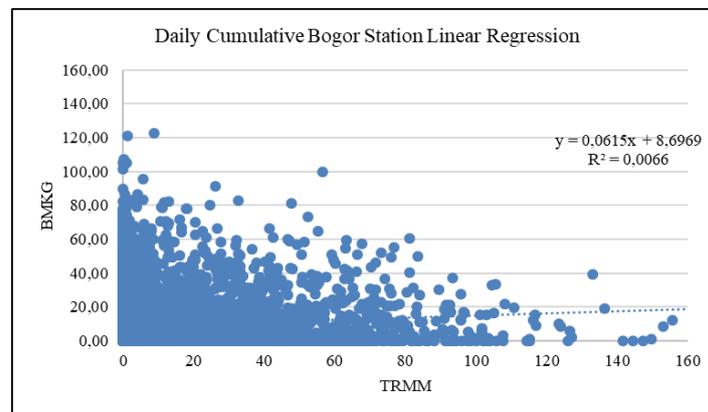


Figure 4. Daily Cumulative Bogor Station Linear Regression Chart.

Correlation Analysis of BMKG and TRMM 2 Daily Rainfall Data

Correlation analysis with a cumulative 2 days to see how much change occurs if the data used is data with a cumulative 2 days. The results of the correlation analysis stated that the correlation value produced was much better than the correlation value from the daily cumulative results. The results of the 2-day cumulative correlation analysis have a low scale with a value of 0,27 – 0,39. So it is stated that the 2 daily results are much better than the daily cumulative results. The graphical comparison between the two rainfall data, namely BMKG and TRMM, it is stated that the values of the BMKG and TRMM rainfall data have the same pattern, but the maximum value of the BMKG rainfall data has a higher tendency than the TRMM data.

Statistical parameters obtained that the average value (Mean) and the median value (Median) of the BMKG and TRMM data have a greater difference than the daily cumulative data, namely 0,7 - 2,88 for the average value and 2,64 - 3,23 for the middle value. The variance and standard deviation values still have the same tendency, which is away from the zero value, so it can be concluded that the data has a diverse and dynamic distribution. The value of the Skewness Coefficient also states that the value has a positive distribution so it can be concluded that the graph tends to the right. From the results of the Kurtosis Coefficient, it is also shown that the value has the characteristic level of the steepness of the Leptokurtic curve. For the results of the regression analysis that has been produced, it is stated that the coefficient of determination or the model's ability to predict BMKG rainfall data is 0,07 - 0,15 with a very low scale. The results can be seen in the following figure 5 - 8.

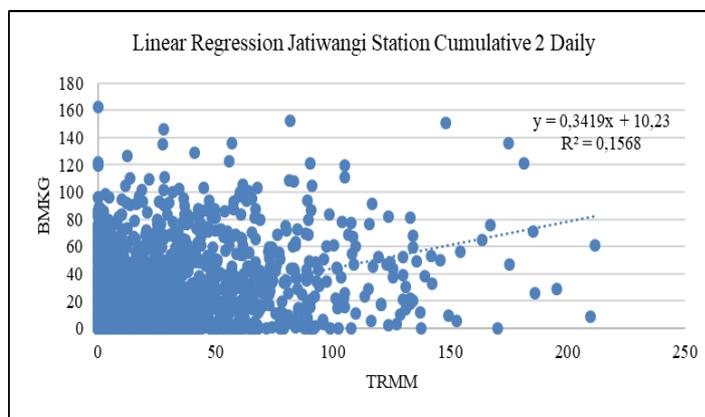


Figure 5. Linear Regression Graph Jatiwangi Station Cumulative 2 Daily.

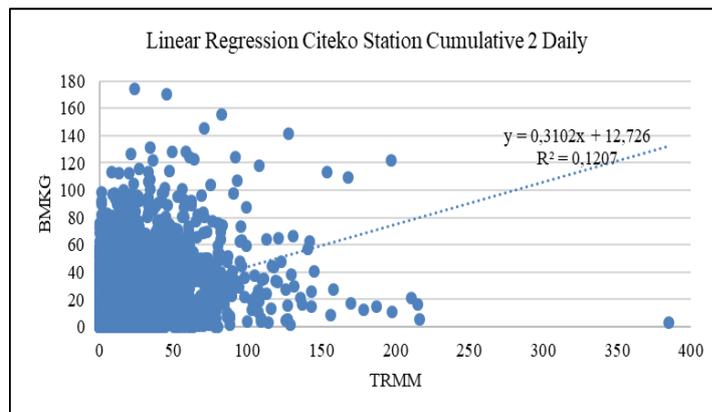


Figure 6. Linear Regression Graph Citeko Station Cumulative 2 Daily.

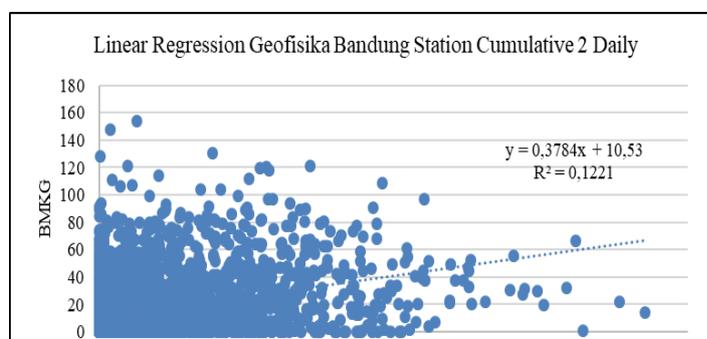


Figure 7. Linear Regression Graph Geofisika Bandung Station Cumulative 2 Daily.

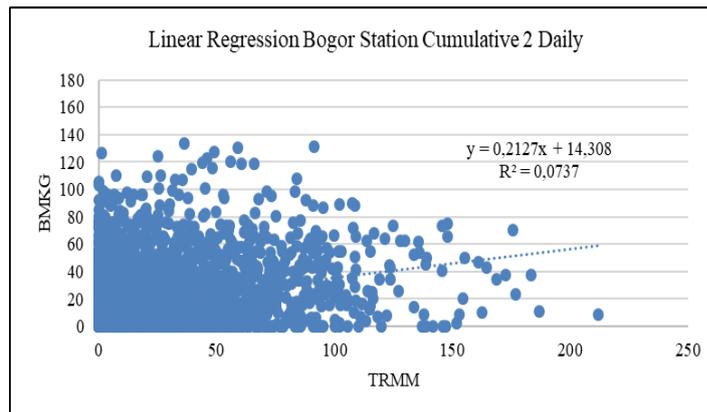


Figure 8. Linear Regression Graph Bogor Station Cumulative 2 Daily.

Correlation Analysis of BMKG and TRMM 7 Daily Rainfall Data

Analysis of 7-day rainfall is carried out by testing whether the more cumulative days of rain the greater the correlation value, this is also done to prove how much the daily cumulative affects the value of statistical parameters. The correlation value shows that the similarity of rainfall data patterns in BMKG data to TRMM data has a value that tends to increase compared to the 2-day data. From the value, it is also stated that the correlation value is on a medium scale with the smallest correlation value being Bogor Station and the largest is Jatiwangi Station. Comparisons with graphs have been compared and it can be concluded that the values have a similar pattern, but it can also be seen that the maximum value of the rain data has a value that differs greatly between BMKG and TRMM so this maximum value may cause the correlation value to be on a medium scale.

Comparison of statistical parameter values from BMKG and TRMM data, it was found that the difference between BMKG and TRMM stations for the mean value was 2,4 - 10,12 and 1,53 - 11,6 for the median value. This concludes that the greater the cumulative days used, the greater the difference in value. From the results of the analysis of standard deviation and variance, it is stated that they still have the same tendency, which is away from the zero value, so it can be concluded that the data has a diverse and dynamic distribution.

The value of the Skewness Coefficient also states that the value has a positive distribution so it can be concluded that the graph tends to the right. From the results of the Kurtosis Coefficient, it is also shown that the value has the characteristic level of the

steepness of the Leptokurtic curve. As for the results of the regression analysis, it was found that the coefficient of determination or the model's ability to predict BMKG rainfall data was 0,19 – 0,33 with a very low to low scale. The results can be seen in the following figure 9 - 12.

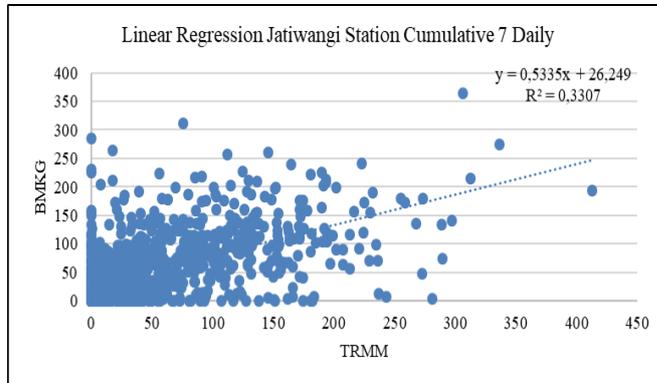


Figure 9. Linear Regression Graph Jatiwangi Station Cumulative 7 Daily.

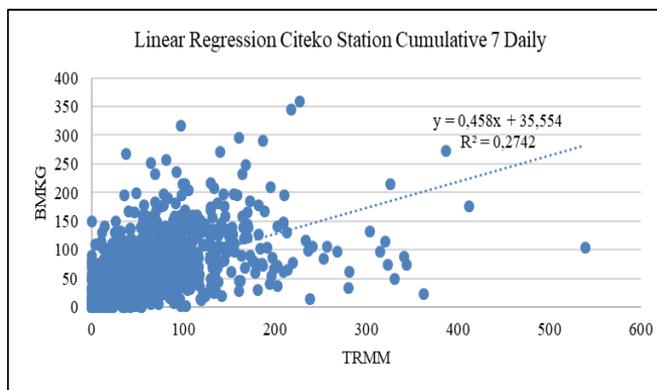


Figure 10. Linear Regression Graph Citeko Station Cumulative 7 Daily.

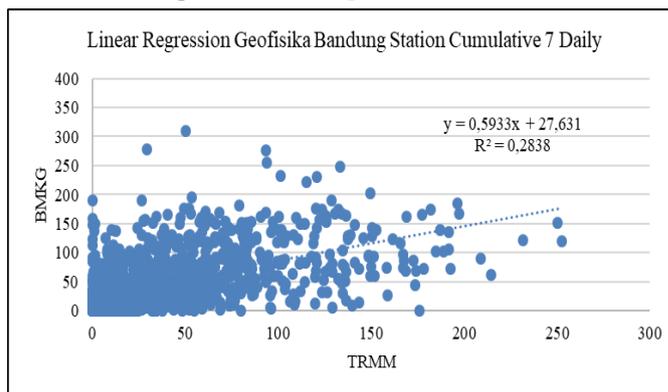


Figure 11. Linear Regression Graph Geofisika Bandung Station Cumulative 7 Daily.

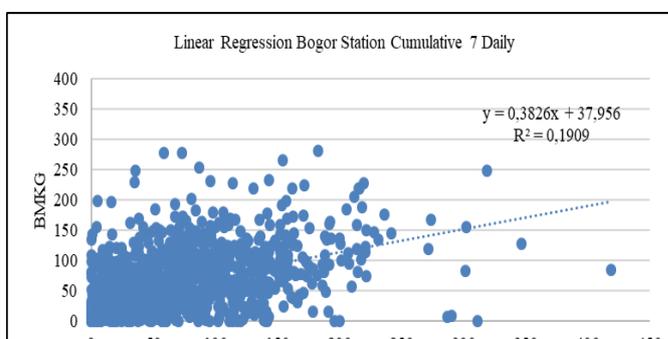


Figure 12. Linear Regression Graph Bogor Station Cumulative 7 Daily.

Correlation Analysis of BMKG and TRMM 15 Daily Rainfall Data

Analysis with a cumulative total of 15 days was analyzed as a means of comparison in analyzing rainfall data. The correlation value shows that the similarity of rainfall data patterns in BMKG data to TRMM data has a value that tends to increase compared to 7 daily data. From the value, it is also stated that the correlation value is on a high scale except for Bogor station data on a medium scale with the smallest correlation value being Bogor Station and the largest being Jatiwangi station. The comparison of the graphs can be concluded that the values have a similar pattern but it can also be seen that the maximum value of the rain data has a much different value between BMKG and TRMM so this maximum value may cause the correlation value to be on a medium to high scale.

Analysis of statistical parameter values found that the difference between the BMKG and TRMM stations for the mean value was 5,4 – 21 and 8,2 – 43,13 for the median value. This concludes that the greater the cumulative days used, the greater the difference in value. From the results of the analysis of standard deviation and variance, it is stated that they still have the same tendency, which is away from the zero value, so it can be concluded that the data has a diverse and dynamic distribution.

The value of the Skewness Coefficient also states that the value has a positive distribution so it can be concluded that the graph tends to the right. The results of the Kurtosis Coefficient also show that each station has a characteristic level of the steepness of the Leptokurtic curve except for the Jatiwangi TRMM station with Platykurtic characteristics. For regression analysis, it is stated that the coefficient of determination or the model's ability to predict BMKG rainfall data is 0,22 – 0,46 with a low and medium scale. The results can be seen in the following figure 13 – 16.

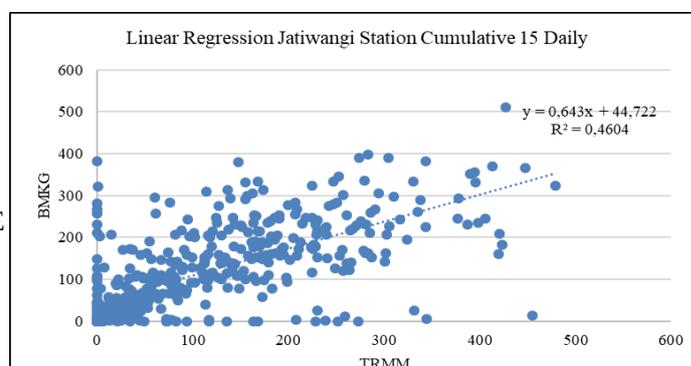


Figure 13. Linear Regression Graph Jatiwangi Station Cumulative 15 Daily.

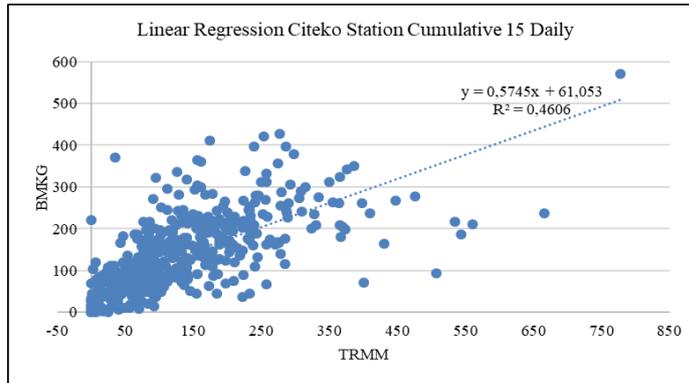


Figure 14. Linear Regression Graph Citeko Station Cumulative 15 Daily.

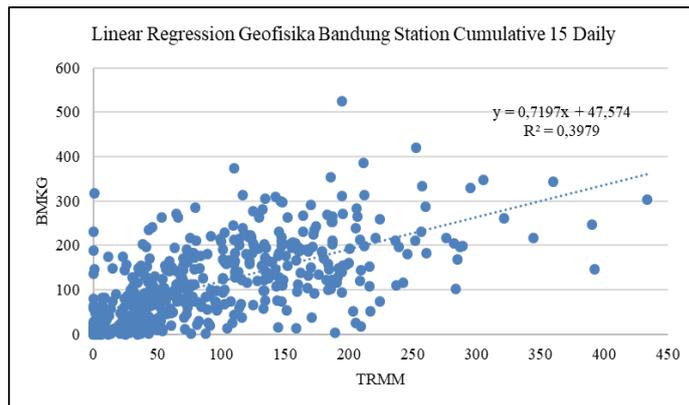


Figure 15. Linear Regression Graph Geofisika Bandung Station Cumulative 15 Daily.

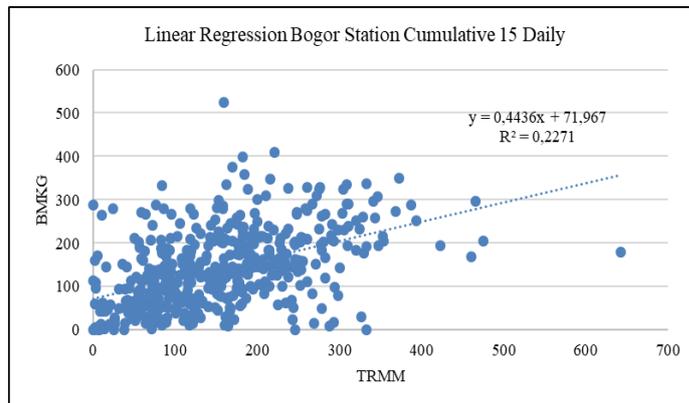


Figure 16. Linear Regression Graph Bogor Station Cumulative 15 Daily.

Correlation Analysis of BMKG and TRMM 30 Daily Rainfall Data

This analysis is carried out by testing whether the more cumulative days of rain the greater the correlation value, this is also done to prove how much the daily

cumulative affects the value of statistical parameters. The correlation value shows that the similarity of rainfall data patterns in BMKG data to TRMM data has a value that tends to increase compared to 15 daily data. From the value, it is also stated that the correlation value is on a high scale except for Bogor station data on a medium scale with the smallest correlation value being Bogor Station and the largest being Citeko Station. The comparison of the results of the graph of the 30-day data pattern shows that the values have a similar pattern, but it can also be seen that the maximum value of the rain data has a much different value between BMKG and TRMM so this maximum value may cause the correlation value to be on a medium to high scale.

Statistical parameter analysis showed that the difference between the BMKG and TRMM stations for the mean value was 10,99 – 43,36 and 8,04 – 43,78 for the median value. This concludes that the greater the cumulative days used, the greater the difference in value. From the results of the analysis of the standard deviation and variance, it is stated that it still has the same tendency, namely away from the zero value, so it can be concluded that the data has a diverse and dynamic distribution.

The value of the Skewness Coefficient also states that the value has a positive distribution, so it can be concluded that the graph tends to the right. From the results of the Kurtosis Coefficient, it is also shown that each station has a characteristic steepness level of the Leptokurtic curve except for the Jatiwangi station with Platykurtic characteristics for BMKG data, while for TRMM rainfall data all stations have a different sharpness level from BMKG, namely with Platykurtic characteristics. While the regression analysis resulted that the coefficient of determination or the model's ability to predict BMKG rainfall data was with a value of 0,27 – 0,57 with a low to medium scale. The results can be seen in the following figure 17 - 20.

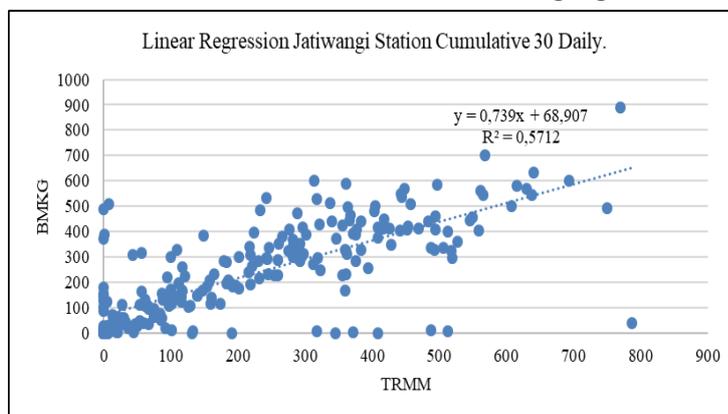


Figure 17. Linear Regression Graph Jatiwangi Station Cumulative 30 Daily.

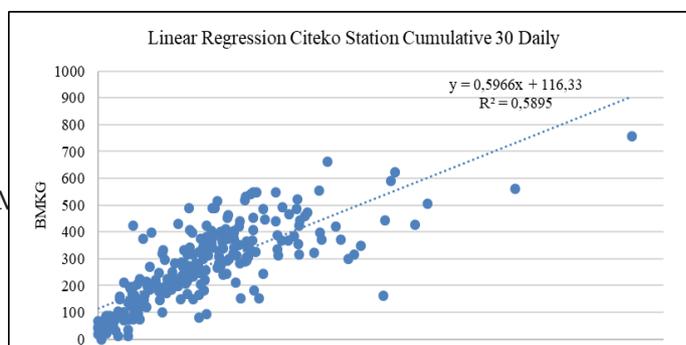


Figure 18. Linear Regression Graph Citeko Station Cumulative 30 Daily.

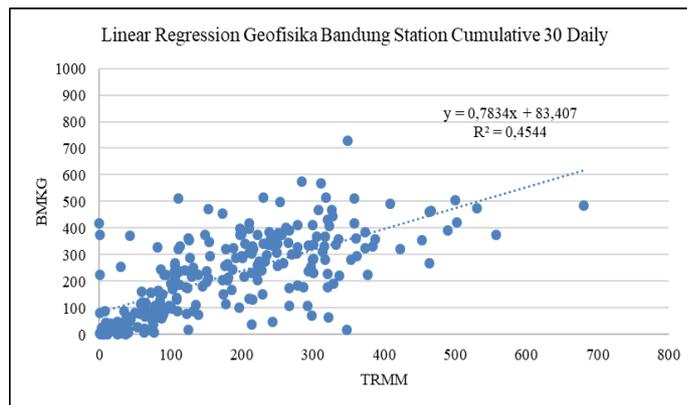


Figure 19. Linear Regression Graph Geofisika Bandung Station Cumulative 30 Daily.

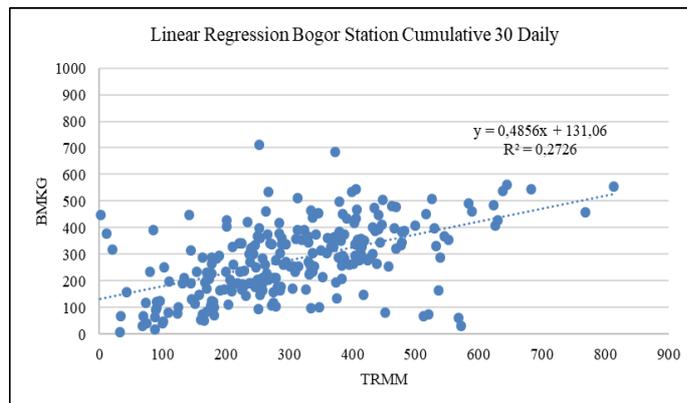


Figure 20. Linear Regression Graph Bogor Station Cumulative 30 Daily.

Correlation Analysis of BMKG and TRMM 1 Year Rainfall Data

This analysis is carried out by testing whether the more cumulative days of rain the greater the correlation value, this is also done to prove how much the daily cumulative affects the value of statistical parameters. The correlation value shows that the similarity of rainfall data patterns in BMKG data to TRMM data has a value that tends to increase compared to 1-year data. From the value, it is also stated that the correlation value is on the High scale except for the Citeko station data on a very high scale with the smallest correlation value being Bogor Station and the largest being Bogor Station. Comparison of the graphs shows that the values have a similar pattern, but it can also be seen that the maximum value of the rain data has a much different value between BMKG and TRMM so this maximum value may cause the correlation

value to be on a medium to high scale.

Statistical parameter analysis stated that the difference between BMKG and TRMM stations for the mean value was 76,82 – 484,96 and 213,28 – 592,84 for the median value. This concludes that the greater the cumulative days used, the greater the difference in value. From the results of the analysis of the standard deviation and variance, it is stated that they still have the same tendency, namely away from the zero value, so it can be concluded that the data has a diverse and dynamic distribution.

The value of the Skewness Coefficient also states that the value has a positive distribution, so it can be concluded that the graph tends to the right. From the results of the Kurtosis Coefficient, it is also shown that each station has a characteristic level of sharpness of the Platikurtic curve. For regression analysis, it is found that the coefficient of determination or the model's ability to predict BMKG rainfall data is 0,78 – 0,89 with a very high scale. The results can be seen in the following figure 21 - 24.

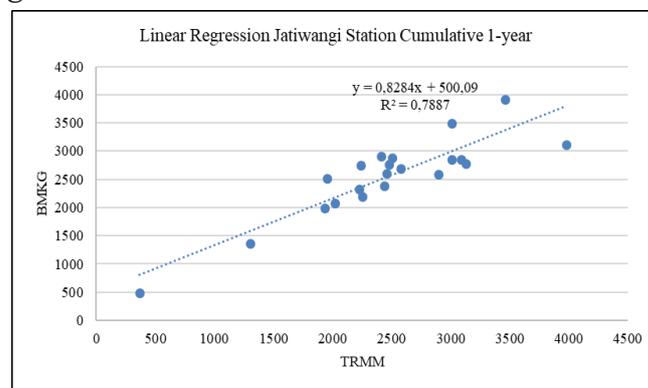


Figure 21. Linear Regression Graph Jatiwangi Station Cumulative 1-year.

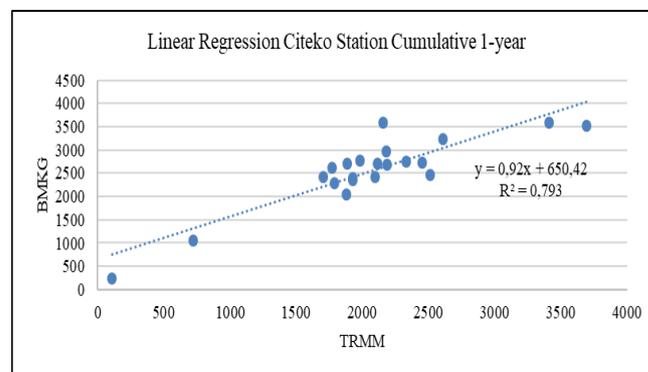


Figure 22. Linear Regression Graph Citeko Station Cumulative 1-year.

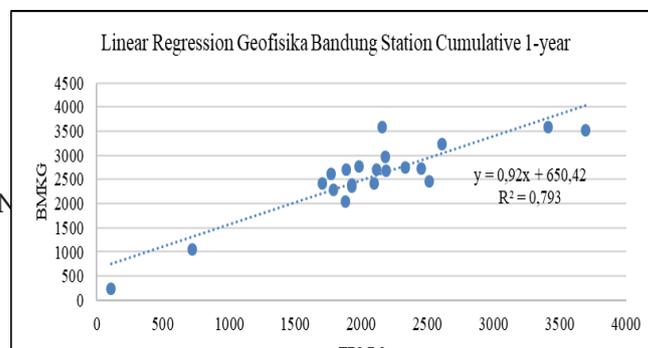


Figure 23. Linear Regression Graph Geofisika Bandung Station Cumulative 1-year.

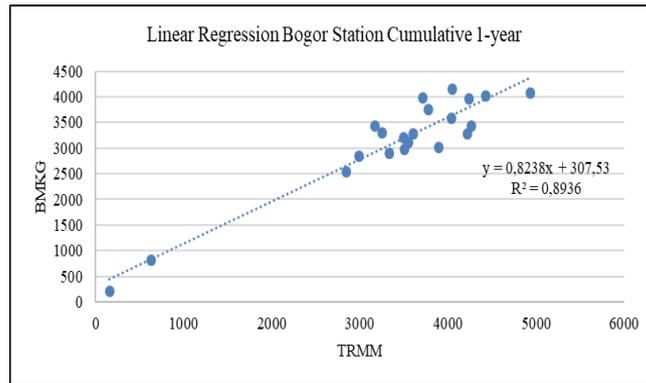


Figure 24. Linear Regression Graph Bogor Station Cumulative 1-year.

Based on the results of the regression analysis that has been carried out from daily to annual data, the equation results for each daily to annual rain station are presented in table 1.

Table 1. Results of Regression Analysis Equations at Each Rain Station.

Rain Station	Regression Analysis Equation					
	day	2 days	7 days	15 days	30 days	1-year
Jatiwangi	$y=0,1952x + 6,1653$ $R^2 = 0,052$	$y=0,3419x + 10,23$ $R^2 = 0,1568$	$y=0,5335x + 26,249$ $R^2 = 0,3307$	$y=0,643x + 44,722$ $R^2 = 0,4604$	$y=0,739x + 68,907$ $R^2 = 0,5712$	$y=0,8284x + 500,09$ $R^2 = 0,7887$
Citeko	$y=0,1321x + 7,9151$ $R^2 = 0,0212$	$y=0,3102x + 12,726$ $R^2 = 0,1207$	$y=0,458x + 35,554$ $R^2 = 0,2742$	$y=0,5745x + 61,053$ $R^2 = 0,4606$	$y=0,5966x + 116,33$ $R^2 = 0,5895$	$y=0,8625x + 521,45$ $R^2 = 0,7858$
Geofisika Bandung	$y=0,1712x + 6,5385$ $R^2 = 0,026$	$y=0,3784x + 1053$ $R^2 = 0,1221$	$y=0,5933x + 27,631$ $R^2 = 0,2838$	$y=0,7197x + 45,574$ $R^2 = 0,3979$	$y=0,7834x + 83,407$ $R^2 = 0,4544$	$y=0,92x + 650,42$ $R^2 = 0,793$
Bogor	$y=0,0615x + 8,6969$ $R^2 = 0,0066$	$y=0,2127x + 14,308$ $R^2 = 0,0737$	$y=0,3826x + 37,956$ $R^2 = 0,1909$	$y=0,4436x + 71,967$ $R^2 = 0,2271$	$y=0,4856x + 131,06$ $R^2 = 0,2726$	$y=0,8238x + 307,53$ $R^2 = 0,8936$

Source: Analysis Results, 2021

Conclusions

The results of research and discussion can be concluded:

1. From the results of the correlation analysis, it can be stated that the largest correlation value is in the annual cumulative with a correlation value of 0,88 – 0,94

while the lowest correlation value is in the daily cumulative ie 0,08 – 0,22. The correlation value obtained from the analysis is directly proportional to the cumulative amount, namely the smaller the number of days, the smaller the correlation value.

2. The results of the graphical comparison analysis show that the pattern formed from the rainfall data from BMKG and TRMM has a relatively similar pattern, but the maximum data has differences so that it reduces the correlation value.
3. The results of the Statistical Parameter analysis stated that the greater the difference between the median and mean values in the BMKG and TRMM data, the greater the cumulative value. The characteristics of the standard deviation, variance, and skewness coefficient have the same value, but the value of the standard deviation and variance increases as the number of days is accumulated. The kurtosis coefficient has a difference in value that is directly proportional to the number of days, but the characteristics of the kurtosis coefficient will be more different on a larger cumulative day.
4. From the results of linear regression analysis, it was found that the greatest value was the cumulative 1-year value with a coefficient of determination from 0,78 – 0,89. As for the low coefficient of determination, the daily cumulative value is 0,01 – 0,05.

Acknowledgment

The authors of this research gratefully acknowledge various parties who have contributed to the completion of this research. This research was realized to complete the Master of Civil Engineering at the University of Lampung.

References

- Apriyanal. Y. dan Lindawati. 2015, Aplikasi Model Prediksi Curah Hujan Pada Dua Sentra Produksi Padi Di Jawa Barat, Informatika Pertanian, Vol. 24, No.2, 149 – 156.
- Badan Pusat Statistik Provinsi Jawa Barat 2021, Provinsi Jawa Barat Dalam Angka Tentang Geografi dan Iklim.
- Hadi, A. I., Suwarsono., dan Heliana. 2006. Analisis Karakteristik Intensitas Curah Hujan Di Kota Bengkulu. Jurnal Fisika FLUX.
- Hadi, A. I., Suwarsono., dan Heliana. 2006. Analisis Karakteristik Intensitas Curah Hujan Di Kota Bengkulu. Jurnal Fisika FLUX.
- Gunawan, D. 2014. Perbandingan Curah Hujan Dari Data Pengamatan Permukaan, Satelit TRMM dan Model Permukaan NOAH. Puslitbang BMKG.
- Pangestu, I. T. 2019. Analisis Korelasi Data Curah Hujan Bmkg Dengan Trmm (Studi Kasus Stasiun Bmkg Di Sumatra Utara). Skripsi. Fakultas Teknik Universitas Lampung.
- Syaifullah, M. D. 2014. Validasi data TRMM terhadap data hujan aktual di tiga DAS di Indonesia. Puslitbang BMKG.
- Wiratri, M., 2012. Perbandingan Data curah hujan observasi dan estimasi curah hujan dari satelit TRMM (*Tropical Rainfall Measuring Mission*) untuk wilayah Banjarbaru

- dan Kotabaru. Laporan Kerja Praktik S-1 Fisika. Universitas Lambung Mangkurat. Banjarbaru.
- Wong, W. F. J., Chiu, L. S. 2008. Spatial and Temporal Analysis of Rain Gauge Data and TRMM Rainfall Retrievals in Hong Kong. *Geographic Information Sciences*, 14(2):105-112.
- Zakaria, A. 2010. Studi Pemodelan Stokastik Curah Hujan Harian Dari Data Curah Hujan Stasiun Purajaya. *Journal Proc. Seminar Nasional Sain Mipa dan Aplikasinya* page 8-9.

SIMULATION OF IRRIGATION AREA BY USING DEPENDABLE FLOW BASIC YEAR AND BASIC MONTH

JD Lantika^{1*}, A Zakaria², and DI Kusumastuti²

¹Master Student in Civil Engineering, Faculty of Engineering, Universitas Lampung, Jl Prof. Soemantri Brojonegoro No.1 Bandar Lampung, 35145, Indonesia

²Departement of Civil Engineering, Faculty of Engineering, Universitas Lampung, Jl Prof. Soemantri Brojonegoro No.1 Bandar Lampung, 35145, Indonesia

*Email: juppydamay02@gmail.com

Abstract

The purpose of this study was to analyze the availability of irrigation water from the reservoir by using a dependable flow of basic month, analyze the availability of irrigation water from the reservoir by using the dependable flow of basic year and compare the calculation of the availability of irrigation water from the reservoir by using a dependable flow of basic month and the basic year, Where which is more effective. The research was conducted using secondary data, the research location was in Way Rarem Reservoir, data obtained from the Mesuji-Sekampung River Basin Center and the North Lampung Geophysics Station UPT. Analysis of the data calculates the availability of irrigation water and irrigation water needs, to determine the maximum irrigation area that can be irrigated. The availability of irrigation water is made of two types of calculations, first using the basic month dependable flow with a reliability of 40%, 50%, and 60%, and the second with the basic year dependable flow from 2011-2020. Irrigation water needs are calculated using a modified penman, with a cropping pattern used of Paddy-Paddy-secondary crop and 4 groups. The results of this study are the basic year dependable flow gets an irrigation area of 1328,65 Ha and the basic month dependable flow gets an area of 11186,83 Ha, the basic dependable flow area gets a larger area than the basic month dependable flow, the maximum area of dependable flow basic month and basic year in Group IV started on January 1.

Keywords: dependable flow, basic year, basic month.

Introduction

Rice is one of the cultivated plants in Indonesia. The majority of Indonesia people consume rice which is the result of processed rice. Indonesia is known as an agricultural country where most of the population is farmers [1].

In agricultural activities, reservoirs are used for irrigation to support increased rice production. The efforts were made to up rice productivity in cropping patterns using irrigation water for the growing season, as well as regulating irrigation water requirements during the rendeng (rice) and gadu (paddy and secondary) planting seasons. The cropping pattern in the growing season will be adjusted to the availability of water in water sources. Irrigation is the provision of water to plants for the water needs of their growth [2].

To calculate the ability of water sources to irrigation water needs in an irrigation

area, it is usually with a water balance analysis. The dependable flow is the flow that is expected to exist or be available within a certain period. This study will calculate using dependable flow as the most effective way to calculate the availability of irrigation water from the reservoir.

Materials and Methods

The research location is the Way Rarem Reservoir, 36 km from the district capital, and 113 km from the provincial Lampung, the location of the Way Rarem Reservoir can be seen in Figure 1. In this study, the data obtained were secondary data from the Mesuji-Sekampung River Basin Center and North Lampung Geophysical Station UPT. The data obtained from the Mesuji-Sekampung River Basin Center is rainfall data for 10 years from 2011-2020 from 5 rain posts (Kelapa Tujuh, Subik, Kebon Tebu, Bukit Kemuning and Perukun). The data obtained from the UPT Geophysics Station of North Lampung are air temperature ($^{\circ}\text{C}$), wind speed (m/s), humidity (%), duration of sunshine (hours), and solar radiation (mm. day).



Figure 1. Way Rarem Reservoir

2.1. Availability of Irrigation Water

Calculating the availability of irrigation water is using the FJ Mock concept. Rainfall data from the Mesuji-Sekampung River Basin Center is calculated annually. Then the dependable flow calculation with two types, first using the basic year dependable flow method from 2011-2020, and second using the basic month dependable flow method with a reliability of 40%, 50%, and 60%.

2.2. Irrigation Water Needs

Analysis of irrigation water needs is calculating the inflow and outflow on agricultural land, the inflow into agricultural land is the discharge from the water

source from effective rain, while the outflow out of agricultural land is evapotranspiration, percolation, water for land preparation.

The need for irrigation water is using empirical theoretical formulas taking into account meteorological factors. From the meteorological data, evapotranspiration was calculated using the modified Penman method. After getting the evapotranspiration value, land preparation (LP) was calculated using the method developed by van de Goor-Zijlstra, then calculated the effective rainfall.

Calculation of irrigation water needs is using a cropping pattern. The cropping pattern aims to get the minimum amount of irrigation water needed in the dry season. In the preparation of this cropping pattern, four initial planting groups with simulated,

- a. Group I started on November I,
- b. Group II started on December I,
- c. Group III started on December II, and
- d. Group IV started on January I.

From these four groups, it is known that the need for irrigation water and the area that can be irrigated (Ha).

Results and Discussions

3.1. Availability of Irrigation Water

To calculate the availability of irrigation water, the F.J.MOCK concept is used. Mock is used to estimate the discharge of a watershed based on the concept of water balance [3]. The availability of irrigation water uses two models, the first is the basic year dependable flow from 2011-2020 and the second is the basic month dependable flow with a reliability of 40%, 50% and 60%. The results of the calculation of the basic year dependable flow in table1.

Table 1. Dependable flow basic year (m³/s)

Year	Jan	Feb	Mar	Apr	May	Jun
2011	7,57	7,84	8,22	8,24	7,15	6,13
2012	7,12	9,19	6,42	8,37	7,56	6,42
2013	10,12	8,61	7,95	8,14	7,17	6,93
2014	7,91	9,37	7,91	8,03	7,33	6,24
2015	9,98	9,77	9,18	8,13	6,35	5,91
2016	8,89	9,72	9,16	7,90	6,55	6,20
2017	7,67	8,88	8,19	8,18	6,14	6,61
2018	6,84	10,79	9,01	8,13	6,71	6,43
2019	7,71	10,87	9,66	8,21	6,08	5,73
2020	9,42	7,71	9,14	9,85	8,71	6,80
Jul	Aug	Sep	Oct	Nov	Dec	Quantity
5,81	5,01	5,35	6,12	7,90	7,83	83,18
5,43	4,99	5,31	6,07	8,28	9,15	84,31

7,80	5,88	6,11	7,75	7,49	10,64	94,58
5,93	6,48	5,20	5,65	7,23	9,61	86,89
5,24	5,03	5,13	5,06	6,80	8,55	85,13
6,32	5,97	7,72	8,09	8,44	7,79	92,75
5,76	5,75	5,92	7,83	8,15	9,71	88,81
5,34	5,79	5,75	5,58	7,77	7,35	85,49
5,48	4,96	5,15	5,20	5,98	9,56	84,60
6,52	6,11	6,38	6,90	6,43	8,08	92,05

the calculation results From the above data it is known that the dependable flow of basic year highs in 2013 is 94,58 m³/s, lowest was in 2011 at 83,18 m³/s .

The calculation of the basic month is sorting the discharge from the largest to the smallest by month, then calculations are determine the level of reliability based on the probability of occurrence following the Weibull formula [4]. Basic month dependable flow with a reliability of 40%, 50% and 60% can be seen in Table 2.

Table 2. Dependable flow basic month (m³/s)

Dependable flow	Jan	Feb	Mar	Apr	May	Jun
40%	8,50	9,58	9,09	8,20	7,16	6,43
50%	7,81	9,28	8,62	8,16	6,93	6,33
60%	7,69	9,01	8,21	8,13	6,62	6,22

Next

Dependable flow	Jul	Aug	Sep	Oct	Nov	Dec
40%	5,88	5,84	5,85	6,59	7,85	9,40
50%	5,79	5,77	5,55	6,10	7,63	8,85
60%	5,59	5,32	5,33	5,82	7,33	8,27

the calculation results

From the above data to the highest discharge in the dependable flow of 40% amounting to 9,58 m³/s in February, and the lowest at 60% dependable flow in the month of August at 5,32 m³/s.

3.2. Irrigation Water Needs

The need for irrigation water is the volume of water needed to meet the needs of evaporation, water loss, water needs for plants by taking into account the amount of water provided by nature through rain and the contribution of groundwater [5]. In this study, evapotranspiration using the Modified Penman method. The results of the calculation of evapotranspiration can be seen in table 3.

Table 3. Evapotranspiration (mm/day)

Month	Jan	Feb	Mar	Apr	May	Jun
Eto	4,71	4,43	4,40	3,47	3,44	3,33

Next

Month	Jul	Aug	Sep	Oct	Nov	Dec
Eto	3,48	4,48	5,28	5,16	4,75	4,29

the calculation results

From the results, the highest evapotranspiration in September was 5,28 mm/day, and the lowest was 3,33 mm/day. The results of daily evapotranspiration using the Penman-Mointeinth method vary from 3,2 mm/day to 5,2 mm/day [6].

Land preparation (LP) is the work of wet soil processing starting from the first application of water, cleaning the straw and roots of the remaining rice plants until they are planted. The results of the calculation of land preparation can be seen in table 4.

Table 4. Land Preparation (mm/day)

Month					
Jan	Feb	Mar	Apr	May	Jun
13,71	14,52	13,50	13,19	12,86	13,10

Next

Month					
Jul	Aug	Sep	Oct	Nov	Dec
12,89	13,55	14,40	14,02	14,04	13,42

the calculation results

The calculation method using van de Goor and Zlklstra is based on a constant water rate during the land preparation period. From the data above, it is known the highest land preparation in February was 14,52 mm/day and the smallest in July was 12,89 mm/day.

Analysis of irrigation water needs using a cropping pattern with four groups. The results of the calculation of four simulations of irrigation water needs with the paddy-paddy-secondary crops, irrigation water needs in table 5.

Table 5. Irrigation water needs (l/s/ha)

Month	Irrigation Water Needs			
	Group I	Group II	Group III	Group IV
Nov-01	2,80	1,07	1,51	1,33
Nov-02	2,75	2,75	0,68	1,47
Dec-01	1,28	2,64	2,64	1,39
Dec-02	1,24	1,24	2,60	0,97
Jan-01	1,55	1,37	1,37	2,69
Jan-02	1,32	1,54	1,37	2,69
Feb-01	1,22	1,26	1,47	1,30
Feb-02	0,59	1,20	1,25	1,27
Mar-01	0,00	0,62	1,22	1,48

Mar-02	2,63	0,00	0,60	1,25
Apr-01	2,63	2,63	0,00	1,04
Apr-02	1,14	2,67	2,67	0,56
May-01	1,16	1,16	2,63	0,00
May-02	1,34	1,15	1,15	2,57
Jun-01	1,13	1,34	1,16	2,64
Jun-02	1,10	1,13	1,34	1,16
Jul-01	0,62	1,14	1,17	1,20
Jul-02	0,00	0,62	1,14	1,39
Aug-01	0,89	0,00	0,70	1,36
Aug-02	1,13	0,90	0,00	1,33
Sep-01	1,43	1,21	0,93	0,78
Sep-02	1,63	1,42	1,21	0,00
Oct-01	1,55	1,56	1,36	0,88
Oct-02	1,11	1,58	1,59	1,18

the calculation results

From the calculation results, it is known that the highest irrigation water requirement in November-01 of 2,80 l/s/ha in group I.

To find out the area of irrigation that can be irrigated, use the formula:

$$A = (Q_{and} / DR) * 1000 \quad (1)$$

Where:

A : The area that can be drained for a certain alternative during a certain period of time, ha

Q_{and} : Mainstay discharge over a period of time, m³ /s

DR : The demand for water intake is l/sec/ha [7]

Based on the calculation of the highest minimum area from the sum of the planting period in Group I, Group II, Group III and Group IV, the maximum yield is obtained in Group IV, both basic year mainstay discharge and Basic month mainstay discharge with a reliability of 40%, 50% and 60%. The data from the calculation of the highest minimum area for the sum of the planting period in group IV of the basic year dependable flow can be seen in table 6 and the basic month dependable flow can be seen in table 7.

The maximum area that can flow through the area for the basic month dependable flow is 1186.83 Ha and the basic year dependable flow is 13286.65 Ha. the greater the dependable flow and the smaller the demand for water intake, the greater the area of land that can be drained [7]

The Way Rarem Reservoir has a main function as a water supply with a certain designation, namely flood control, water reservoir during the rainy season, irrigation and tourist attraction [8].

Based on the Regional Regulation of North Lampung Regency No. 4 of 2014 concerning the spatial plan of the North Lampung Regency in 2014-2034 that the Way Rarem Irrigation Area has an area of 9259 Ha. Thus, when compared with the calculation area, the highest minimum area of the total planting period for Groups I, II, III, and IV, the basic year dependable flow and the basic month dependable flow have a greater value compared to the planned area based on regional regulations.

Table 6. The area that is flowed in the fourth category of basic year dependable flow.

Month	Group IV				
	2011	2012	2013	2014	2015
Nov-01	5948,53	6232,41	5635,78	5444,13	5116,14
Nov-02	5368,95	5625,17	5086,68	4913,69	4617,67
Dec-01	5649,13	6604,79	7678,70	6930,53	6171,95
Dec-02	8076,25	9442,51	10977,8	9908,21	8823,70
Jan-01	2812,96	2644,15	3756,49	2937,51	3707,49
Jan-02	2818,15	2649,03	3763,42	2942,93	3714,33
Feb-01	6035,25	7078,80	6631,14	7215,60	7524,09
Feb-02	6148,57	7211,71	6755,64	7351,08	7665,36
Mar-01	5558,02	5654,74	5505,00	5428,69	5492,04
Mar-02	6580,61	6695,12	6517,83	6427,48	6502,49
Apr-01	7902,70	7245,52	6876,86	7025,12	6093,10
Apr-02	14761,53	13533,97	12845,36	13122,28	11381,36
May-01	0,00	0,00	0,00	0,00	0,00
May-02	2776,91	2493,28	2693,13	2425,42	2294,34
Jun-01	2318,56	2055,42	2949,97	2243,77	1981,33
Jun-02	5265,36	4667,78	6699,29	5095,51	4499,52
Jul-01	4842,95	4161,02	4898,77	5402,91	4192,80
Jul-02	4193,61	3603,12	4241,95	4678,49	3630,63
Aug-01	3686,38	3904,08	4494,17	3827,28	3773,99
Aug-02	3773,88	3996,75	4600,84	3918,13	3863,57
Sep-01	6835,74	7749,60	9889,36	7208,74	6463,90
Sep-02	0,00	0,00	0,00	0,00	0,00
Oct-01	6991,62	6929,25	8842,51	6445,65	5779,66
Oct-02	5202,84	5156,43	6580,19	4796,55	4300,95
MIN MT 1	2812,96	2644,15	3756,49	2937,51	3707,49
MIN MT 2	2318,56	2055,42	2949,97	2243,77	1981,33
MIN MT 3	5202,84	5156,43	6580,19	4796,55	4300,95
Result	10334,35	9856,00	13286,65	9977,83	9989,77

Next

Month	Group IV				
	2016	2017	2018	2019	2020
Nov-01	6355,90	6137,78	5846,69	4505,88	4839,48
Nov-02	5736,63	5539,76	5277,03	4066,87	4367,96

Dec-01	5620,12	7002,67	5303,30	6899,45	5829,10
Dec-02	8034,78	10011,34	7581,84	9863,76	8333,55
Jan-01	3302,60	2848,55	2540,80	2864,25	3500,03
Jan-02	3308,69	2853,81	2545,49	2869,53	3506,49
Feb-01	7486,97	6842,07	8310,70	8374,86	5938,31
Feb-02	7627,54	6970,53	8466,73	8532,10	6049,80
Mar-01	5336,54	5532,35	5492,04	5552,51	6654,68
Mar-02	6318,38	6550,22	6502,49	6574,09	7879,03
Apr-01	6283,85	5891,47	6435,07	5832,17	8349,51
Apr-02	11737,66	11004,74	12020,13	10893,97	15596,12
May-01	0,00	0,00	0,00	0,00	0,00
May-02	2407,34	2568,17	2498,66	2227,48	2643,47
Jun-01	2390,00	2180,20	2021,88	2074,14	2465,26
Jun-02	5427,60	4951,16	4591,62	4710,29	5598,52
Jul-01	4976,93	4789,36	4824,91	4130,96	5094,59
Jul-02	4309,62	4147,20	4177,99	3577,09	4411,51
Aug-01	5681,40	4358,59	4228,51	3788,10	4693,21
Aug-02	5816,26	4462,05	4328,88	3878,01	4804,62
Sep-01	10328,89	9994,64	7129,78	6633,66	8811,58
Sep-02	0,00	0,00	0,00	0,00	0,00
Oct-01	9235,51	8936,64	6375,05	5931,44	7878,82
Oct-02	6872,64	6650,23	4744,01	4413,91	5863,05

MIN MT 1	3302,60	2848,55	2540,80	2864,25	3500,03
MIN MT 2	2390,00	2568,17	2021,88	2074,14	2465,26
MIN MT 3	5736,63	5539,76	4744,01	4066,87	4367,96
Result	11429,23	10956,49	9306,70	9005,25	10333,25

Table 7. The area flowed in group IV basic month dependable flow

Month	Group IV		
	Dependable Flow 40%	Dependable Flow 50%	Dependable Flow 60%
Nov-01	5907,79	5741,23	5520,79
Nov-02	5332,18	5181,85	4982,89
Dec-01	6781,58	6388,37	5966,24
Dec-02	9695,26	9133,11	8529,61
Jan-01	3156,56	2900,88	2854,83
Jan-02	3162,39	2906,23	2860,10
Feb-01	7378,42	7147,20	6936,77
Feb-02	7516,95	7281,39	7067,00
Mar-01	6143,92	5824,84	5546,48
Mar-02	7274,31	6896,52	6566,95
Apr-01	7865,73	7829,17	7798,73
Apr-02	14692,48	14624,18	14567,33
May-01	0,00	0,00	0,00
May-02	2782,38	2691,98	2570,29
Jun-01	2431,30	2395,12	2503,16
Jun-02	5521,41	5439,23	5340,20
Jul-01	4902,21	4822,34	5179,02
Jul-02	4244,92	4175,76	4036,54
Aug-01	4299,60	4244,77	4116,22
Aug-02	4401,65	4345,52	4005,89

Sep-01	7472,96	7086,63	6790,05
Sep-02	0,00	0,00	0,00
Oct-01	7523,94	6960,44	6639,09
Oct-02	5598,97	5179,63	4940,50
MIN MT 1	3156,56	2900,88	2854,83
MIN MT 2	2431,30	2395,12	2503,16
MIN MT 3	5598,97	5179,63	4940,50
Result	11186,83	10475,63	10298,50

Conclusions

The conclusions in this study are based on the irrigation water needs and the existing dependable flow, calculations have find the maximum area of each alternative. The basic month dependable flow can an irrigation area of 11186,83 Ha and the basic year dependable flow can an irrigation area of 13286,65 Ha. The maximum area of basic year and basic month dependable flow is obtained in group IV starting in January 1st week (first). The area that flows through the land area using the basic year dependable flow can flow through a wider irrigation area than using the basic month dependable flow.

References

- Prayogi, "Faktor-Faktor yang Berpengaruh Terhadap Audit Delay (Studi Empiris pada Perusahaan Telekomunikasi yang Terdaftar di Bursa Efek Indonesia pada Tahun 2009-2011)", *Journal Fakultas Ekonomi, Universitas Gunadarma, Bekasi*, 2012.
- J Basri, *Dasar-dasar Mekanisasi Pertanian*. Raja Grafindo Perkasa, Jakarta, 1987.
- Indra Z., Jasin M.I., Binilang A., dan Mamoto J.D, "Analisis Debit Sungai Munte dengan Metode Mock dan Metode NRECA untuk Kebutuhan Pembangkit Listrik Tenaga Air", *Journal Sipil Statik*, Vol 1 No 1 page 34-38, 2012.
- Setiawan A.H. dan Anwar, "Optimasi Pola Tanam Menggunakan Program Linier Waduk Batutegei Daerah Aliran Sungai Way Sekampung Lampung", *Journal Teknik*, Vol 6 No 1 page 2301-9171, ISSN 2337-3539, 2017.
- Sosrodarsono S. dan K. Takeda, "Hidrologi untuk Pengairan" PT Pradnya Paramita, Jakarta, 2003.
- Taolin ICO, Impron, Hidayati R, Budianto B, "Pendugaan Evapotranspirasi Padi Sawah dengan Metode Nisbah Bowen", *Journal Pertanian Konservasi Lahan Kering*, ISSN 2477-7927, Savana Cendana 2(2)23-26, 2017
- Suprpto, "Modul Perencanaan Operasi Jaringan Irigasi", Pusat Pendidikan dan Pelatihan Sumber Daya Air dan Konstruksi, Jakarta, 2016.
- Wiadnyana, N. and Lukman "Potensi , Pengembangan dan Pemanfaatan Perikanan KPP PUD 438", AMaFRad Press, ISBN :978-602-5791-73-4, 2014.

ANALISIS KARAKTERISASI PENYAKIT PADA TANAMAN PISANG MENGGUNAKAN KAMERA TERMAL DENGAN

METODE TRESHOLDING

Elka Pranita¹, Dr. Eng. Helmy Fitriawan, S.T., M.Sc. ², Dr. Eng. F.X. ArintoS., S.T., M.T.

Jurusan Teknik Elektro Universitas Lampung, Bandar Lampung

Jl. Prof. Sumantri Brojonegoro No.1 Bandar Lampung 35145

¹elkapranita@gmail.com

²helmy.fitriawan@eng.unila.ac.id

³fx.arinto@eng.unila.ac.id

Intisari – Pisang merupakan tanaman buah yang banyak diproduksi di Indonesia. Sayangnya tanaman ini sangat rentan terhadap penyakit yang dapat menurunkan kualitas dan kuantitas hasil panen. Makalah ini mengusulkan deteksi penyakit pada tanaman pisang menggunakan kamera termal. Deteksi dilakukan menggunakan teknik pengolahan citra dengan metode multilevel thresholding. Gambar diambil dengan menggunakan kamera termal, kemudian gambar diproses terlebih dahulu agar sesuai dengan yang diinginkan. Setelah itu agar posisinya sama dengan citra yang diambil dengan menggunakan kamera digital maka citra yang dihasilkan oleh kamera thermal dilakukan proses registrasi citra. Hasil pengolahan citra dibandingkan dengan citra ground truth yang diperoleh dari kamera digital untuk mengetahui keefektifan metode yang diusulkan. Efektivitas metode yang diusulkan diukur menggunakan parameter Recall, Precision, F-measure, dan Accuracy. Efektivitas metode yang diusulkan diukur menggunakan parameter Recall, Precision, F-measure, dan Accuracy. Keefektifan metode yang diusulkan cukup efektif menghasilkan nilai Recall 76,65%, Precision 58,38%, F-measure 64,68%, dan Accuracy 62,87%.

Kata kunci – Penyakit Tanaman Pisang, Citra Termal, Citra RGB, Multi Tresholding, Pengukuran Efektifitas.

Abstract

Banana is a fruit plant that is widely produced in Indonesia. Unfortunately, this plant is very susceptible to diseases which can reduce the quality and quantity of the crop. This paper proposes disease detection in banana plants using a thermal camera. The detection is carried out using image processing techniques with multilevel thresholding methods. The image is captured using a thermal camera, then the image is preprocessed to suit what is desired. After that, so that the position is the same as the image taken using a digital camera, the image produced by the thermal camera is carried out by an image registration process. The image processing result is compared with the ground truth image obtained from a digital camera to determine the effectiveness of the proposed method. The effectiveness of the proposed method is measured using the parameters Recall, Precision, F-measure, and Accuracy. The effectiveness of the proposed method is effective enough to produce a recall value of 76.65%, Precision 58.38%, F-measure 64.68%, and Accuracy 62.87%.

Keywords– Banana Plant Disease, Thermal Image, RGB Image, Multi Thresholding, Effectiveness Measurement.

I. PENDAHULUAN

Tanaman buah adalah salah satu bagian utama dari kehidupan masyarakat. buah merupakan makanan yang hampir setiap hari dikonsumsi oleh masyarakat dikarenakan berbagai macam manfaatnya. Dari berbagai jenis buah-buahan, pisang merupakan salah satu buah yang memberikan banyak manfaat bagi tubuh. Buah pisang mengandung banyak serat, antioksidan dan vitamin yang baik bagi tubuh selain itu pisang juga bisa meningkatkan kesehatan pencernaan. Daunnya biasanya dimanfaatkan masyarakat untuk membungkus makanan karena memberikan aroma wangi dan membuat makanan lebih sedap serta memiliki manfaat kesehatan.

Produksi buah Pisang di Lampung pada tahun 2017 mencapai 1.642.000 ton. Selain untuk keperluan konsumsi lokal, buah ini juga diekspor ke luar negeri terutama ke Tiongkok, Singapura dan Spanyol. Untuk konsumsi lokal biasanya dipergunakan untuk membuat keripik pisang dan berbagai macam olahan lain nya. Produksi Pisang tahun 2017 ini mengalami penurunan sebesar 54,6 ribu ton dari tahun sebelumnya dikarenakan adanya penyakit yang menyerang tanaman pisang [1].

Penyakit utama yang menyerang pada tanaman Pisang antara lain adalah bercak Sigatoka, layu Fusarium, dan juga Moko. Penyakit ini dapat menyebabkan kematian pada tanaman Pisang atau menyebabkan tanaman menghasilkan buah yang buruk dan tidak layak konsumsi. Gejala penyakit pada tanaman pisang umumnya dapat diamati dari perubahan warna daunnya. Daun mengalami bercak kekuningan atau perubahan warna dari hijau menjadi kekuningan kemudian berubah menjadi coklat dan akhirnya mati. Perubahan warna daun ini tidak terjadi secara mendadak melainkan secara perlahan dan tiap penyakit memiliki pola tertentu. Jika diamati menggunakan mata manusia maka perubahan warna daun ini tidak dapat memberikan informasi secara cepat. Akan tetapi, jika menggunakan sensor visual maka informasi adanya perubahan pada daun yang mengindikasikan adanya penyakit dapat diketahui secara cepat. Penggunaan sensor visual dan metode pengolahan citra yang tepat dapat mengetahui adanya penyakit tanaman ini secara dini. Perubahan warna pada daun ini terjadi karena adanya perubahan suhu pada daun. Oleh karena itu, perlu penggunaan kamera thermal untuk dapat mengambil gambar perubahan suhu disetiap bagian daun. Hasil gambar perubahan suhu dipergunakan untuk mengetahui karakteristik masing-masing penyakit yang menyerang pada tanaman pisang.

Penelitian mengenai penyakit pada tanaman pisang telah banyak dilakukan sebelumnya. Penelitian banyak dilakukan di dalam dan di luar negeri terutama oleh Negara-negara penghasil pisang. Penelitian ini berfokus untuk mengetahui karakter pada tanaman pisang yang terpapar penyakit. citra tanaman pisang ditangkap menggunakan kamera thermal secara terjadwal. Tanaman yang diambil gambarnya berupa tanaman berpenyakit yang terlihat oleh kasat mata. Citra yang diperoleh diolah secara preprocessing untuk mendapatkan citra yang dikehendaki dimana fitur-fitur

yang akan dipergunakan dalam segmentasi lebih tampak. Setelah citra hasil preprocessing didapatkan maka dilakukan proses segmentasi menggunakan metode thresholding. Daerah-daerah yang mengalami perubahan pada daun ditentukan untuk mengetahui adanya penyakit pada tanaman atau tidak.

Efektivitas metode yang diusulkan diukur menggunakan parameter standar pendeteksian objek menggunakan pengolahan citra yaitu Recall, Precision, F-measure, dan Accuracy. Luaran penelitian ini adalah mengetahui karakteristik warna pada tanaman pisang yang terpapar penyakit

II. TINJAUAN PUSTAKA

A. Penyakit pada Tanaman Pisang

1) Penyakit Layu Fusarium (Penyakit Panama)



Gbr 1 Gejala Penyakit Layu Fusarium

Gambar 1 memperlihatkan penyakit Layu fusarium pada tanaman pisang yang disebabkan oleh jamur *Fusarium oxysporum*. Gejala yang menyolok dari layu fusarium pada awalnya adalah terjadi penguningan tepi daun pada daun-daun yang lebih tua. Gejala menguning berkembang dari daun tertua menuju ke daun termuda. Daun-daun yang terserang secara berangsur-angsur layu pada tangkainya atau lebih umum pada dasar ibu tulang daun dan menggantung ke bawah menutupi batang semu. Ratarata lapisan luar batang palsu terbelah dari permukaan tanah atau terjadi retakan memanjang pada batang semu. Pada bagian dalam apabila dibelah, terlihat garis-garis coklat atau hitam menuju ke semua arah, dari batang (bonggol) ke atas melalui jaringan pembuluh ke pangkal daun dan tangkai. Daun-daun termuda menampilkan gejala yang paling akhir dan seringkali berdiri tegak [10].

2) .Penyakit Darah(Blood Disease Bacterium).



Gbr 2 Gejala Penyakit Darah

Gambar 2 memperlihatkan penyakit darah, terlihat pada gambar Daun tanaman pisang yang terserang penyakit ini Daun menguning terkulai, buah busuk, bila disayat tampak bercak coklat kemerahan pada daging buah atau membusuk berlendir. Kelayuan menyeluruh terjadi pada tanaman muda. Pada sayatan batang atau bonggol terlihat coklat berlendir merah menyerupai darah, dan tanaman mati mengering. Bila infeksi terjadi saat keluar jantung, maka tanaman segera layu tanpa didahului penguningan daun dan buah tidak terbentuk. Serangan pada tanaman yang telah membentuk buah menyebabkan pembusukan pada buah [11].

3) Penyakit Moko



Gbr 3 Gejala Penyakit Moko

Gambar 3 memperlihatkan gambar penyakit moko, penyakit moko atau sering disebut Layu bakteri pada tanaman pisang disebabkan oleh bakteri *Pseudomonas solanacearum*. Bakteri ini menyerang akar, bonggol hingga batang pisang. Gejala awal terlihat adanya perubahan warna pada daun muda. Pada daun terdapat garis coklat kekuningan ke arah tepi daun, lama kelamaan seluruh daun menguning, berwarna coklat dan akhirnya layu. Bonggol, batang, tandan dan buah pisang yang terserang mengeluarkan lendir berbau, berwarna putih keabu-abuan hingga coklat kemerahan [12].

B. Pengolahan Citra

Pengolahan citra adalah istilah umum untuk berbagai teknik yang keberadaannya untuk memanipulasi dan memodifikasi citra dengan berbagai cara. Foto adalah contoh gambar berdimensi dua yang bisa diolah dengan mudah. Setiap foto dalam bentuk citra digital (misalnya berasal dari kamera digital) dapat diolah melalui perangkat-lunak tertentu. Sebagai contoh, apabila hasil bidikan kamera terlihat agak gelap, citra dapat diolah agar menjadi lebih terang. Dimungkinkan pula untuk memisahkan foto orang dari latar belakangnya. Jika ditinjau arti pengolahan menurut kamus besar bahasa Indonesia (KBBI) adalah suatu cara atau proses mengusahakan sesuatu supaya menjadi lain atau menjadi sempurna. Sedangkan citra berarti rupa atau gambar, dalam hal ini adalah gambar yang diperoleh menggunakan sistem visual. Secara keseluruhan pengolahan citra berarti suatu cara atau mengusahakan suatu citra agar menjadi citra yang lain yang lebih sempurna atau yang diinginkan. Dengan kata lain pengolahan citra adalah suatu proses dengan masukan citra dan menghasilkan keluaran berupa citra seperti yang dikehendaki [13].

C. Citra RGB

Sebuah warna didefinisikan dengan jumlah intensitas pokok yang terdiri dari warna pokok RGB (Red, Green and Blue) yang diperlukan untuk membuat suatu warna. Pada kondisi setiap warna piksel RGB (triplet dari warna merah, hijau dan biru), kedalaman warnanya adalah 24bit untuk 3 lapis citra dengan jumlah bit setiap lapisnya yang memiliki intensitas nilai maksimum 255 atau sama dengan 8 bit [14].

D. Akuisisi Citra

Akuisisi citra adalah tahap awal untuk mendapatkan citra digital. Tujuan akuisisi citra untuk menentukan data yang diperlukan. Tahap ini dimulai dari objek yang akan diambil gambarnya, persiapan alat-alat, dan pada pencitraannya. Pencitraan merupakan kegiatan transformasi dari citra tampak (misal: foto, gambar, lukisan) menjadi citra digital. Citra yang akan digunakan pada penelitian ini adalah citra yang diperoleh dengan menggunakan kamera Thermal. Objek yang digunakan adalah daun pisang yang difoto dengan jarak 3 meter, tinggi kamera sekitar 1,5 meter. Citra termal yang telah diperoleh akan dilakukan proses *resize resolution* sehingga memiliki ukuran 590x 590 pixel. Hal tersebut dilakukan agar citra yang diproses tidak berukuran terlalu besar, sehingga pengolahan citra dapat dilakukan sesuai dengan yang diinginkan.

E. Histogram Citra

Histogram citra merupakan diagram yang menggambarkan frekuensi setiap nilai intensitas yang muncul di seluruh piksel citra. Nilai yang besar menyatakan bahwa piksel-piksel yang mempunyai intensitas tersebut sangat banyak. Histogram disebut dengan grafik yang menunjukkan frekuensi kemunculan setiap gradasi warna, bila digambarkan pada koordinat kartesian maka sumbu X menunjukkan tingkat warna atau jumlah pixel dan sumbu Y (ordinat) menunjukkan frekuensi kemunculan atau intensitas. Histogram juga bisa menggambarkan frekuensi setiap nilai intensitas yang muncul di

seluruh piksel citra. Dalam penelitian ini manfaat histogram adalah untuk pemilihan batas ambang (threshold).

F. Segmentasi Citra

Dalam pengolahan citra, terkadang kita menginginkan pengolahan hanya pada obyek tertentu. Oleh sebab itu, perlu dilakukan proses segmentasi citra yang bertujuan untuk memisahkan antara objek (foreground) dengan background. Pada umumnya keluaran hasil segmentasi citra adalah berupa citra biner di mana objek (foreground) yang dikehendaki berwarna putih, sedangkan background yang ingin dihilangkan berwarna hitam. Sama halnya pada proses perbaikan kualitas citra, proses segmentasi citra juga bersifat eksperimental, subjektif, dan bergantung pada tujuan yang hendak dicapai. Segmentasi citra merupakan tahapan penting dalam proses pengenalan pola. Setelah objek berhasil tersegmentasi, maka kita dapat melakukan proses ekstraksi ciri citra yang merupakan tahapan yang bertujuan untuk mengekstrak ciri dari suatu objek di mana ciri tersebut digunakan untuk membedakan antara objek satu dengan objek lainnya. Pada penelitian ini segmentasi citra dilakukan untuk memisahkan obyek dengan backgroundnya. Proses pemisah bertujuan untuk memudahkan proses klasifikasi, sehingga obyek yang diinginkan pada citra dapat di kelompokkan dengan tepat dan dilakukan perhitungan dengan akurat.

G. Metode Thresholding

Metode yang digunakan dalam penelitian ini adalah Metode Thresholding. Proses thresholding merupakan teknik yang penting dalam proses segmentasi citra karena menghasilkan citra yang memiliki ukuran file kecil, pemrosesan yang cepat, dan kemudahan dalam proses manipulasi. Dalam metode thresholding, piksel dibandingkan dengan beberapa nilai ambang batas yang ditetapkan. Banyaknya nilai threshold tergantung dari banyaknya segmen citra yang diinginkan. Secara matematis proses thresholding diekspresikan menggunakan Persamaan.

$$f'(x,y) = \begin{cases} a_1 & \text{if } f(x,y) < T_1 \\ a_2 & T_1 \leq f(x,y) < T_2 \\ a_3 & \text{if } f(x,y) \geq T_2 \end{cases}$$

Dimana $f'(x, y)$ adalah intensitas baru piksel pada posisi (x, y) , a_1 nilai intensitas yang lebih rendah, a_2 nilai intensitas menengah, a_3 nilai intensitas atas, $f(x, y)$ intensitas citra lama pada posisi (x, y) , dan T_1 adalah nilai ambang bawah dan T_2 adalah nilai ambang atas yang ditentukan. Thresholding memungkinkan sebanyak n segmen yang diinginkan.

H. Pengukuran Efektifitas

Untuk mengevaluasi efektifitas dari algoritma yang digunakan dalam penelitian ini, yaitu dengan cara membandingkan antara hasil ekstraksi objek dengan frame aslinya. Perbandingan ini akan menghasilkan daerah *truepositif* (TP), *falsepositive* (FP) dan *false negative* (FN). TP merupakan daerah yang dideteksi sebagai objek dengan menggunakan metode yang digunakan. FP adalah daerah yang terdeteksi sebagai objek namun kenyataannya adalah *background*. Sedangkan FN adalah daerah yang seharusnya adalah

objek namun tidak terdeteksi sebagai objek atau terdeteksi sebagai *background*. Algoritma yang baik adalah memiliki nilai FP dan FN yang kecil [4].

Dalam pengolahan citra untuk pendeteksian objek setelah didapati data tersebut terdapat parameter penting untuk menganalisis yaitu menggunakan parameter *recall* atau disebut juga sensitifitas yang dinyatakan dalam Persamaan 2.2, *precision* (ketelitian) atau perkiraan positif yang dinyatakan dalam Persamaan 2.3, *F-measure* dinyatakan dalam Persamaan 2.4 dan Akurasi dinyatakan dalam persamaan 2.5 sebagai berikut [4].

$$recall = \frac{TP}{TP + FN} \times 100\% \quad (1)$$

$$precision = \frac{TP}{TP + FP} \times 100\% \quad (2)$$

$$F = 2 \frac{recall \times precision}{(recall + precision)} \quad (3)$$

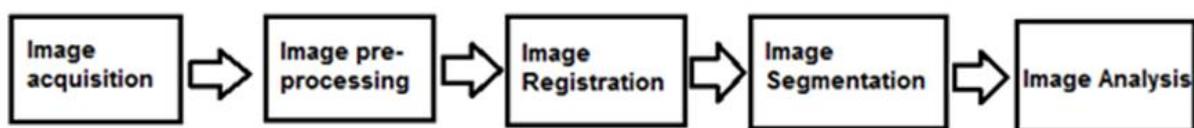
$$Akurasi = \frac{TP+TN}{TP+FP+TN+FN} \quad (4)$$

TP merupakan jumlah *pixel* pada daerah *true positive*, FN adalah jumlah *pixelfalse negatif*, dan FP merupakan jumlah *pixelfalse positive*.

III. METODELOGI PENELITIAN

A. Diagram blok metode pengolahan citra

Pengolahan data dilakukan menggunakan komputer i5 dengan memori 4GB, GPU 2GB, Windows 7 Enterprise 32 bit, dan bahasa pemrograman MatLab. Sedangkan kamera yang digunakan dalam penelitian ini adalah kamera FLIR termal. Penelitian ini menggunakan tahapan seperti yang ditunjukkan pada Gambar 4.



Gbr 4 Diagram blok metode pengolahan citra

Pada tahapan ini peneliti melakukan pengolahan data yang sudah dikumpulkan sebelumnya. Data yang diperoleh dari lapangan akan menjadi inputan pada penelitian ini, berikut tahapan data yang akan dilakukan:

A) Pengolahan Awal

Pada tahapan ini merupakan tahapan akuisasi citra dan pengolahan citra awal (*preprocessing*) dimana proses yang dapat dilakukan adalah pengaturan kecerahan, peregangan kontras, dan penghilangan derau. Hasil pengolahan citra awal ini sangat berpengaruh pada keberhasilan proses selanjutnya.

B) Pengolahan Lanjutan

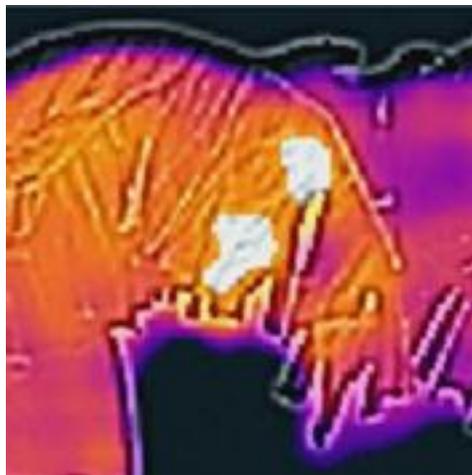
Tahap berikutnya adalah tahap cropping citra, histogram citra, segmentasi citra dan menggunakan metode thresholding untuk mengetahui daerah pada daun yang mengalami perubahan warna untuk setiap citra.

C) Tahap Analisis data Pengukuran Efektifitas (Recall, Precision & F-Measure)

Pada tahapan ini Efektivitas sistem dihitung berdasarkan parameter Recall, Precision, F-Measure, dan akurasi. Penghitungan ini menggunakan persamaan (1), (2), (3), dan (4) yang sudah di paparkan di tinjauan pustaka.

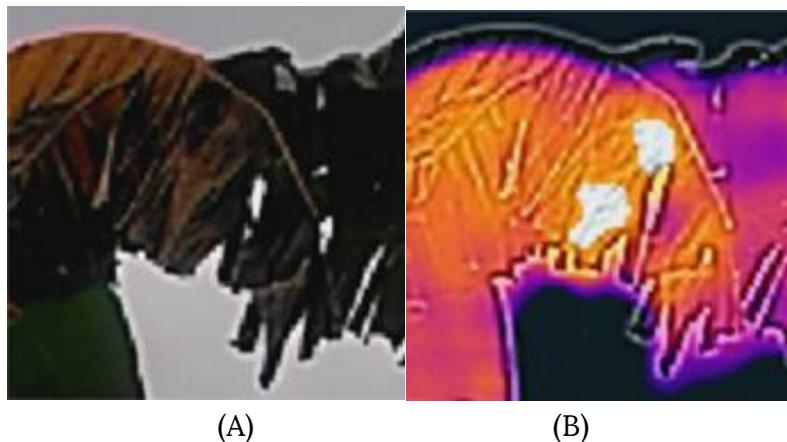
IV. HASIL DAN PEMBAHASAN

Pengambilan gambar menggunakan kamera termal didapatkan gambar yang ditunjukkan pada Gambar 5.



Gbr 5. Gambar daun pada tanaman pisang yang berpenyakit

Untuk menentukan apakah bercak daun dapat dideteksi, perlu dilakukan perbandingan dengan menggunakan gambar yang diambil dengan kamera digital. Gambar diambil pada posisi yang sama, seperti terlihat pada Gambar 6. Untuk mendapatkan posisi yang sama maka perlu dilakukan proses registrasi gambar.



Gambar 6 Gambar diambil menggunakan 6a. kamera digital dan 6b. kamera termal di posisi yang sama.

Nilai Rata-Rata Hasil Perhitungan Efektivitas

Setelah dihitung nilai efektifitas setiap sampel maka nilai rata-rata hasil perhitungan efektifitas dari 5 sampel daun pisang yang berpenyakit sebagai berikut.

$$\begin{aligned} \text{Recall} &= (76,48+ 65,46+72,86+82,18+86,30)/5 \\ &= 76,65 \% \\ \text{Precision} &= (62,70+ 22,07+60,43+57,46+89,28)/5 \\ &= 58,38 \% \\ \text{F-Measure} &= (68,91+33,02+66,07+67,63+87,77)/5 \\ &= 64,68 \% \\ \text{Accuracy} &= (68,16 +34,41+68,95+61,60+81,23)/5 \\ &= 62,87\% \end{aligned}$$

V. KESIMPULAN

Berdasarkan hasil analisis dan pembahasan dapat disimpulkan bahwa :

1. Hasil analisis diperoleh bahwa Metode Thresholding yang diusulkan cukup efektif dalam mendeteksi karakteristik daun yang berpenyakit pada tanaman pisang cukup terbukti dari nilai ambang batas yang di hasilkan bahwa intensitas daun pisang yang berpenyakit untuk nilai RGB adalah, nilai R yaitu 150-250, nilai G 30-160 dan nilai B 25-170.
2. Dari hasil pengukuran efektifitas dengan menggunakan recall, precision dan f-measure serta perhitungan Accuracy diperoleh nilai rata-rata dari 5 sampel daun pisang yang berpenyakit, Setelah di rata-rata yaitu recall mencapai 76,65%, nilai Precision 58,38%, nilai F-Measure 64,68 %, dan tingkat Accuracy mencapai 62,87%. Dari hasil diatas metode tresholding dalam mendeteksi karakteristik daun yang berpenyakit cukup efektif dengan nilai rata rata diatas 0% Serta di buktikan dengan hasil di luar citra uji.

REFERENSI

- D. Suharyati, 2017, Produksi Tanaman Sayuran Dan Buah-Buahan Provinsi Lampung Tahun 2017, BPS Provinsi Lampung.
- M. Correa, G. Hermosilla, R. Verschae, and J. Ruiz-del-Solar, "Human Detection and Identification by Robots Using Thermal and Visual Information in Domestic Environments," *J. Intell. Robot. Syst.*, vol. 66, no. 1-2, pp. 223-243, Apr. 2012.
- N. S. Jaffar, K. Ramachandran, M. R. M. Noor, T. Ab. M. Tengku Maamun, 2016, Penyakit layu bakteri pada pisang di Malaysia: Moko atau penyakit darah pisang (BDB)?, *Buletin Teknologi MARDI*, Bil. 9, pp. 31-39.
- F.X. A. Setyawan, Sulistiyanti, Sri Ratna. 2017. *Extraction of Moving Objects on Underwater Video Using Method of Subtraction the Background Modeling Results*. Electrician. Volume 11, No.2.
- M. Arif B., dkk.. 2017. *Thermal Vision pada Manusia dengan Pengaruh Terhadap Warna Pakaian*

- F. Rahayu Lestari,. dkk.. 2018. Tdeteksi Penyakit Tanaman Jeruk Siam Berdasarkan Citra Daun Menggunakan Segmentasi Warna RGB-HSV, Seminar Nasional terapan berbasis kearifan lokal (SNT2BKL) ISSN : 978-602-71928-1-2.
- Mustika Mentari,. dkk.2015.Segmentasi Penyakit Pada Citra Daun Tebu Menggunakan Fuzzy C Means – Support Vector Machine Dengan Fitur Warna, Jurnal Ilmiah Teknologi Informasi, Vol 13 No. 1, hal 45-52.
- M. Rahmad Suhartono,. Sobir,. Heri Harti. 2012. Teknologi Sehat Budidaya Pisang. Bogor: Pusat Kajian Hortikultura Tropika, LPPM-IPB.
- B. Tigadi, B. Sharma, 2016, *Banana Plant Disease Detection and Grading Using Image Processing*, *International Journal of Engineering Science and Computing*, Vol. 6, Issue 6, pp. 6512-6516.
- M. T. Habazar,. Dkk. 2012, Potensi Trigona Spp. Sebagai Agen Penyebar Bakteri Ralstonia Solanacearum Phlotipe IV Penyebab Penyakit Darah Pada Tanaman Pisang, *J. HPT Tropika*, Vol. 12, No. 1, pp. 92-101.
- N. A. Authi, S. Kadam, S. Satav, P. Bhapkar, S. Dhumal, 2018, *Image Processing based Banana Leaf recognition and recommendation using machine learning*, *IJIRMPS*, Vol. 6, Issue 6, pp. 269-271.
- N. Edy, S,. Dkk. 2011, Karakterisasi Dan Deteksi Cepat Bakteri Penyebab Penyakit Darah Pada Pisang, *Jurnal Perlindungan Tanaman Indonesia*, Vol. 17, No.1, pp. 26–30.
- Sulistiyanti, S.R., Setyawan, FX Arinto., Komarudin, Muhamad. 2016. Pengolahan Citra Dasar dan Contoh Penerapannya, Teknosain.
- A. Kadir,. A. Susanto,. 2012. Pengolahan Citra. Yogyakarta

FREQUENCY STABILITY CONTROL IN LOW - INERTIA POWER SYSTEM USING VIRTUAL SYNCHRONOUS GENERATOR

Novia Utami Putri^{1,*}, Khairudin^{1,a}, Nining Purwasih¹

^aCorresponding Author : khairudin.eng.unila.ac.id

¹Department of Electrical Engineering, Lampung University, Jalan Prof. Soemantri Brojonegoro No.1, Bandar Lampung, 35145, Indonesia

*Email: novia.utamiputri@gmail.com **Article Information**

Abstract

The stability of the electric power system is divided into transient stability, steady state stability and dynamic stability. Things that affect the performance of the generator include the addition of generators, changes in the load that vary in the system which have an impact on system stability and the distance between the generator and the load. The addition of a Virtual Synchronous Generator (VSG) is needed to improve the power system that is integrated with Renewable Energy Systems Source in maintaining system stability. When the integration between conventional generators and Renewable Energy Systems Source without Virtual Synchronous Generator (VSG) has a frequency response of 58.2 Hz when the generating capacity is -40% of the initial state, while integration between conventional generators and Renewable Energy Systems Source with Virtual Synchronous Generator (VSG) has a steady state response of 60 Hz even though the generating condition is 40% of the initial capacity of the generator. This means that the Virtual Synchronous Generator (VSG) can stabilize the return frequency in its nominal value on the system.

Keywords : Inertia, Conventional Generating, Renewable Energy Systems Source, Virtual Synchronous Generator (VSG).

I. INTRODUCTION

Things that affect generator performance include the addition of generators, variable load changes and system disturbances that have an impact on stability system^[1]. The load change must be followed by a change in the generator drive, the goal is that the frequency and voltage of the system can be maintained in a normal position, but the greater the performance of the generator reduces the inertia constant^[2]. Reducing inertia can significantly increase grid frequency deviation. Permanent deviation can result in failure of power system operation, safety, reliability and efficiency by damaging equipment, lowering load performance, overloading transmission lines and triggering protection devices^[3].

Renewable Energy Resources can help balance the needs of electricity consumers, but the network constraints connected between generators and renewable energy networks such as PLTS and PLTB result in a low total energy system so that if a

disturbance occurs it will result in oscillations at a certain frequency which can be damage the power system^[4].

Types of problems in the dynamics of electric power systems include high / low frequency oscillations, large / small disturbances and large / small systems. The electric power system must have good quality, including the frequency of the system must be considered within the tolerance limit of $\pm 1\%$. If the frequency value is within the stability limit, the quality of the power supply in the electric power system will be more optimal^[5].

Small changes in load will result in changes in frequency and angular velocity will swing around synchronous speed and the generator terminal voltage converges around its nominal voltage^[6].

Virtual Synchronous Generator (VSG) concept which operates like a synchronous generator which can help by showing the amount of inertia and damping properties of conventional synchronous generators, this virtual inertia concept maintains most of the RES (Renewable Energy Sources) in future power systems without compromising power system stability electricity. Virtual Synchronous Generator (VSG) can operate in parallel with several other VSG which are expected to maintain frequency stability in low-core middle systems^[7].

II. METHOD

The principle of the Virtual Synchronous Generator (VSG) is based on the integration of dynamic converter technology from static and dynamic operation to electromechanical characteristics. This can be represented by the VSG concept as shown in Figure 2.4. The three distinct components of VSG are a PEC (which consists of two power conversion stages, namely a DC to DC level and a DC to AC level), an energy storage device (battery, supercapacitor, flywheel, etc.) and a control scheme that controls the exchange of power between energy storage and power systems. This power exchange supports system power by preventing frequency fluctuations similar to rotational inertia SGs^[8]. VSG is usually placed between the Distributed Generator (or DC source) and the grid^[9]. The DC source leading to the VSG algorithm performs the Synchronous Generator (SG) function by providing inertia and damping that supports the grid system.

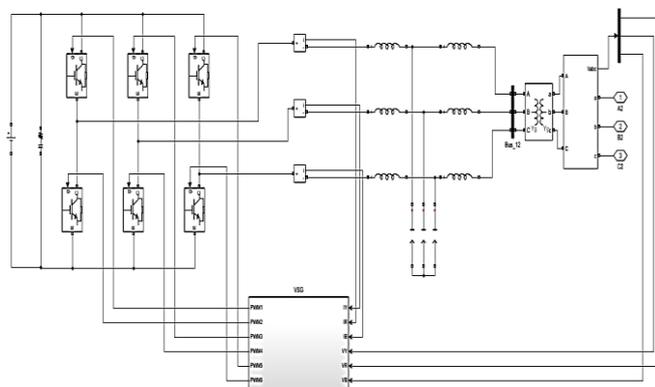


Fig 1. Virtual Synchronous Generator (VSG) modeling at Renewable Energy Systems Source

In a generator, the load is basically an electrical load. If the load is referred to as torque, the torque can be interpreted as electric torque while the power that comes out or rises from the generator can be interpreted as mechanical torque. In the operation of the generator in constant conditions, the value of the mechanical torque will be the same as the value of the electric torque^[10]. The basic principle of synchronous machine rotor rotation equations is that the moment of rotational acceleration (accelerating torque) is the product of the moment of inertia J (moment of inertia) of the rotor with the angular acceleration it has $\frac{d^2\theta_m}{dt^2}$, rotor dynamic differential equation^[11]:

The electric rotational speed in relation to the mechanical rotational speed is $\omega_{sm} = \frac{P}{2}\omega_s$ so that equation as follow :

$$\frac{2H}{\omega_s} \cdot \frac{d^2\delta}{dt^2} = P_m - P_e (pu) \quad (1)$$

By substituting $\omega = 2\pi f$ into equation will be obtained^[12]

$$\frac{H}{\pi f} \cdot \frac{d^2\delta}{dt^2} = P_m - P_e (pu) \quad (2)$$

Equation is called the swing equation which is the basic equation that regulates the dynamics (motion) of synchronous engine rotation in stability studies^[13]. Changes in the value of generating capacity against fixed loads are assumed to be -20%, -30%, and -40% of the initial capacity, namely $P_1 = 192$ MVA, $P_2 = 128$ MVA, $P_3 = 247.5$ MVA causes resonance frequency and affects the stability of the system^[14]. The load and power equation in this study has different variations, represented as the following equation

$$\Delta P_{in,g} - \Delta P_{out,g} = M_g(d\Delta\omega_g/dt) \quad (3)$$

Assumed $H_{gov,g}(s)$ is a representation of the governor function, then equation becomes,

$$-H_{gov,g}(s)\Delta\omega_g - \Delta P_g = M_g s \Delta\omega_g \quad (4)$$

And

$$G_{P\omega,g}(s) = \frac{\Delta\omega_g}{\Delta P_g} = - \frac{1}{M_g s + H_{gov,g}(s)} \quad (5)$$

In order to get the results of expansion $H_{gov,g}(s)$ simplified to be

$H_{gov,g}(s) = K_g/(1 + sT_g)$, then obtained,

$$G_{P\omega,g}(s) = - \frac{T_g s + 1}{M_g T_g s^2 + M_g s + K_g} \quad (6)$$

From equation it can be explained that resonance occurs if the load power fluctuates in frequency if the frequency exceeds the tolerance limit, then a Virtual Synchronous Generator (VSG) is needed to overcome the resonance that occurs, the Virtual Synchronous Generator (VSG) equation can be obtained by determining $T_{vsg} = 0$ then the equation becomes,

$$G_{P\omega,g}(s) = - \frac{1}{M_{vsg}s + K_{vsg}} \quad (7)$$

Due $G_{P\omega,g}(s)$ does not have frequency resonance, because of this the Virtual Synchronous Generator (VSG) can avoid unnecessary interference between generators running parallel, therefore the relationship of the equation $\Delta P_{vsg} + \Delta P_g = \Delta P_L$ diperoleh ΔP_{vsg} and ΔP_g as follows,

$$\left\{ \begin{array}{l} \Delta P_{vsg} = \frac{P'_{vsg} P'_{g}}{P'_{vsg} + P'_{g}} \frac{\omega_0(\Delta\omega_{vsg} - \Delta\omega_g)}{s} + \frac{P'_{vsg}}{P'_{vsg} + P'_{g}} \Delta P_L \\ \Delta P_g = \frac{P'_{vsg} P'_{g}}{P'_{vsg} + P'_{g}} \frac{\omega_0(\Delta\omega_g - \Delta\omega_{vsg})}{s} + \frac{P'_{g}}{P'_{vsg} + P'_{g}} \Delta P_L \end{array} \right\} \quad (8)$$

ΔP_L pu to the frequency deviation $\Delta\omega$ pu is derived from Figure 2 and expressed as shown at the bottom of this page.

$$G_{PL \rightarrow \omega r}(s) = \frac{\Delta\omega_r \text{ pu}}{\Delta P_L \text{ pu}} = \frac{-R(1+sT_G) + (1+sT_{RH})(1+sT_{RH})}{(2H_s + D)(1+sT_G)(1+sT_{RH}) R + sF_{HP} T_{RH} + 1} \quad (9)$$

III. RESULTS AND DISCUSSION

This study tested 4 different parameter conditions, namely initial conditions, 20% conditions, 30% conditions, 40% conditions of the network, this study are shown as in figure 2 and figure 3.

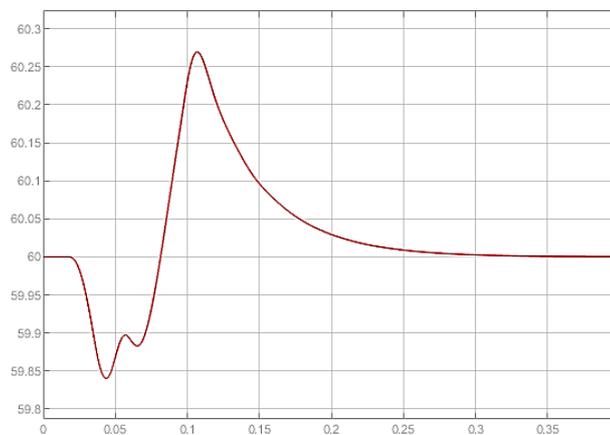


Fig. 2. Initial Response to the IEEE 9 BUS System

In Figure 2, the frequency fluctuation of 60.27 Hz occurs due to the effect of load and capacity differences between generators, because the system has the same frequency of 60 Hz and the load is sufficient does not affect the system significantly

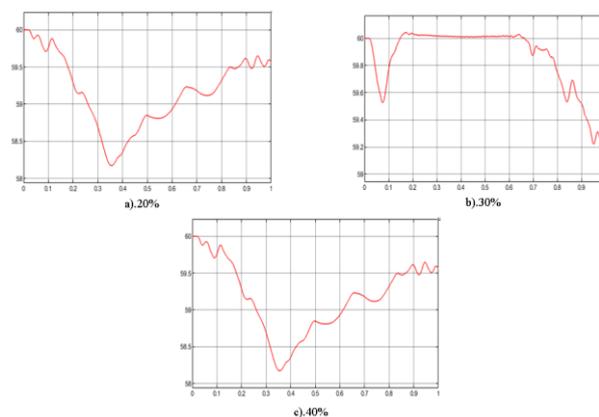


Fig 3. Frequency Response of Integrated IEEE 9 BUS Renewable Energy Systems Source without Virtual Synchronous Generator (VSG), a). Condition 1, b). Condition 2, c). Condition 3

The addition of Renewable Energy Systems Source without Virtual Synchronous Generator (VSG) control causes significant frequency oscillations with time, seen in

Figure 3 part (a) shows the change in frequency due to condition 1, namely -20% oscillations occur in realtime and continue the highest value reaches 58.53 Hz for 1 second from the frequency it should be, (b) the change in frequency due to condition 2, namely -30% also experiences the same thing as the graph (a) occurs in real time and continues the highest deviation of 59.1 Hz for 1 second, (c) changes in frequency due to conditions 3 ie -40% reaches the highest point of 58.2 for 1 second and changes in real time and continuously. The three graphs are triggered by the state of a conventional generator coupled with a Renewable Energy Systems Source without a Virtual Synchronous Generator (VSG) which causes system instability in addition to changes in generating capacity of -20%, -30%, and -40% from the initial state, has an effect to frequency oscillations, with reduced generating capacity the power supply to the load decreases and this can cause a voltage drop.

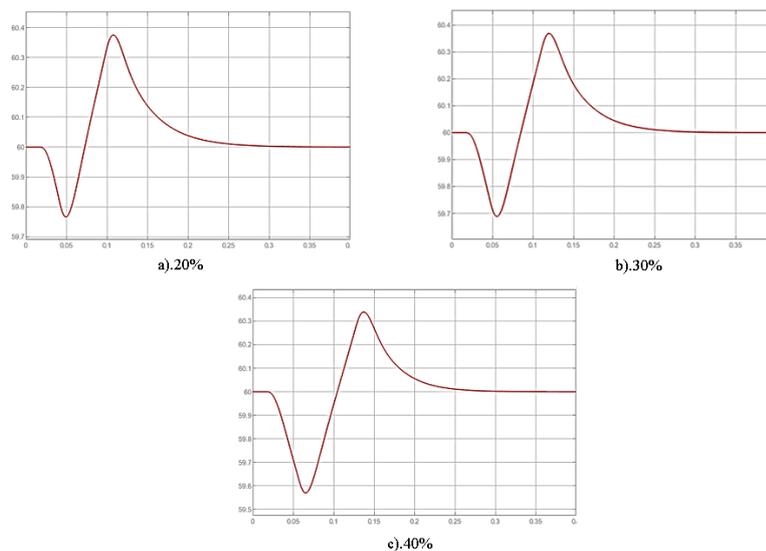


Fig 4. Frequency Response of Integrated IEEE 9 BUS System Renewable Energy Systems Source with Virtual Synchronous Generator (VSG) a). Condition 1, b). Condition 2, c). Condition 3

The addition of the Virtual Synchronous Generator (VSG) aims to control the frequency oscillations that occur due to the addition of Renewable Energy Systems Source, Renewable Energy Systems Source does not have inertia, so it is necessary to control the Virtual Synchronous Generator (VSG) so that it can be properly integrated. Virtual Synchronous Generator (VSG) control seems to make Renewable Energy Systems Source have artificial inertia. Judging from Figure 4 the frequency response after the addition of Virtual Synchronous Generator (VSG), graph (a) shows that after condition 1 occurs, which is -20% and experiences the lowest deviation of 59.78 Hz, overshoot reaches 60.38 Hz and returns stable 0.3 seconds takes place, (b) the frequency response of the condition 2, namely -30% experiencing the same effect and the lowest deviation reaches 59.69 Hz, 60.38Hz overshoot returns to stability after 0.3 seconds, (c) the frequency response of condition 3 is -40% experiencing the lowest deviation reaching 59.58 Hz overshoot 60.32 Hz. From the three graphs, changes in generating capacity have an effect on system stability due to the lack of power supply capacity to the load,

but the addition of a Virtual Synchronous Generator (VSG) at Renewable Energy Systems Source can maintain system stability over time.

IV. CONCLUSION

Virtual synchronous generator can change the nature of Renewable Energy Systems Source which is based on power electronics to make it appear as if there is a synchronous generator by controlling the inverter through the switching process in PWM (pulse width modulation).

The Virtual Synchronous Generator (VSG) is able to return a nominal frequency value of 60 Hz when there is a power drop of 20%, 30% and 40% of the network when a conventional generator is integrated with Renewable Energy Systems Source.

REFERENCES

- Nor Shahida Hasan, Norzanah Rosmin, Nor Julia Mohd Nordin, Aede Hatibc Mustaamal, Siti Maherah Husin, Apripriharta, Ira Devi Sara, "Virtual Inertia Support For Wind Turbine System," Indonesian Journal of Electrical Engineering and Computer Science, 2020.
- Mohammed, O.O, A. O. Otuoze, S. Salisu, O. Ibrahim dan N. A. Rufa'I, "Virtual Synchronous Generator: An Overview." Nigerian Journal of Technology (NIJOTECH), Vol. 38, No. 1, pp. 153 – 164. 2019.
- Padiyar, K.R, "Power System Dynamic Second Edition," Indian Institute of Science, Bangalore, 2008.
- Lu, Nanjun, Jingyang Fang, Yi Tang and Branislav. Hredzak, "A Frequency Deadband-Based Virtual Inertia Control for Grid-Connected Power Converters," IEEE Transactions on Industrial Electronics, 2017.
- Bevrani, Hassan and Jorg Raisch, "On Virtual inertia Application in Power Grid Frequency Control," International Conference on Power and Energy Systems Engineering, 2017 Saadat, Hadi, "Power System Analysis," New York: McGraw-Hill, 1999.
- Liu J, Yushi Miura and Toshifumi Ise, "Comparison of Dynamic Characteristics between Virtual Synchronous Generator and Droop Control in Inverter-Based Distributed Generators," IEEE Transactions on Power Electronics, 2015.
- Kamdar, Renuka etc, "Transient Stability Analysis and Enhancement of IEEE-9 Bus System," Electrical & Computer Engineering: An International Journal (ECIJ) Volume 3, Number 2, India, 2014.
- Kundur, Prabha, "Power System Stability and Control," New York: McGraw-Hill Book, 1993.
- Jingyang, Hongchang Li, Yi Tang, Frede Blaabreg, "Distributed Power System Virtual Inertia Implemented by Grid-Connected Power Converters," IEEE Transactions On Power Electronics, Vol. 33, No. 10, 2018.
- Rahman, Rifai Hasan, "Analisis Pengaruh Pemasangan Kompensator Seri Terhadap Stabilitas Sistem SMIB dan Sistem IEEE 14 Bus," Universitas Diponegoro, 2008.

- D' Arco, Salvatore dan Jon Are Suul, “ *Equivalence of Virtual Synchronous Machines and Frequency-Droops for Converter-Based MicroGrids*”,IEEE TransSmart Grid,vol.5,no.1,pp.394-395, 2014.
- Grainger, Jhon J & Stevenson, William., “*Power System Analysis*,”Singapore: McGraw-Hill, Inc., 1994.
- Ahammad, Fakir Uddin Ali dan Mandal Sharmistha, “*Robust Load Frequency Control in Multi Area Power System An LMI Approach*,” IEEE First International Conference On Control, Measurement and Instrumentation (CMI), 2016.

GREEN BUILDING ASSESSMENT AND RECOMMENDATIONS FOR OPTIMIZATION CASE STUDY OF THE RECTORATE BUILDING UNIVERSITY OF LAMPUNG

Nur Syahidah Aini^{1,a}, Ika Kustiani¹, Masdar Helmi¹, Ratna Widayawati¹,
Endro P. Wahono¹

¹Civil Engineering Department the University of Lampung
Jl. S. Brojonegoro No. 1 Bandarlampung, Indonesia 35145

Abstract

Constructional working has the potential to generate carbon emissions of more than 40% which can cause global warming on the planet. This phenomenon can be averted by using a concept that pays attention to the environmental conditions called the concept of green building. Recently, the University of Lampung has implemented this concept to its building. Therefore, it is necessary to conduct research related to this implementation. The Rectorate Building of the University of Lampung was chosen as the research location because the building served as the University's academic and administrative center. The research objectives are to identify and to make an inventory of the building based on the green building standard. This study also aims to analyze the requirements and feasibility of the building using the Greenship assessment tool. The output of this research is to provide recommendations so that the Rectorate Building of the University of Lampung can meet the standard criteria for green building. The analysis was carried out using direct observation, on-site measurements, questionnaires, interviews, and also using secondary data analysis based on the Greenship Rating Tools for Existing Building Version 1.1 assessment tool. The results of the study show that the building has not meet the required criteria of a green building, so recommendations are needed to complement the missing point of the criteria.

Keywords: Green Building, Greenship Existing Building 1.1., recommendation

1. Introduction

Based on data compiled by the Central Statistics Agency in 2020, every year, there is an increase in the demand for buildings caused by the Indonesian population growth rate of 1.25% per year. This development can produce carbon gas emissions of more than 40% which will have an impact on environmental quality and can cause global warming (Ervianto, 2012).

Global warming and environmental destruction are phenomena that have occurred not only in Indonesia, but also throughout the world. In order to prevent this phenomenon, a concept that takes into account environmental conditions is needed when construction work is carried out. This concept is referred to as a green building or green building (Post The President, 2013).

According to Hong and Minfang (2011) Green buildings or green buildings are buildings that are effective in the utilization of space, energy saving, protecting the environment, reducing pollutants produced as well as maintaining the health of the environment. A building is said to have applied the concept of Green building or green building if it has gone through the evaluation process of assessment benchmarks or rating system named greenship (GBCI, 2016).

According to Hildegradis (2013) the largest energy consumption comes from educational buildings. Educational buildings are a construction sector that consumes 72% of electrical energy and emits 39% of carbon emissions. Research on green building in several educational buildings is conducted by means of observation, interview and measurement using greenship assessment benchmarks (Putri et al., 2012; God et al., 2016).

Universitas Lampung is one of the campuses in Indonesia that plays an active role in implementing the green development movement. One of them is by establishing a Center for Research and Development of Sustainable Development Goals or UNILA SDGs Center in 2019 to realize sustainable development goals by applying the concept of Green Building in University of Lampung.

According to Haritsah (2015) the Rectorate Building is a central building of academic and administrative in university which important in the development of the university because in this building all campus activities are planned, directed, and controlled by campus management within an academic. Therefore, researchers made the Rectorate Building of Lampung University as the object of research that will be studied related to conformity to green building criteria according to greenship assessment tools.

The study of the green building implementation in the Rectorate building of Lampung University was analyzed according to greenship assessment devices that were adjusted to the standards of the Green Building Council Indonesia (GBCI). The Rectorate Building of Lampung University has been operating for 26 years, so the GBCI Rating Tools used is Green Building for Existing Building v1.1.

The purpose of the research is to identify and to make an inventory of the Rectorate Building of Lampung University based on Green Building criteria and also to analyze the terms and eligibility of the building using Greenship assessment tools. The output of this study is to provide recommendations so that the Rectorate Building of Lampung University can meet the standard criteria for green building.

2. Materials and Methods

2.1. Research Variables

In the conducted study, variables used are the green building category based on the rating system in the Greenship Assessment Device for old building Version 1.1. The variables contain 6 (six) feasibility tests and selected sub-criteria from general variables that refer to the national certification body, the Green Building Council Indonesia (GBCI), namely Appropriate Site Development (ASD), Energy Efficiency & Refrigerant (EEC), Water Conservation (WAC), Material Resources & Cycle (MRC), Indoor Air Health & Comfort (IHC) and Building & Environment Management (BEM).

2.2. Research Instruments

Research instruments to be used in research at the Rectorate Building of Lampung University are:

1) Literature Studies

The literature needed for the preparation of this study consists of:

- a. Greenship Assessment Device for Old Buildings Version 1.1 (Greenship Rating Tools for Existing Building Version 1.1)
- b. Regulations and research journals related to the criteria stated in greenship rating tools such as Permendagri, Ministerial Regulation of Public Works, SNI, and ASHRAE Standards

2) Direct Observation or Observation

Direct observation data (observation) is obtained from the building eligibility checklist form and Greenship prerequisite category, criteria category and Greenship bonus.

3) Research Equipment

In this study, research equipment was used to assist researchers in retrieving the primary data. Primary data taken in the room accordance to the provisions of the Greenship Rating Tools for Existing Building Version 1.1 form, or room that has the most dominant occupant activity. The equipments used are: Air Quality Monitor, Sound Level Meter, Thermo-hygrometer, Lux Digital Meter and Laser Distance Measure.

4) Interview

the interviewees on this study are the building household staff in order to find out information related to maintenance and operation of the building. The information obtained must be supported by formal documents.

5) Questionnaires

Questionnaires are used to facilitate in conducting surveys related to the number of building users, including the cleanliness of the building, temperature and sound level, room lighting level and the presence of pest control. Selected respondents are at least 30% of the total building users.

2.3. Data Processing and Calculation

After obtaining points from each criterion, the number of accumulated points can be calculated by the following equation:

$$\sum \text{actual point} = \text{ASD} + \text{EEC} + \text{WAC} + \text{MRC} + \text{IHC} + \text{BEM} \quad (1)$$

Keterangan:

\sum Actual Point	= total points of all criteria.
ASD	= Appropriate Site Development criteria total points
EEC	= Energy Efficiency and Conservation criteria total points
WAC	= Water Conservation criteria total points
MRC	= Material Resource and Cycle criteria total points
IHC	= Indoor Health and Comfort criteria total points
BEM	= Building Environmental Manajement criteria total points

After the actual point value has been obtained, we can determine what type of Green Building rank achieved. There are four levels of Green Building ranking based on Greenship, namely Platinum with 74 Points, Gold with 58 Points, Silver with 47 Points and Bronze with 35 Points.

3. Results and Discussion

3.1. measurements

Testing using research equipment is taken in the room in accordance to the provisions of the *Greenship Rating Tools for Existing Building Version 1.1 form* or the room that has the most dominant occupant activity. The equipments used are Air Quality Monitor, Sound Level Meter, Thermo-hygrometer, Lux Digital Meter and Laser Distance Measure from September 15 to 24, 2021. Here are the test results conducted:

3.1.1. Air Quality Measurement

Table 1. Results on air quality measurement

Floor	Room	HCHO		VOC	
1	Main Lobby	0.005	0.001	0.005	0.027
	Bureau of Academic and Student Affairs	0.039	0.026	0.177	0.038
2	Vice Chancellor of Student Affairs and Alumni	0.001	0.015	0.003	0.003
	Vice Chancellor of Academic Affairs	0.001	0.013	0.005	0.006
	Department of Finance	0.019	0.017	0.088	0.008
3	Bureau of Planning and Human Resources	0.001	0.001	0.127	0.127
	Department of Personnel	0.019	0.011	0.05	0.101
4	SDG's	0.03	0.001	0.002	0.008
	Meeting Room	0.001	0.002	0.008	0.076
5	Research and Community Service: Head	0.001	0.005	0.005	0.003
	Research and community service: Secretary	0.001	0.013	0.002	0.005
	Research and community service: Data and Information	0.011	0.019	0.008	0.003
Air Quality Average Score		0.0105		0.036875	

Data on Air Quality Measurement Results in the Rectorate Building of Lampung University obtained levels of Volatile Organic Compound (VOC) and Formaldehyde (HCHO) below the maximum concentration allowed. Then it gets the maximum value, which is 2 (two) points.

3.1.2. Thermal comfort measurement

Table 2. Results on thermal comfort measurement

Floor	Room	Morning Measurement	
		Temperature (°C)	Humidity (%)
1	Main Lobby	26.9	66
	Bureau of Academic and Student Affairs	29.3	56
	Sub-department of House hold	25	57
	Sub-department of Government Own Properties	27.3	64
	Administration and Protocol	29.4	66
2	Vice Chancellor of Student Affairs and Alumni	27.2	66
	Vice Chancellor of Academic Affairs	27.6	63
	Vice Chancellor of Planning, Cooperation and Information & Communication Technology	28.5	68
	Department of Finance	25.9	69
	Staff of Vice Chancellor of Academic Affairs	26.3	65
3	Bureau of Planning	27.3	53
	Cooperation and International Services Development	27.7	68
	Department of Personnel	25.9	69
4	Educational Development and Quality Assurance	26.9	52
	SDG's	26.8	61
	Meeting Room	27.8	63
	Foundation Year Course	27.5	61
5	Research and Community Service: Head	26.9	63
	Research and community service: Secretary	29.3	67
	Research and community service: Data and Information	31.8	27
	Research and community service: Meeting Room	28.3	61
Thermal Average Score		27.6	61.2

Based on Indonesian National Standard 6390:2011: on Energy Conservation of Building Air System, the thermal condition of the room is generally declared appropriate if it has a temperature of 24 ° C - 27 ° C and relative humidity of 60% ± 5%. Based on the thermal measurements of the Rectorate Building of the University of Lampung in table 4.10, the average temperature is 27.6 ° C and relative humidity is 61.19%. Therefore, for this criterion, the Rectorate Building of Lampung University does not earn points.

3.1.3. Visual comfort

Table 3. Results on visual comfort measurement

Floor	Room	Lighting Measurement (Lux) - Morning
1	Main Lobby	328
	Bureau of Academic and Student Affairs	239
	Sub-department of House hold	203
	Sub-department of Government Own Properties	142
	Administration and Protocol	328
2	Vice Chancellor of Student Affairs and Alumni	259
	Vice Chancellor of Academic Affairs	314
	Vice Chancellor of Planning, Cooperation and Information & Communication Technology	288
	Department of Finance	107
	Staff of Vice Chancellor of Academic Affairs	176
3	Bureau of Planning	305
	Cooperation and International Services Development	144
	Department of Personnel	192
4	Educational Development and Quality Assurance	172
	SDG's	241
	Meeting Room	336
	Foundation Year Course	173
5	Research and Community Service: Head	315
	Research and community service: Secretary	234
	Research and community service: Data and Information	308
	Research and community service: Meeting Room	259
Lighting Average Score		241

In accordance to SNI 03-6197-2000 Table 4.15, the average lighting level allowed for the Office area is between 150-350 lux. Meanwhile, for lighting conditions in the rectorate building of the university lampung after the measurement, obtained an average lighting value of 241 lux. Thus, for this criterion the building earns 1 (one) point.

3.1.4. Noise Level

Table 4. Results on visual comfort measurement

Floor	Ruangan	Noise Level Measurement (dB) - Morning				
		Location				
		1	2	3	4	5
1	Bureau of Academic and Student Affairs	51.1	60,0	65.9	67.4	59.3
3	Deoartment of Personnel	54.8	52.1	54.4	52.4	52.7
5	Research and Community Service: Head	48.5	52.3	42.3	46.7	53.1
Average Noise Level		54.2				
Minimum Noise Level		40				
Maximum Noise Level		45				

Based on the Decree of the Minister of Environment No. 48 of 1996, the noise level for the office was set at 65 dB (<65 dB). From the samples taken, some rooms had noise

values above the allowed number. Therefore, for the noise level criteria, the Rectorate Building of Lampung University does not earn points.

3.2. Determination of Greenship Predicate Level

All assessments are then tabulated into the Greenship Matrix rating tools for existing building version 1.1. Furthermore, the final assessment stage (FA), with a maximum value of 117 points.

Based on the assessment of the Rectorate Building of Lampung University does not qualify even for the lowest Green Building category. The minimum points to obtain bronze rank were 35, while rectorate building points were only awarded 23 points.

3.3. Evaluation and Recommendations

According to the analysis and observations that have been done at the Rectorate Building of Lampung University, several recommendations can be given that make the building get points according to the ranking level. The followings are recommended to achieve bronze ratings that can be applied for the first year

Table 5. Evaluation and Recommendations

Code	Criterion	Recommendations	Points
ASD 4	Heat Island Effect	Using materials that has average albedo value at least 0.3 in accordance with the calculations on the roof and non-roof areas of buildings covered by pavement	2
ASD 6	Site Management	Creating and implementing Operational Control Standards (SPO) against disease pests and plant weeds by using non-toxic ingredients.	1
EEC 5	Implementations and Maintenance	a) Guidance on the operation and maintenance of all AC system (chiller, Air Handling Unit, Cooling Tower) b) Guide the regular operation and maintenance of all other equipment systems (in-building transportation systems, clean and dirty water distribution systems (pumps) and backup power plants c) making monthly reports minimum for the last 6 months of the maintenance and operation of building systems in an orderly manner in accordance with the format set out in the operating and maintenance guidelines.	3
WAC 2	Water Control	Make standard operating procedures and their implementation regarding the maintenance and inspection of plumbing systems periodically to prevent leakage and waste of water	2
MRC 1	Non-ODS Use	Using cleaning materials that have a small Ozone Depleting Potential (ODP) value, <1.	1
MRC 3	Waste Management	Campaigning for efforts to reduce packaging waste made from Styrofoam and non-foodgradeplastic.	1
BEM 3	Environment-Friendly Maintenance and Operations Team	a) There is an integrated structure in the operational structure and maintenance of the building that is tasked with maintaining the implementation of sustainability / green building principles. b) Minimum involved a Greenship Professional in operational and maintenance working full time (fulltime)	2

BEM 4	Green Contract	Have SPO and Training that includes efforts to meet the criteria in greenship for existing building minimum 1 rating in each category ASD, EEC, WAC, IHC and MRC.	2
		SUBTOTAL	14

4. Conclusion

From the results of this study, can be concluded that:

- 1) The value / points for implementing Green Building at the University of Lampung Rectorate Building is 23 points out of a maximum of 117 points. Based on this assessment, the University of Lampung Rectorate Building does not meet the requirements even for the lowest Green Building category, namely Bronze rank with a minimum of 35 points. Therefore, this building cannot be categorized as a building that has a Green Building concept.
- 2) The implementation of technical recommendations will increase the rating of the Rectorate Building of The University of Lampung so that the building can obtain bronze level with a total value of 37points.
- 3) Measurements of lighting, noise, temperature and humidity of the room are carried out by researchers during the rainy season. It is expected that in the next study, measurements are carried out on two seasons in Indonesia which in rainy season and dry season.

Acknowledgements

Acknowledgments are conveyed to the Office of Research and Community Service, the University of Lampung for the funding of this research.

References

- Darmanto, D. dan Wiguna, I. P. A. 2013. Penilaian Kriteria Green Building Pada Gedung Teknik Sipil ITS. *Jurnal Teknik POMITS*, 2(2), 183-190.
- Dewa, B. P., Nugroho, P. A. M., dan Adhitama, M.S. 2016. Kajian Green Building pada Gedung Dekanat Fakultas Teknik Universitas Brawijaya. *Jurnal Teknik ITS* Vol. 4, No. 2.
- Ervianto, W. I. 2012. *Selamatkan Bumi Melalui Konstruksi Hijau*. Penerbit Andi, Yogyakarta.
- Gulo, W. 2000. *Metodologi Penelitian*. PT Grasindo Anggota IKAPI, Jakarta.
- Gupta, A. 2013. Green Building and Productivity. *International Journal of Emerging Trends in Engineering and Development*. Issue 3. Vol. 2: 179184
- Hong, G. and Minfang, S. 2011. Green Construction in Real Estate Development in China. *Energy Procedia*, Vol.13 : 2631-2637.
- Pemerintah Kota Bandar Lampung. 2011. *Perda Kota Bandar Lampung Nomor 10 Tahun 2011 Tentang Rencana Tata Ruang Wilayah Tahun 2011-2030*. Bandar Lampung : Bandar Lampung.
- Putri, A. A., Rohman, M. A., dan Utomo, C. 2012. Penilaian Kriteria Green Building pada Gedung Teknik Sipil ITS. *Jurnal Teknik ITS* Vol. 1, No. 1.
- Sulistiyanto, T. 2011. Green Building Tidak Bisa Dilihat Dari Fisik Bangunan. *Majalah Techno Konstruksi*, hal 12.

BENEFIT ANALYSIS OF APPLICATION OF RAINWATER HARVESTING IN DUCK FARMING BUSINESS IN TERBANGGI BESAR-CENTRAL LAMPUNG

PUJI TRI ANDIKA¹ ENDRO P. WAHONO² DYAH INDRIANA KUSUMASTUTI³

Universitas Lampung
Email : puji3andika@gmail.com

ABSTRACT

Rainwater is a natural resource that has not been utilized optimally and is only allowed to flow into drainage channels. into rivers that eventually flow into the sea. In fact, if it can be processed and managed properly, the rainwater will have many benefits for the survival of living things. Utilization of rainwater can also be used as an alternative to drinking water on duck farms. To use rainwater as an alternative to drinking water on duck farms, a system called rainwater harvesting is needed. In this study, the data used are secondary data issued by an agency and primary data obtained through direct surveys. Based on the calculation analysis, the results show that the potential for rainwater in Karang Endah for the use of drinking water for ducks has great potential. In one period, with a capacity of 100 heads, 36.000 liters are needed, which can be met by 36.000 liters by harvesting rainwater. In the analysis of the benefits of laying ducks with a population of 100 individuals in a period days, the profit is Rp. 14.799.536,155,-

Keyword: benefit analysis, rain water harvesting, duck farm

ABSTRAK

Air hujan merupakan salah satu sumber daya alam yang selama ini belum termanfaatkan secara optimal dan hanya dibiarkan mengalir ke saluran-saluran drainase. menuju ke sungai-sungai yang akhirnya mengalir ke laut. Padahal jika mampu diolah dan dikelola dengan baik, air hujan tersebut akan memiliki banyak manfaat bagi keberlangsungan makhluk hidup. Pemanfaatan air hujan juga dapat dimanfaatkan sebagai alternatif penggunaan air minum pada peternakan itik. Untuk memanfaatkan air hujan sebagai alternative penggunaan air minum pada peternakan itik dibutuhkan sistem yang disebut dengan pemanenan air hujan (*Rain Water Harvesting*). Pada penelitian ini data yang digunakan yakni data sekunder yang dikeluarkan oleh suatu badan dan data primer yang diperoleh melalui survey langsung. Berdasarkan analisis perhitungan yang diperoleh hasil bahwa potensi air hujan di Karang Endah untuk pemanfaatan air minum itik berpotensi besar. Dalam satu periode dengan kapasitas 100 ekor memerlukan 36.000 liter, yang dapat dipenuhi seluruhnya dengan pemanenan air hujan. Pada analisis benefit peternakan itik petelur dengan populasi 100 ekor dalam satu periode hari mendapatkan keuntungan sebesar Rp 14.799.536,155,-

Kata kunci: analisis benefit, pemanenan air hujan, peternakan itik

1. PENDAHULUAN

1.1 Latar Belakang

Desa Karang Endah, Kecamatan Terbanggi Besar, Kabupaten Lampung Tengah adalah sentra peternakan unggas terutama itik di Provinsi Lampung. Desa Karang Endah terletak sekitar 2 km dari Bandar Jaya, salah satu pusat perekonomian di Lampung Tengah. Desa Karang Endah merupakan tempat yang strategis untuk budidaya ternak itik karena masih banyak lahan persawahan yang merupakan sumber pangan itik dan lahan untuk dibuat kandang itik. Menurut (Arianti, 2009) Unggas jenis itik adalah unggas dengan kebutuhan air tinggi terutama air yang digunakan untuk minum. Konsumsi air minum pada itik berkisar 408,05 - 427,94 ml/ekor/hari Air hujan merupakan salah satu sumber daya alam yang selama ini belum termanfaatkan secara optimal dan hanya dibiarkan mengalir ke saluran-saluran drainase menuju ke sungai-sungai yang akhirnya mengalir ke laut. Padahal jika mampu diolah dan dikelola dengan baik, air hujan tersebut akan memiliki banyak manfaat bagi keberlangsungan makhluk hidup.

Menurut (Yulistyorini, 2011) Pemanfaatan air hujan juga dapat dimanfaatkan sebagai alternatif penggunaan air minum pada peternakan itik. Untuk memanfaatkan air hujan sebagai alternative penggunaan air minum pada peternakan itik dibutuhkan sistem yang disebut dengan pemanenan air hujan (Rain Water Harvesting). Teknik pemanenan air hujan atau disebut juga dengan istilah rain water harvesting didefinisikan sebagai suatu cara pengumpulan atau penampungan air hujan atau aliran permukaan pada saat curah hujan tinggi untuk selanjutnya digunakan pada waktu air hujan rendah (Harsoyo, 2010). Berdasarkan (UNEP International Technology Centre, 2001) Pemanenan air hujan (PAH) merupakan metode atau teknologi yang digunakan untuk mengumpulkan air hujan yang berasal dari atap bangunan, permukaan tanah, jalan atau perbukitan batu dan dimanfaatkan sebagai salah satu sumber suplai air bersih.

Menurut (Yan Zhang, Donghui Chen, Liang Chen, 2009). Pemanenan air hujan (PAH) dengan memanfaatkan atap bangunan umumnya merupakan alternatif dalam memperoleh sumber air bersih yang membutuhkan sedikit pengolahan sebelum digunakan untuk keperluan manusia. Penggunaan air hujan sebagai salah satu alternatif sumber air sangat potensial untuk diterapkan di Indonesia mengingat Indonesia adalah negara tropis yang mempunyai curah hujan yang tinggi. Lampung Tengah merupakan salah satu daerah yang memiliki musim panas dan musim penghujan yang datang setiap tahun. Namun, pada saat ini potensi pemanfaatan air hujan untuk menambah keuntungan bagi peternak itik belum dikelola secara maksimal. Oleh karena itu penelitian untuk mengetahui potensi pemanfaatan air hujan untuk menambah keuntungan bagi peternak itik di Desa Karang Endah adalah penting untuk dilakukan.

1.2 Tujuan Penelitian

Adapun tujuan dari penelitian ini sebagai berikut :

1. Menganalisis prosedur pemanfaatan air bersih pada peternakan itik petelur di Desa Karang Endah
2. Menganalisis besaran potensi air hujan sebagai air bersih pada peternakan itik di Desa Karang Endah

3. Menganalisis aspek biaya dan lingkungan penerapan pemanenan air hujan untuk peternak itik di Desa Karang Endah

2. METODE

2.1 Studi Literature

Studi literatur adalah kegiatan melakukan pencarian terhadap berbagai sumber tertulis, baik berupa buku-buku, arsip, majalah, artikel, dan jurnal, atau dokumen-dokumen yang relevan dengan masalah penelitian yang sedang direncanakan. Fungsi studi literatur adalah sebagai rujukan untuk memperkuat hasil-hasil penelitian. Studi literatur ini dilakukan oleh peneliti setelah menentukan topik penelitian dan menetapkan rumusan permasalahan. Studi literatur dilakukan sebelum terjun ke lapangan untuk mengumpulkan data yang diperlukan.

2.2 Jenis Data

Dalam penelitian ini jenis data kuantitatif dan bersumber dari data sekunder dan data primer. Data sekunder adalah data yang dikeluarkan oleh suatu badan yang telah dikumpulkan terlebih dahulu dan menerbitkannya dalam bentuk buku, laporan dan situs web resmi diperlukan sedangkan data primer adalah data yang diperoleh melalui survey langsung ke lapangan. Data hujan diperoleh dari stasiun way kekah 10 tahun terakhir, dan data operasional itik diperoleh secara survey langsung.

2.3 Analisis Data

Dalam penelitian ini untuk menghitung analisis benefit dengan adanya Penerapan Pemanenan Air Hujan Pada Usaha Peternakan Itik menggunakan pendekatan secara ekonomi. Dari hasil perhitungan secara konvensional dan dengan menggunakan simulasi air hujan nantinya akan dibandingkan manakah yang memiliki benefit yang lebih menguntungkan. Dari rumus menghitung analisis benefit diatas nantinya TC (Total Cost) akan berpengaruh dalam menentukan hasil manakah yang lebih menguntungkan apakah dengan cara konvensional atau dengan menggunakan simulasi air hujan. Adapun rumusnya sebagai berikut :

$$\begin{aligned}\pi &= TR - TC \\ &= P.Q - TC\end{aligned}$$

Keterangan :

- π = Keuntungan usaha (Rupiah)
- TR = Penerimaan total usaha (Rupiah)
- TC = Biaya total usaha (Rupiah)
- P = Harga produk hasil usaha (Rupiah)
- Q = Jumlah produk hasil usaha (Ekor/Butir)

2.4 Simulasi Pemanenan Air Hujan

Dalam melakukan simulasi pemanenan air hujan dalam model ini digunakan beberapa model tampungan yakni dengan ukuran Panjang 1.5 m, Lebar 1.5 m, dan tinggi 1,5 m. Terdapat 5 model desain tampungan yakni Model A,B,C,D, dan E guna untuk

menampung air hujan. Dari ke 5 model tersebut memiliki ukuran yang sama, namun yang membedakan hanya jumlah tampungan yang disediakan. Pada model A hanya disediakan 1 tampungan dan seterusnya hingga model E maka disediakan 5 tampungan dengan kapasitas yang berbeda-beda. Dari permodelan yang digunakan nanti nya akan didapatkan hasil tampungan mana yang ideal dan efektif dalam menampung air hujan dan mengurangi penggunaan air tanah dalam konsumsi air pada peternakan itik petelur yang terdapat di desa Karang Endah.

3. HASIL DAN PEMBAHASAN

3.1 Curah Hujan

Dalam pengamatan curah hujan tahun 2012, 2013, 2014, 2015, 2018, 2019 dan 2020 di Desa Karang Endah kecamatan Terbanggi Besar dapat diperoleh data yang telah diolah dalam bentuk tabel berikut :

Tabel 1. Data curah hujan

Variable	Obs	Mean	Std. Dev.	Min	Max
CH_2012	365	5.139726	12.15789	0	84
CH_2013	365	7.539726	16.07701	0	105
CH_2014	365	6.734247	15.53613	0	104
CH_2015	365	4.876712	12.47348	0	114
CH_2018	365	5.776712	14.45427	0	95
CH_2019	365	4.541096	12.48718	0	104
CH_2020	365	7.102192	15.97451	0	103

Tabel diatas menunjukkan curah hujan selama 7 tahun periode pengamatan yang terdiri dari jumlah observasi (hari), rata-rata hujan setiap tahun nya, standar deviasi, serta curah hujan minimal dan curah hujan maksimal yang terjadi pada setiap tahun nya. Hasil yang dapat disimpulkan dari tabel diatas yakni rata-rata hujan tertinggi dari 7 tahun pengamatan terjadi pada tahun 2012 yakni sebesar 7.539726 m³ dan terendah terjadi pada tahun 2019 yakni hanya sebesar 4.541096 m³. Untuk data curah hujan maksimum dengan angka tertinggi yakni terjadi pada tahun 2013 sebesar 105 mm dan pada tahun 2012 menjadi angka terendah pada curah hujan maksimum hanya sebesar 84 mm.

3.2 Inflow

Dalam pengamatan inflow tahun 2012, 2013, 2014, 2015, 2018, 2019 dan 2020 di Desa Karang Endah kecamatan Terbanggi Besar dapat diperoleh data yang telah diolah dalam bentuk tabel berikut :

Tabel 2. Data inflow

Variable	Obs	Mean	Std. Dev.	Min	Max
inflow_2012	365	.1427597	.3412726	0	2.3814
inflow_2013	365	.2137512	.4557832	0	2.97675
inflow_2014	365	.1909159	.4404494	0	2.9484
inflow_2015	365	.1382548	.3536232	0	3.2319
inflow_2018	365	.1637698	.4097786	0	2.69325
inflow_2019	365	.1287401	.3540115	0	2.9484
inflow_2020	365	.2013471	.4528772	0	2.92005

Tabel diatas menunjukkan inflow selama 7 tahun periode pengamatan yang terdiri dari jumlah observasi (hari), rata-rata inflow setiap tahun nya, standar deviasi, serta inflow minimal dan inflow maksimal yang terjadi pada setiap tahun nya. Hasil yang dapat disimpulkan dari tabel diatas yakni rata-rata inflow tertinggi dari 7 tahun pengamatan terjadi pada tahun 2013 yakni sebesar 0.2137512 m³ dan terendah terjadi pada tahun 2019 yakni hanya sebesar 0.1287401 m³. Untuk data inflow maksimum dengan angka tertinggi yakni terjadi pada tahun 2015 sebesar 3.2319 m³ dan pada tahun 2012 menjadi angka terendah pada curah hujan maksimum hanya sebesar 2.3814 m³.

3.3 Model Tampungan Rata-rata

Tabel 3. Model tampungan

Model Tampungan	Penggunaan Air Tanah
A (3,375 m3)	6,4139
B (6,750 m3)	3,5209
C (10,125 m3)	1,4453
D (13,500 m3)	0,4203
E (16,875 m3)	0

Berdasarkan tabel diatas dapat disimpulkan bahwa ukuran yang paling ideal dalam pemeliharaan itik petelur dengan kapasitas 100 ekor dan dengan ukuran atap kandang panjang 7 m dan lebar 4,5 m adalah ukuran tampungan E dengan kapasitas tampungan 16,875 m³. Pada tampungan ini kebutuhan air pada peternakan itik dapat dipenuhi seluruhnya dengan pemanfaatan pemanenan air hujan.

3.4 Analisis data perhitungan biaya listrik

Penelitian ini dilakukan untuk meninjau dari kebutuhan biaya listrik. Adapun analisis kebutuhan listrik untuk memompa air tanah dapat dijelaskan pada tabel di bawah ini:

Tabel 4. Perhitungan biaya listrik

No	Uraian	Jumlah Satuan
1	Kapasitas Tampungan	3.375 Liter / 3,375 m ³
2	Kecepatan Mesin Pompa Air	30 Liter / Menit
3	Waktu Pengisian Air 3.375 Liter	112,5 Menit/ 1,875 Jam
4	Daya Listrik	510 Watt
5	Biaya Tarif Per kWh	Rp. 1.353

Analisis Biaya Listrik Per Liter Air

$$\begin{aligned}
 \text{Biaya Listrik} &= \text{Pemakaian (kWh)} \times \text{Tarif dasar listrik} : 3.375 \text{ Liter} \\
 &= (\text{Daya alat listrik} \times \text{Lama pemakaian}) \times \text{Tarif dasar} \\
 &= (510 \times 1,875) : 1000 \times (1.353 : 3.375) \\
 &= 0,95625 \times 0.4008 \\
 &= 0,3833
 \end{aligned}$$

Jadi kebutuhan Biaya Listrik Per Liter adalah Rp. 0,3833

3.5 Analisis Biaya Operasional Tanpa RWH

Biaya penyusutan itik sebagai berikut :

Tabel 5. Biaya penyusutan itik petelur

No	Uraian	Jumlah Satuan
1	Itik Siap Telur (Usia 6 Bulan)	Rp. 65.000,00
2	Harga Jual Afkir	Rp. 45.000,00
3	Mortalitas/ Kematian	5% dari Populasi
4	Populasi Pemeliharaan	100 ekor
5	Waktu Produksi	365 Hari

Analisis Biaya Penyusutan itik Petelur dalam waktu 1 tahun adalah :

$$\begin{aligned}
 \text{Penyusutan} &= \text{Harga Beli} - \text{Harga Jual} : \text{Jumlah Populasi} : 365 \text{ Hari} \\
 &= (100 \times 65.000) - (95 \times 45.000) : 100 : 365 \\
 &= (6.500.000 - 4.275.000) : 100 : 365 \\
 &= (2.225.000 : 100) : 365 \\
 &= 22.250 : 365 \\
 &= \text{Rp. 60,9589}
 \end{aligned}$$

Kebutuhan itik petelur per hari :

Tabel 6. Kebutuhan operasional per hari

No	Uraian	Satuan	Volume	Harga Satuan	Jumlah
1	Pakan kosentrat	Kg	0,15	Rp. 5.300	Rp. 795,-
2	Air Minum Itik	Liter	0,5	Rp. 0,3833	Rp. 0,1917,-
3	Pembersihan	Liter	0,5	Rp. 0,3833	Rp. 0,1917,-
4	Vitamin dll	-	1	Rp. 30,-	Rp. 30,-
5	Upah Tenaga Kerja	-	1	Rp. 150,-	Rp. 150,-
6	Penyusutan Itik	Ekor	1	Rp. 60,9589	Rp. 60,9589,-
Jumlah Total					Rp. 1.036,3423,-
Overhade Langsung 15% dari Jumlah Total					Rp.155,4513
Jumlah Total + Overhade 15%					Rp. 1.191,7936

3.6 Analisis Benefit Secara Normal

Data yang digunakan adalah data dari peternakan itik yang ada di kelompok ternak itik Cahaya Muda di Desa Karang Endah Kecamatan Terbanggi Besar Lampung Tengah.

Tabel 7. Analisis benefit secara normal

No	Uraian	Jumlah Satuan
1	Populasi Pemeliharaan	100 Ekor
2	Oprasional Harian	Rp. 1.191.7936
3	Waktu Pemeliharaan	365 hari

Analisis Oprasional itik populasi 100 ekor

Oprasional = Jumlah Populasi x Oprasional Harian x 365 hari.
 = $100 \times 1.191.7936 \times 365$
 = Rp. 43.500.463,845 (Total Biaya Operasional dalam Satu Periode)

Data Pemasukan Telur yang di hasilkan selama Satu Periode (365 Hari) pemeliharaan dengan populasi pemeliharaan 100 ekor. Produksi telur itik di bedakan menjadi 2 fase yaitu :

fase I = Produksi Saat Usaia 6-12 Bulan mencapai rata-rata 90% (Fase saat itik produksi sangat baik)

fase II = Produksi Saat Usia 12-18 Bulan Mencapai rata-rata 70% (fase saat itik mengalami

rontok bulu secata bergantian, sehingga produksi telur mengalami penurunan)

Jadi jumlah telur yang di hasilkan pada setiap fase adalah:

Fase I = $100 \text{ Ekor} \times 90\%$
 = 90 butir per hari x 180 hari
 = 16.200 Butir

Fase II = $100 \text{ Ekor} \times 70\%$
 = 70 butir per hari x 185 hari
 = 12.950 Butir

Jumlah Telur = Jumlah fase I + Jumlah fase II
 Jumlah Telur = 16.200 + 12.950
 Jumlah Telur = 29.150 Butir
 Penjualan = 29.150 x Rp 2.000 (Harga telur per butir)
 Penjualan = Rp. 58.300.000,00

Jadi Keuntungan dalam pemeliharaan 1 kali periode itik petelur (365 hari) dengan populasi 100 ekor secara Normal adalah:

Profit = Total Pemasukan - Total Modal yang dikeluarkan
 Profit = Rp. 58.300.000,00 - Rp. 43.500.463,845
 Profit = Rp. 14.799.536,155

3.7 Rekap Perbandingan Benefit Secara Normal dan Menggunakan RWH

Tabel 8. Biaya harian

No	Uraian	Sat	Secara Normal			Menerapkan RWH		
			Volume	Harga Satuan	Jumlah Total	Volume	Harga Satuan	Jumlah Total
1	Pakan Kosekstrat	Kg	0.15	5,300.00	795.0000	0.15	5,300.00	795.00
2	Air Minum Itik	Ltr	0.50	0.3833	0.1917	0.50	-	-
3	Pembersihan Tempat Minum	Ltr	0.50	0.3833	0.1917	0.50	-	-
4	Vitamin	-	1.00	30.00	30.0000	1.00	30.00	30.00
5	Upah Tenaga Kerja	-	1.00	150.00	150.0000	1.00	150.00	150.00
6	Penyusutan Itik	Ekor	1.00	60.9589	60.9589	1.00	60.96	60.96
Jumlah Total					1,036.34220	1,035.9589		
Overhade Langsung 15%					155.45133	155.3938		
Jumlah Total + Overhade 15%					1,191.79353	1,191.3527		

Tabel di atas adalah tabel perbandingan antara biaya oprasional harian itik petelur secara normal dan dengan penerapan RWH yang di tinjau dari biaya listrik. Data tersebut diasumsikan apabila kebutuhan air dapat terpenuhi secara keseluruhan oleh air hujan. Perbedaan dari data pemeliharaan secara normal dan dengan menggunakan RWH sebesar Rp.0,44 Per hari.

Tabel 9. Biaya secara keseluruhan

No	Uraian	Sat	Secara Normal			Menerapkan RWH		
			Volume	Harga Satuan	Jumlah Total	Volume	Harga Satuan	Jumlah Total
1	Pakan Kosekstrat	Kg	5,475.00	5,300.00	29,017,500.00	5,475.00	5,300.00	29,017,500.00
2	Air Minum Itik	Ltr	18,250.00	0.3833	6,995.23	18,250.00	-	-
3	Pembersihan Tempat Minum	Ltr	18,250.00	0.3833	6,995.23	18,250.00	-	-
4	Vitamin	-	36,500.00	30.00	1,095,000.00	36,500.00	30.00	1,095,000.00
5	Upah Tenaga Kerja	-	36,500.00	150.00	5,475,000.00	36,500.00	150.00	5,475,000.00
6	Penyusutan Itik	Ekor	36,500.00	60.96	2,224,999.85	36,500.00	60.96	2,224,999.85
Jumlah Total					37,826,490.30	37,812,499.85		
Overhade Langsung 15%					5,673,973.55	5,671,874.98		
Jumlah Total + Overhade 15%					43,500,463.85	43,484,374.83		

Tabel diatas adalah tabel perbanfingan biaya operasional itik petelur secara normal dan dengan penerapan RWH yang di tinjau dari biaya listrik dalam kurun waktu satu periode

pemeliharaan yaitu 365 hari. Dapat disimpulkan bahwa benefit yang di dapat dengan menggunakan RWH adalah Rp. 16.089,02.

3.8 Analisis Kandungan pH Air

Analisis dilakukan pada sampel air hujan dan air tanah yang ada di peternak Desa Karang Endah. Adapun Hasil Sampel dapat di lihat pada Tabel di bawah ini :

Tabel 10. Kandungan pH air

No	Keterangan	pH
1	Sampel Air Hujan kandang A	6.9
2	Sampel Air Tanah Kandang A	6.3
3	Sampel Air Hujan Kandang B	6.7
4	Sampel Air Tanah Kandang B	6.1
5	Sampel Air Hujan Kandang C	6.7
6	Sampel Air Tanah Kandang C	4.9

Pada tabel diatas menunjukkan masing-masing kandungan pH air hujan dan pH air tanah dari 3 titik lokasi kandang yang berbeda. Berdasarkan Permenkes **No. 492/Menkes/Per/IV/2010** nilai pH normal yaitu berada dalam kisaran 6,5 - 9. pH penting dalam proses penjernihan air karena keasaman air pada umumnya disebabkan gas oksida yang larut dalam air terutama karbondioksida. Salah satu parameter kualitas air hujan yang sering diragukan nilainya yaitu derajat keasaman (pH). Dalam analisis diatas menunjukkan bahwa pH air hujan ternyata lebih baik daripada pH air tanah. pH air hujan menunjukkan skor diatas 6.5 yang artinya kandungan yang terdapat pada air hujan bersifat normal.

4. KESIMPULAN

Berdasarkan data hasil analisis data dalam penelitian ini dapat di ambil kesimpulan sebagai berikut:

1. Prosedur dalam penelitian ini adalah dengan populasi itik 100 ekor, ukuran atap Panjang 7 m dan Lebar 4,5m , dan ukuran Tampungan Air sebesar 16,875 m³ dapat menghasilkan 36.500 liter air dalam satu periode pemeliharaan. Sehingga benefit yang didapatkan sebesar Rp. 16.089,02 selama Satu Periode pemeliharaan.
2. Potensi air hujan yang ada di Desa Karang Endah untuk pemanfaatan air minum itik sangat berpotensi besar. Hal ini dikarenakan dalam Satu Periode pemeliharaan itik dengan kapasitas 100 ekor memerlukan 36.500 liter yang dapat di penuhi seluruhnya oleh pemanenan air hujan.
3. Pada analisis benefit peternakan itik petelur dengan populasi 100 ekor yang di pelihara secara normal di Desa Karang Endah selama Satu Periode mendapatkan keuntungan sebesar Rp. 14.799.536,155

DAFTAR PUSTAKA

- Arianti, A. A. dan. (2009). PERFORMANS ITIK PEDAGING (LOKAL X PEKING) ' PADA FASE STARTER YANG DIBER ! PAKAN DENGAN PERSENTASE PENAMBAHAN, 6(2).
- Harsoyo, B. (2010). Teknik Pemanenan Air Hujan (Rain Water Harvesting) Sebagai Alternatif Upaya Penyelamatan Sumberdaya Air Di Wilayah Dki Jakarta. *Jurnal Sains & Teknologi Modifikasi Cuaca*, 11(2), 29. [https:// doi.org/ 10.29122/jstmc.v11i2.2183](https://doi.org/10.29122/jstmc.v11i2.2183)
- UNEP International Technology Centre. (2001). Rain Water Harvesting. Murdoch University of Western Australia.
- Yan Zhang, Donghui Chen, Liang Chen, S. A. (2009). Potential for rainwater use in high-rise buildings in Australian cities. *Journal of Environmental Management*, Volume 91, Pages 222-226.
- Yulistyorini, A. (2011). Pemanenan Air Hujan Sebagai Alternatif Pengelolaan Sumberdaya Air di Perkotaan. *Teknologi Dan Kejuruan*, 34(1), 105-114. Retrieved from <http://journal.um.ac.id/index.php/teknologi-kejuruan/article/view/3024/408>

PENGARUH PENGGUNAAN LAPISAN CAT DAN MATERIAL DINDING TERHADAP OVERALL THERMAL TRANSFER VALUE (OTTV) DINDING BANGUNAN

Ruli Boyke Hastien^{1*}, Muhammad Irsyad², Amrul³

²Prodi Magister Teknik Mesin, Fakultas Teknik, Universitas Muhammadiyah Metro
Jl. Ki Hajar Dewantara 15 A Kota Metro, Lampung, Indonesia

³Jurusan Teknik Mesin, Fakultas Teknik, Universitas Muhammadiyah Metro
Jl. Ki Hajar Dewantara 15 A Kota Metro, Lampung, Indonesia

*Corresponding author: eko_budiyanto99@yahoo.com

Abstract

A building is said to be comfortable if a building has a temperature that suits the desired needs. The heat that enters the room from the sun's rays will affect the temperature in the room. The rate of heat transfer into the room is highly dependent on the thermal conductivity of the wall materials, including coating materials such as water proof, and paint. The wall material stores thermal energy, and is proportional to its specific heat. The lower the thermal conductivity, the less heat enters the room. When the wall temperature is higher than the room temperature, the heat in the walls is sent into the room. This causes the room temperature to increase so that to get the thermal comfort of the room it is necessary to use an air conditioning system (AC abbreviated as AC). The entry of energy from this wall results in an increase in the cooling load, thereby increasing the consumption of AC electrical energy. The consumption of AC electrical energy in Indonesia's commercial building sector reaches 65%. Based on the description above, it is necessary to make efforts to consume AC electrical energy. One of the efforts to reduce AC electrical energy consumption is to reduce the room's thermal load. Thermal loads that enter through the walls need to be reduced or inhibited. Several studies have shown that there is a positive effect on reducing the room's thermal load, such as: the use of coatings can reduce the incoming thermal load, as well as the use of bright colors. With the OTTV method on the wall, it can be minimized by using a didding material with an OTTV value of 26.9 W/m². The use of red brick can be reduced slightly OTTV.

Keywords: OTTV, Thermal Conductivity, building walls

Abstrak

Sebuah bangunan dikatakan nyaman jika sebuah bangunan memiliki temperatur yang sesuai dengan kebutuhan diinginkan. Panas yang masuk keruangan dari pancaran sinar matahari akan mempengaruhi temperatur didalam ruangan. Laju perpindahan panas ke dalam ruangan sangat tergantung dengan konduktivitas termal material dinding, termasuk material pelapis seperti *water proof*, dan cat. Material

dinding menyimpan energi termal, dan besarnya sebanding dengan kalor spesifiknya. Semakin kecil konduktivitas termalnya maka semakin sedikit kalor yang masuk ke dalam ruangan. Pada saat temperatur dinding lebih tinggi dari temperatur ruangan, maka panas dalam dinding dilepaskan ke dalam ruangan. Hal ini mengakibatkan temperatur ruang meningkat sehingga untuk mendapatkan kenyamanan termal ruangan perlu menggunakan sistem pengkondisian udara (*air conditioning* disingkat AC). Masuknya energi termal dari dinding ini mengakibatkan peningkatan beban pendinginan sehingga meningkatkan konsumsi energi listrik AC. Di Indonesia konsumsi energi listrik AC di sektor bangunan komersial mencapai 65%. Berdasarkan uraian di atas perlu adanya upaya meminimalkan konsumsi energi listrik AC. Salah satu upaya mengurangi konsumsi energi listrik AC adalah dengan mengurangi beban termal ruangan. Beban termal yang masuk melalui dinding perlu dikurangi atau dihambat. Beberapa penelitian menunjukkan adanya pengaruh positif terhadap penurunan beban termal ruangan seperti: penggunaan pelapis (*coating*) dapat mengurangi beban termal yang masuk, begitu juga dengan penggunaan warna yang cerah. Dengan metode OTTV pada dinding dapat diminimalkan dengan menggunakan material dinding dengan nilai OTTV sebesar $26,9 \text{ W/m}^2$ Penggunaan bata merah dapat menurunkan sedikit OTTV.

Kata kunci: OTTV, Konduktivitas Termal, dinding bangunan

Pendahuluan

Indonesia termasuk negara tropis dengan intensitas radiasi matahari yang tinggi yang mengakibatkan tingginya temperatur udara lingkungan pada siang hari. Energi termal dari radiasi matahari yang menerpa permukaan dinding gedung, kemudian masuk ke dalam ruangan secara konduksi sehingga menambah beban termal ruangan. Energi termal yang masuk melalui dinding bisa mencapai 30% dari beban termal ruangan (Halimi, 2017).

Laju perpindahan panas ke dalam ruangan sangat tergantung dengan konduktivitas termal material dinding, termasuk material pelapis seperti *water proof*, dan cat. Material dinding menyimpan energi termal, dan besarnya sebanding dengan kalor spesifiknya. Semakin kecil konduktivitas termalnya maka semakin sedikit kalor yang masuk ke dalam ruangan. Pada saat temperatur dinding lebih tinggi dari temperatur ruangan, maka panas dalam dinding dilepaskan ke dalam ruangan. Hal ini mengakibatkan temperatur ruang meningkat sehingga untuk mendapatkan kenyamanan termal ruangan perlu menggunakan sistem pengkondisian udara (*air conditioning* disingkat AC). Masuknya energi termal dari dinding ini mengakibatkan peningkatan beban pendinginan sehingga meningkatkan konsumsi energi listrik AC. Di Indonesia konsumsi energi listrik AC di sektor bangunan komersial mencapai 65% (Studi dkk., 2013).

Berdasarkan uraian di atas perlu adanya upaya meminimalkan konsumsi energi listrik AC. Salah satu upaya mengurangi konsumsi energi listrik AC adalah dengan mengurangi beban termal ruangan. Beban termal yang masuk melalui dinding perlu dikurangi atau dihambat. Beberapa penelitian menunjukkan adanya pengaruh positif terhadap penurunan beban termal ruangan seperti: penggunaan pelapis (*coating*) dapat

mengurangi beban termal yang masuk (Nurwidyaningrum dkk., 2015), begitu juga dengan penggunaan warna yang cerah (Simona dkk., 2020).

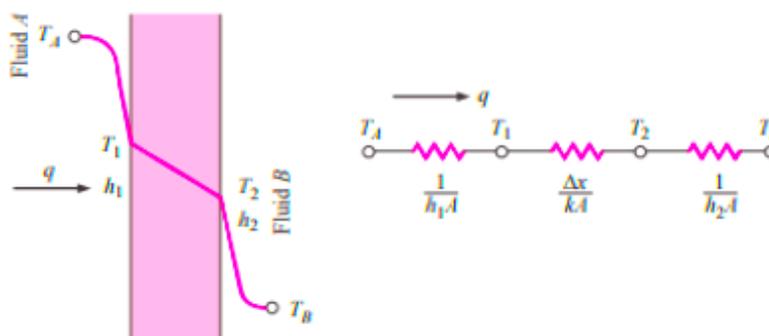
Informasi terkait dengan karakteristik termal pelapis dinding seperti *water proof*, warna cat, dan material dinding lainnya yang digunakan di Indoensia masih sedikit, begitu juga dengan kajian kemampuan mereduksi termal yang masuk baik secara simulasi maupun eksperimental. Berdasarkan hal ini perlu melakukan kajian mengenai permasalahan tersebut dengan mendapatkan data-data sifat termal dan karakteristik perpindahan panas akan membantu dalam pemilihan material dinding, cat, *coating*, dan insulasi sehingga dapat membantu mewujudkan bangunan rendah energi.

Tinjauan Pustaka

Perpindahan Panas

Perpindahan panas secara konduksi ialah proses perpindahan panas dimana panasmengalir dari keadaan yang memiliki temperatur tinggi ke keadaan yang bertemperatur rendah dalam suatu medium (padat, cair atau gas) atau antara medium-medium yang berlainan yang bersinggungan secara langsung sehingga dapat terjadi pertukaran energi dan momentum.

Di dalam sebuah cairan atau gas, molekul-molekul juga mudah bergerak, dan tenaga juga dihantar oleh tumbukan-tumbukan molekul seperti yang terlihat pada skema Gambar 1. (Yang dkk., 2017)



Gambar 1. Perpindahan Panas Konduksi (Holman, 1999).

Laju perpindahan panas yang terjadi pada kondisi perpindahan panas konduksi adalah berbanding dengan gradien suhu normal Pada Gambar 1. Perpindahan panas dapat dihitung dengan melihat selisih suhu antara T_A dan T_B . Perpindahan panas konduksi adalah berbanding dengan gradien suhu normal sesuai dengan persamaan 2.1. dan untuk perpindahan panas konveksi seperti persamaan 2.2

$$q_k = -kA \frac{dT}{dx} \quad (1)$$

$$q = h A \Delta T \quad (2)$$

Konduktivitas Termal

Konduktivitas termal merupakan sifat spesifik yang dimiliki oleh zat padat, cair, dan gas. Koefisien konduktivitas termal (k_c atau λ) menyatakan besarnya laju perpindahan panas yang tegak lurus terhadap permukaan material sepanjang bidang yang dilewati (Δx). Semakin kecil nilainya, akan semakin baik insulasi termal material tersebut. Konduktivitas termal pada material dipengaruhi oleh massa jenis, kandungan uap air, dan komposisi mineral penyusunnya (Stacy dkk., 2014).

Hubungan antara massa jenis material dan konduktivitas termalnya dapat dinyatakan oleh persamaan yang diusulkan oleh Valore (1980) dalam laporan *American Concrete Institute ACI 122-0R* (Huang dkk., 2013) berikut:

$$k_c = 0,072 e^{0,00125d} \quad (3).$$

Dalam keadaan normal, tidak dapat mempertahankan bata ringan dalam kondisi kering, akibat adanya pengaruh uap air sehingga persamaan konduktivitas di atas perlu dikoreksi menjadi:

$$k_c = 0,0865 e^{0,00125d} \quad (4).$$

OTTV (*overall thermal transfer value*)

Teori OTTV (SNI 03-6389 2000) (*overall thermal transfer value*) adalah angka yang ditetapkan sebagai kriteria perancangan untuk selubung bangunan yang dikondisikan, maka ditentukan nilai perpindahan termal menyeluruh untuk selubung bangunan tidak melebihi 45 watt/m². Nilai OTTV untuk setiap bidang dinding luar bangunan gedung dengan orientasi tertentu, dapat dihitung dengan persamaan berikut:

$$OTTV = a. [(U_w \times (1 - WWR))] \times TDE_k + (SC \times WWR \times SF) + (U_f \times WWR \times DT) \quad (5).$$

Metode Penelitian

Penelitian yang akan dilakukan merupakan penelitian dasar dengan pengujian eksperimen, dengan pendukung kajian analitik untuk beberapa nilai seperti perpindahan panas keseluruhan (OTTV). Pada penelitian ini untuk memproteksi energi termal masuk ke dalam ruangan dan mendukung penelitian PCM yang mempunyai fungsi untuk menyerap energi termal ruangan. Penelitian ini difokuskan pada sifat termal material dinding dan karakteristik perpindahan panas dinding dengan variasi material, *coating*, dan cat

Hasil dan Pembahasan

Konduktivitas termal

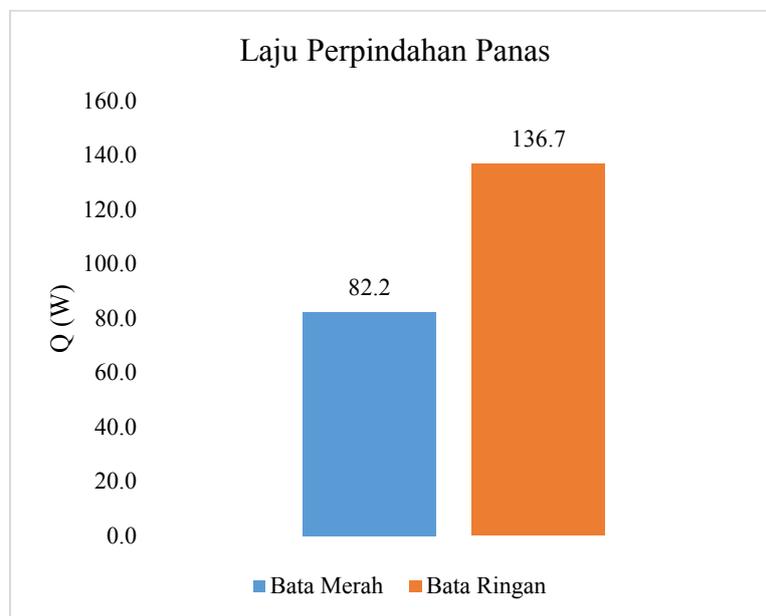
Konduktivitas termal lapisan dinding diuji menggunakan metode pengukuran *Modified Transient Plane Source* (MTPS) mengikuti standar ASTM-D7984. Material lapisan dinding yang diuji ada 6 sampel berupa: bata merah, bata ringan, plaster + aci, Plaster + Aci + Cat Interior, Plaster + Aci + Cat Exterior, Plaster + Aci + Cat Waterproof. Sampel diuji menggunakan alat *C-Therm TCi thermal conductivity analyzer* berguna

untuk mengukur nilai konduktivitas termal pada rentang 0 - 100 W/mK. Tabel 1. Merupakan hasil pengujian konduktivitas termal bata ringan dan bata merah pada laboratorium LIPI menggunakan alat C-Therm TCi thermal conductivity analyzer.

Tabel 1. Konduktivitas material dinding

Sampel	Konduktivitas Termal (W/mK)
Bata Merah	1,426
Bata Ringan	1,533

Perbandingan laju perpindahan panas antara dinding bata merah dan bata ringan diperlihatkan pada Gambar 2. Bata merah menghasilkan laju perpindahan panas lebih kecil dibandingkan dengan bata ringan. Hal ini sesuai dengan nilai konduktivitas termal kedua material ini.

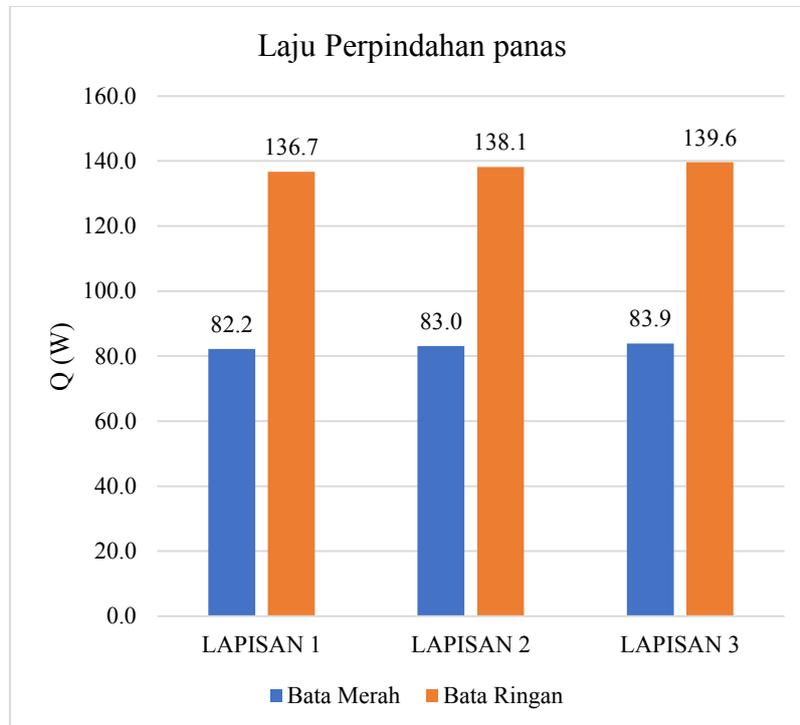


Gambar 2. Grafik perpindahan panas

Pada Gambar 3. Merupakan grafik perpindahan panas dari dinding bata merah dan dinding bata ringan dengan beberapa lapisan material penyusun dinding tiap lapisan diantaranya, lapisan 1 terdiri dari cat eksterior, *waterproof*, plaster & aci, bata ringan, plaster & aci, *waterproof*, cat interior, konveksi permukaan luar, konveksi permukaan dalam. Lapisan 2 terdiri dari, cat eksterior, *waterproof*, plaster & aci, bata ringan, plaster & aci, cat interior, konveksi permukaan luar, konveksi permukaan dalam dan lapisan 3 terdiri dari, cat eksterior, plaster & aci, bata ringan, plaster & aci, cat interior, konveksi permukaan luar, konveksi permukaan dalam.

Pada grafik menunjukan bahwa ketiga lapisan menunjukkan nilai laju perpindahan panas yang berbeda-beda, hal ini di pengaruhi dari tiap lapisan yang tersusun atas beberapa material pelapis pada dinding tersebut. Pada dinding bata merah tiap lapisan mengalami kenaikan laju perpindahan panas, dimana pada lapisan 1 menunjukkan nilai

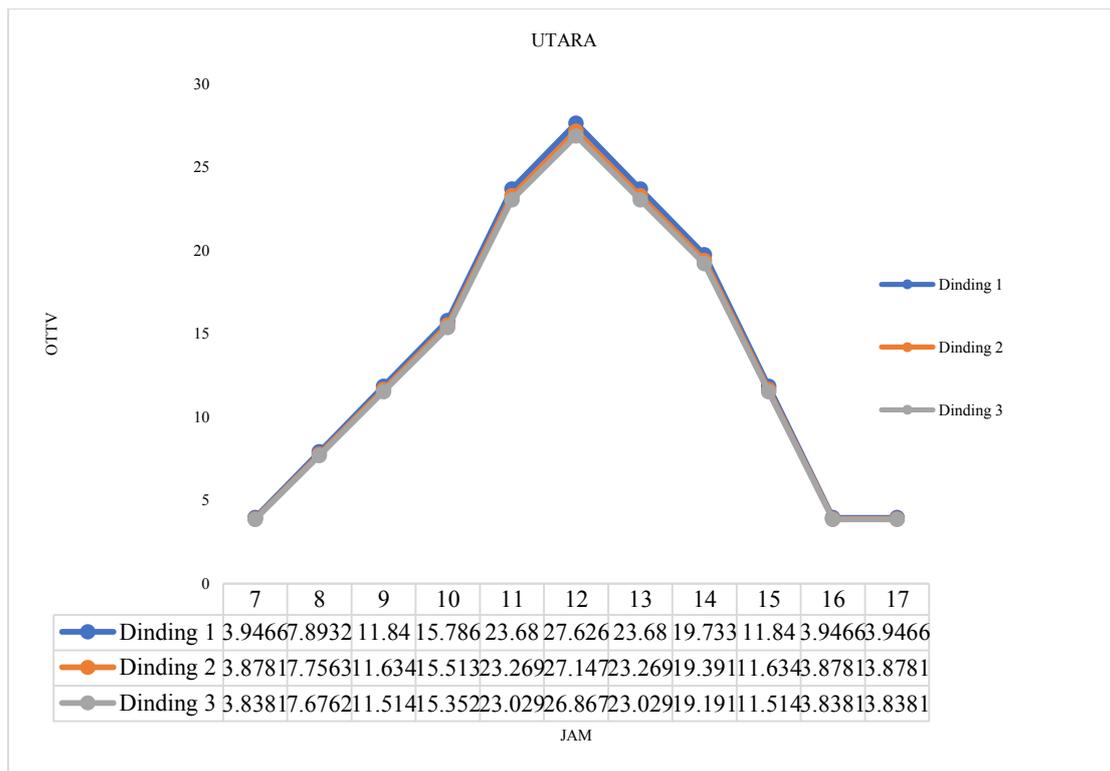
lapisan panas sebesar 82,2 W, lapisan 2 sebesar 83 W dan lapisan 3 sebesar 83,9 W. Kenaikan tersebut selain dipengaruhi dari material penyusun dinding yang memiliki konduktivitas termal yang berbeda-beda juga di pengaruhi dari kuat tekan yang berdampak pada densitas bata merah itu sendiri (Utari dkk., 2013).



Gambar 3. Grafik perpindahan panas

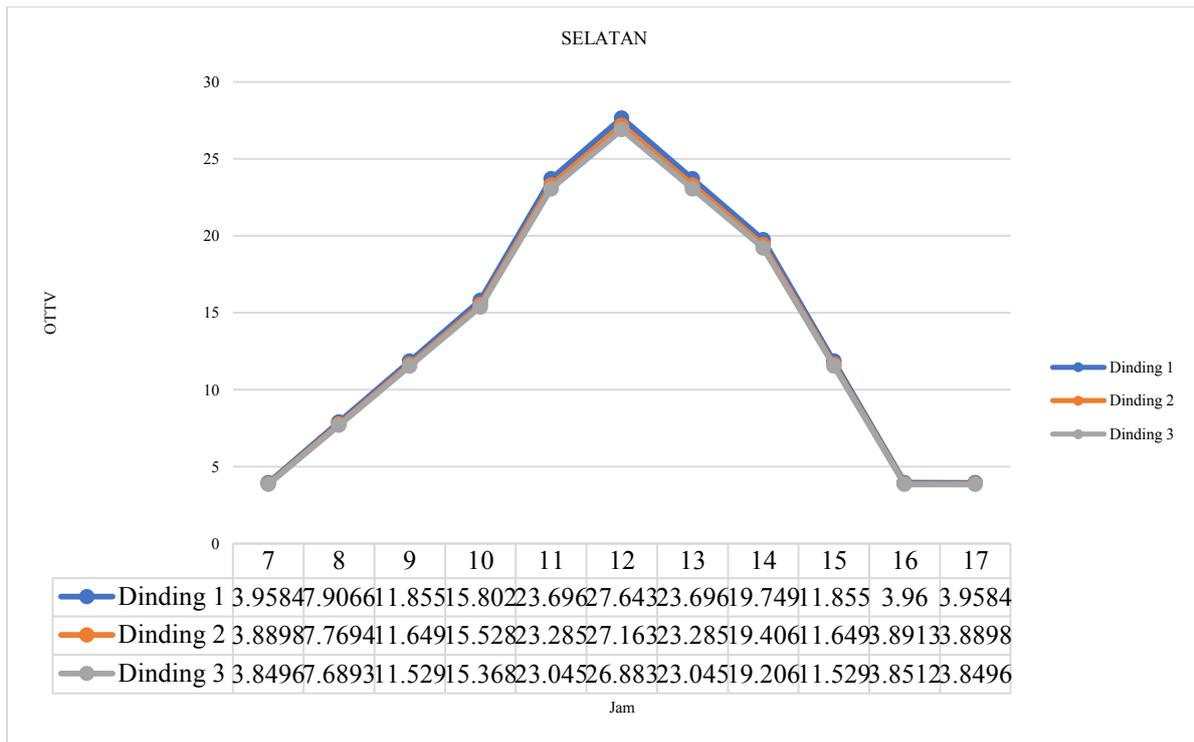
Overall Thermal Transfer Value (OTTV)

Gambar 4. Merupakan grafik distribusi nilai OTTV pada dinding Utara dengan tiga jenis lapisan cat. Pada dinding 1 merupakan dinding dengan lapisan cat biasa yang memiliki nilai OTTV paling besar yaitu $27,6 \text{ W/m}^2$, sedangkan untuk lapisan 2 menggunakan cat interior dan eksterior sebesar $27,1 \text{ W/m}^2$, dan pada dinding 3 menggunakan cat waterproof memiliki nilai OTTV sebesar $26,9 \text{ W/m}^2$. Nilai OTTV paling rendah pada dinding 3 karena dipengaruhi oleh lapisan cat yang memiliki konduktivitas termal lebih rendah di dibandingkan dengan lapisan dinding 1 dan lapisan dinding 2. Selain itu, dipengaruhi juga oleh orientasi arah Utara dimana dinding bagian Utara tidak langsung terkena pancaran sinar matahari yang berlintas dari arah timur menuju barat.



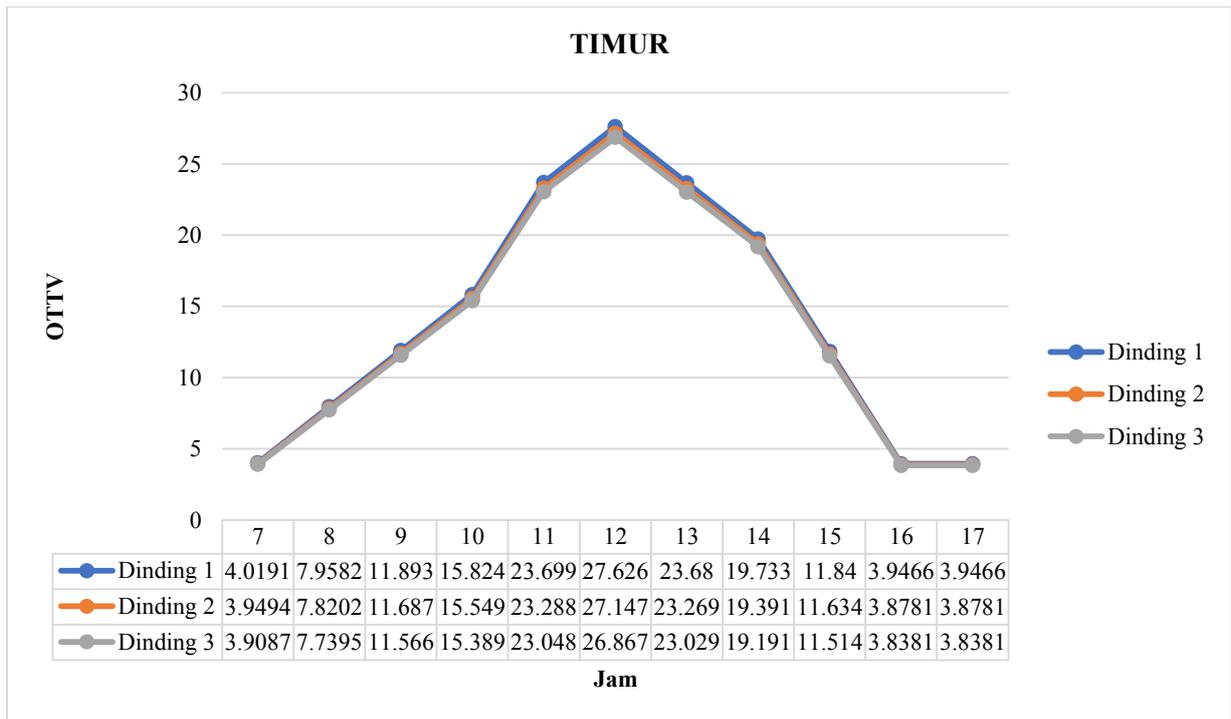
Gambar 4. Distribusi nilai OTTV Lapisan Cat pada dinding Utara

Gambar 5. Merupakan grafik distribusi nilai OTTV pada dinding Selatan dengan tiga jenis lapisan cat. Pada dinding 1 merupakan dinding dengan lapisan cat biasa yang memiliki nilai OTTV paling besar yaitu $27,6 \text{ W/m}^2$, sedangkan untuk lapisan 2 menggunakan cat interior dan eksterior sebesar $27,2 \text{ W/m}^2$, dan pada dinding 3 menggunakan cat waterproof memiliki nilai OTTV sebesar $26,9 \text{ W/m}^2$. Nilai OTTV paling rendah pada dinding 3 karena dipengaruhi oleh lapisan cat yang memiliki konduktivitas termal lebih rendah di bandingkan dengan lapisan dinding 1 dan lapisan dinding 2. Selain itu, dipengaruhi juga oleh orientasi arah Selatan dimana dinding bagian Selatan tidak langsung terkena pancaran sinar matahari yang berlintas dari arah timur menuju barat.



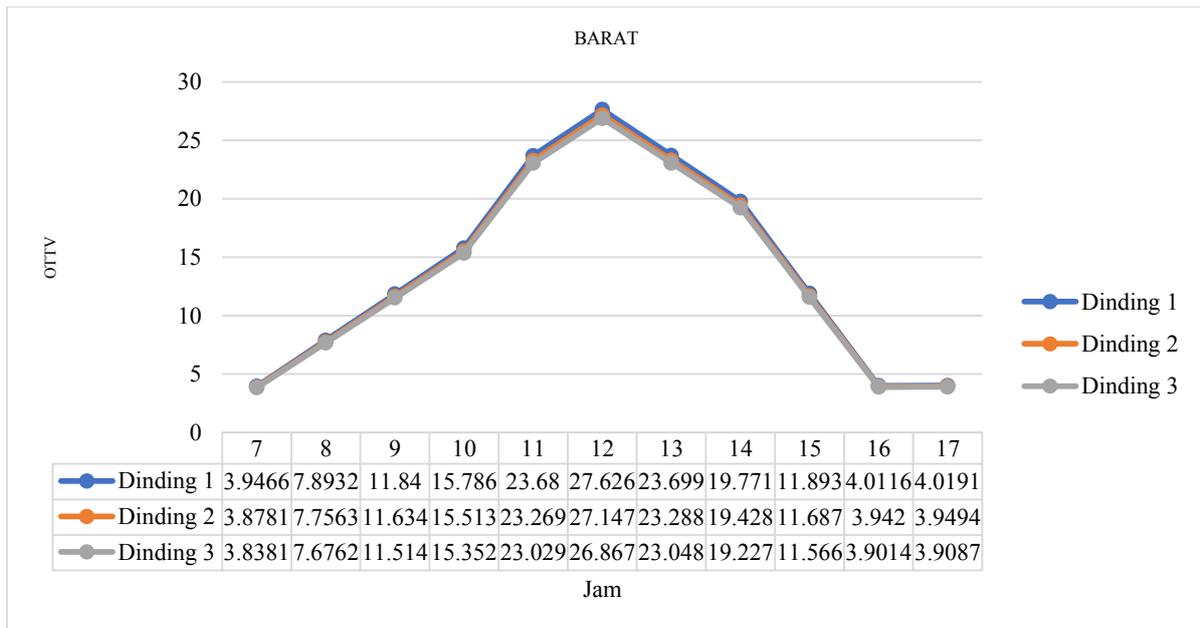
Gambar 5. Distribusi nilai OTTV Lapisan Cat pada dinding Selatan

Gambar 6. Merupakan grafik distribusi nilai OTTV pada dinding Timur dengan tiga jenis lapisan cat. Pada dinding 1 merupakan dinding dengan lapisan cat biasa yang memiliki nilai OTTV paling besar yaitu $27,6 \text{ W/m}^2$, sedangkan untuk lapisan 2 menggunakan cat interior dan eksterior sebesar $27,1 \text{ W/m}^2$, dan pada dinding 3 menggunakan cat waterproof memiliki nilai OTTV sebesar $26,9 \text{ W/m}^2$. Nilai OTTV paling rendah pada dinding 3 karena dipengaruhi oleh lapisan cat yang memiliki konduktivitas termal lebih rendah di dibandingkan dengan lapisan dinding 1 dan lapisan dinding 2. Selain itu, dipengaruhi juga oleh orientasi arah Timur dimana dinding bagian Timur langsung terkena pancaran sinar matahari yang berlintas dari arah timur menuju barat.



Gambar 6. Distribusi nilai OTTV Lapisan Cat pada dinding Timur

Gambar 7. Merupakan grafik distribusi nilai OTTV pada dinding Barat dengan tiga jenis lapisan cat. Pada dinding 1 merupakan dinding dengan lapisan cat biasa yang memiliki nilai OTTV paling besar yaitu $27,6 \text{ W/m}^2$, sedangkan untuk lapisan 2 menggunakan cat interior dan eksterior sebesar $27,1 \text{ W/m}^2$, dan pada dinding 3 menggunakan cat waterproof memiliki nilai OTTV sebesar $26,9 \text{ W/m}^2$. Nilai OTTV paling rendah pada dinding 3 karena dipengaruhi oleh lapisan cat yang memiliki konduktivitas termal lebih rendah di dibandingkan dengan lapisan dinding 1 dan lapisan dinding 2. Selain itu, dipengaruhi juga oleh orientasi arah Barat dimana dinding bagian Barat langsung terkena pancaran sinar matahari yang berlintas dari arah timur menuju barat.



**Gambar7. Distribusi nilai OTTV Lapisan
Cat pada dinding Barat**

Kesimpulan

Berdasarkan hasil penelitian Pengujian OTTV (*Overall Thermal Transfer Value*) dapat diambil kesimpulan bahwa sifat termal yang diperoleh dari material dinding berupa konduktivitas termal dari Plaster + Aci sebesar 1,990 K W/mK, Plaster + Aci + Cat Interior sebesar 1,882 W/mK, Plaster + Aci + Cat Exterior sebesar 1,356 W/mK, Plaster + Aci + Cat Waterproof 1,256 W/mK, dan konduktivitas termal pada Cat Waterproof sebesar 0,0744 W/mK, Cat interior sebesar 0,453 W/mK, dan cat Ekterior sebesar 0,0748 W/mK.

Sedangkan nilai perpindahan panas menyeluruh (OTTV) pada dinding dapat diminimalkan dengan menggunakan material dinding dengan nilai OTTV sebesar 26,9 W/m² Penggunaan bata merah dapat menurunkan sedikit OTTV.

Ucapan terimakasih (jika diperlukan)

Pada bagian ini, nyatakan ucapan terima kasih kepada pihak ketiga selain pemakalah yang sangat berperan dalam penyusunan makalah. Selain itu, sumber pendanaan penelitian juga dapat disebutkan pada bagian ini.

Referensi (tipe indentasi Hanging 1 cm)

Referensi wajib ditulis dalam huruf Roman. Penulisan nama penulis dilakukan dengan format: nama keluarga/terakhir penulis pertama ditulis lebih dahulu, diikuti inisial nama depan penulis pertama. Apabila ada 2 orang penulis, maka gunakan kata sambung 'dan'. Apabila ada 3 orang atau lebih penulis, maka gunakan kata 'dkk.' setelah penulis pertama. Untuk referensi berbahasa Inggris, tetap tuliskan dalam bahasa Inggris, seperti penggunaan 'and' untuk 2 orang penulis dan 'et al.' untuk 3 orang atau lebih penulis.

Referensi jurnal/artikel/prosiding:

- Chan, A. L. S., & Chow, T. T. (2013). Evaluation of Overall Thermal Transfer Value (OTTV) for commercial buildings constructed with green roof. *APPLIED ENERGY*, 107, 10–24. <https://doi.org/10.1016/j.apenergy.2013.02.010>.
- Chan, A. L. S., & Chow, T. T. (2014). Calculation of overall thermal transfer value (OTTV) for commercial , ade in buildings constructed with naturally ventilated double skin fac subtropical Hong Kong. *Energy & Buildings*, 69, 14–21. <https://doi.org/10.1016/j.enbuild.2013.09.049>
- Halimi, B. (2017). Amonia sebagai Fluida Kerja Pembangkit Listrik Tenaga Panas Laut– Alternatif Solusi Kelistrikan di Indonesia. *Prosiding Semnastek*, November, 1–2. <https://jurnal.umj.ac.id/index.php/semnastek/article/view/1909>
- Holman, V. (1999). Introduction. *Visual Resources*, 15(3), ix–x. <https://doi.org/10.1080/01973762.1999.9658510>
- Huang, Y., Niu, J. L., & Chung, T. M. (2013). Study on performance of energy-efficient retrofitting measures on commercial building external walls in cooling-dominant cities. *Applied Energy*, 103, 97–108. <https://doi.org/10.1016/j.apenergy.2012.09.003>
- Lam, J. C. (2000). Energy analysis of commercial buildings in subtropical climates. *Building and Environment*, 35(1), 19–26. [https://doi.org/10.1016/S0360-1323\(98\)00067-5](https://doi.org/10.1016/S0360-1323(98)00067-5)
- Maret, E. X., & Pengantar, K. (n.d.). RADIN INTEN II LAMPUNG.
- Nurwidyaningrum, D., A.G., H., & Farida, R. (2015). Pengaruh material ruang pada kenyamanan termal ruang membuat yang menggunakan. *Jurnal Tesa Arsitektur*, 13(2), 81–92. <https://core.ac.uk/download/pdf/291609757.pdf>
- Simona, L., Acomi, N., Serban, A., & Paraschiv, S. (2020). ScienceDirect A web application for analysis of heat transfer through building walls and calculation of optimal insulation thickness. *Energy Reports*, 6(April), 343–353. <https://doi.org/10.1016/j.egy.2020.08.055>
- Stacy, S. C., Zhang, X., Pantoya, M., & Weeks, B. (2014). The effects of density on thermal conductivity and absorption coefficient for consolidated aluminum nanoparticles. *International Journal of Heat and Mass Transfer*, 73, 595–599. <https://doi.org/10.1016/j.ijheatmasstransfer.2014.02.050>
- Studi, P., Teknik, P., & Fptk, E. (2013). Analisis Audit Energi untuk Pencapaian Efisiensi Penggunaan Energi di Gedung JICA FPMIPA Universitas Pendidikan Indonesia. *Electrans*, 12(1), 81–88.
- Utari, R., Sugianto, & Taer, E. (2013). Penentuan Kualitas Batu Bata Merah Berdasarkan Konduktivitas Termal. *Matematik dan Pengetahuan Alam UNRI*, 7, 78–91.
- Yang, W., Zhu, X., & Liu, J. (2017). Annual experimental research on convective heat transfer coefficient of exterior surface of building external wall Highlights : *Energy & Buildings*. <https://doi.org/10.1016/j.enbuild.2017.08.075>
- Zingre, K. T., Wan, M. P., & Yang, X. (2015). A new RTTV (roof thermal transfer value) calculation method for cool roofs. *Energy*, 81, 222–232. <https://doi.org/10.1016/j.energy.2014.12.030>

RELAY-BASED CLUSTERING METHOD FOR INTERFERENCE MANAGEMENT IN HETEROGENEOUS WIRELESS CELLULAR NETWORK

Misfa Susanto*, Sitronella Nurfitriani Hasim, and Helmy Fitriawan

Department of Electrical Engineering, University of Lampung

Jl. Prof. Dr. Ir. Sumantri Brojonegoro No.1, Bandar Lampung, 35145, Indonesia

**Corresponding author. Email: misfa@eng.unila.ac.id*

Abstract

Femtocell is one of solutions to improve quality of services and network capacity for users in indoor areas. Radio resources used by femtocells are shared from macrocell network, thus it saves the use of frequency spectrum. However, one of problems in deploying femtocells within coverage area of macrocells is interference due to radio resources sharing between femtocells and macrocells. It creates interferences called as cross-tier (macrocell-femtocell/femtocell-macrocell) and co-tier (macrocell-macrocell/ femtocell-femtocell) interferences. This paper proposes a relay-based clustering method to mitigate interference in femtocells located in the whole edge area of macrocell and the cell edge area of sectorized macrocells. Relay nodes are deployed statically (fixed location) in the neighboring macrocell area. Relay node will recruit their members based on the shortest distance. Certain relay node's members do not need to transmit large amounts of power to enhanced Node B (eNB), such that interference from Macrocell User Equipment (MUE) to Home enhanced Node B (HeNB) can be minimized. Simulation experiments has been carried out and optimistic results for the sectorized macrocells scenario show that Signal-to-Interference-plus-Noise-Ratio (SINR) of femtocells for the conventional system that does not reach the targeted SINR of 20 dB is 87%. Meanwhile, after applying the relay-based clustering method, SINR value of femtocells below or equal to 20 dB reaches 72%. Optimistic results for throughput and Bit Error Rate (BER) show improvement of 15% and 14%, respectively. It has been shown that the relay-based clustering method can provide better performance compared to the conventional system even for femtocells densely deployed.

Keywords cross-tier interference, co-tier interference, relay-based clustering method, interference management, femtocell-macrocellnetwork, cell edge area

I. INTRODUCTION

The advancements in cellular communication technology in the last few decades has encouraged the growth of data traffic greatly. High increase in data traffics makes a lot of demand from users to obtain excellent capacity and service quality provided by their mobile devices through the network. This demand mostly comes from users who are indoor residing at house and at office [1]. To achieve these requirements, some standards for high-speed communication have been developed. Some of these standards are 3GPPs High Speed Packet Access(HSPA), Long Term Evolution (LTE), and Ultra-Wide Band (UWB) [2]. However, indoor users cannot experience good quality of services from conventional macrocells of wireless communication networks due to blocking from some objects, (e.g., walls, doors, and windows) [3]. Therefore, some indoor users use a network of small cells known as femtocells that are connected to their preferred service provider. Femtocells can provide a robust network in indoor areas and provide superior quality of service for voice traffic [4].

Deploying femtocells within macrocell area needs often a trade-off. When a Home enhanced Node B (HeNB) or Femtocell Base Station (FBS) is placed in indoor area, some Macrocell Base Station (MBS) signals are transmitted from outdoor to indoor, and the signal from the FBS spreads to the outdoor area. This is why it causes unwanted signals to occur.

It is referred to as interference. This leakage of signals from HeNB to eNB or vice versa can be caused many factors such as the improper installation of the equipment, the material of surrounding building or objects, etc. Moreover, due to the limited frequency spectrum, femtocells and macrocells share the same radio resources and form a heterogeneous wireless cellular network. In other words, deploying femtocells in macrocell area creates interference issues [4].

To overcome the interference problems, several studies have proposed interference management such as using radio resource allocation methods to mitigate co-tier interference between femtocells [5] - [11]. Ref. [5] discusses equitable resource utilization in Long Term Evolution (LTE)/LTE- Advanced femtocell networks. The authors propose a radio resource allocation scheme based on a hybrid spectrum allocation approach. Ref. [6] proposed a semi-clustering of victim-cell (SCVC) approach for the utilization and management of radio resources in a highly congested network environment. The SCVC technique works in identifying the status of the victim's femtocell user whether it is critical or non-critical. In [7], the authors proposed an efficient method to take advantage of the availability of sub channels by identifying inter-femtocell interference by generating patterns that are received in Mobile Station (MS).

Ref. [8] proposed a distributed scheme for managing wireless resources on a heterogeneous network. In [9], the

authors proposed two radio resource allocation schemes, namely optimization and heuristics schemes. The authors in [10] presented a clustering-based interference management scheme and radio resource allocation for a two-tier Orthogonal Frequency Division Multiple Access (OFDMA) femtocell network. In their study, the authors

focused only on OFDMA- based downlink transmissions, where the frame structure can be viewed as time-based frequency resource blocks. Meanwhile, the authors in [11] proposed a dynamic resource allocation algorithm for heterogeneous networks. The authors considered the mobility of macrocell and femtocell users in an algorithm called as IWCA (Interference-Weighted Clustering Algorithm) and spectrum sharing algorithm was proposed for a better utilization of spectrum resources.

Based on several previous studies that have been described above [5] - [11], the resource allocation methods were proposed to mitigate co-tier interference in those references. Meanwhile, in our current study, we look for another way and propose a relay-based clustering method to mitigate the occurrence of cross-tier interference between femtocell and macrocell networks. This femtocell-macrocell network is referred as a heterogeneous wireless cellular network in our paper. In addition, the heterogenous wireless cellular network that we are considering includes the deployment of femtocells densely forming ultra-dense networks (UDN) phenomenon.

In addition to the resource allocation methods, to perform interference management on the femtocell network, we can use the power allocation method as discussed in [12] - [17]. Ref.

[12] studied a distributed resource allocation consisting of subchannel-level allocation and power-level allocation in a two-tier cognitive femtocell network (CFN) during uplink transmission. Meanwhile, in [13] the authors proposed multi-objective optimization which aims to maximize the throughput value for each user. The authors in [14] proposed power control algorithm based on the virtual Proportional-Integral (PI) controller. This method aims to save energy on femtocell users. Ref. [15] considered the optimal transmission power allocation strategy to maximize the aggregate communication rate in a multi-tier network. The simulation results showed that power allocation can improve femtocell performance by adjusting transmit power according to Quality of Service (QoS) requirements. Ref. [16] proposed annealing optimization algorithm by adjusting the transmission power of the femtocell base station. Although, the previous mentioned schemes were used for power management (power control) and were a centralized technique, the authors in [17] proposed an approach to power control and allocation of radio resources spread over femtocell and macrocell networks denoted by the Two-tier Cluster-based Resource and Power Allocation Scheme (TCRPA). However, the power control methods mentioned above need complicated hardware in their implementations. In addition, the disadvantages of the power control method are the decreases in cell coverage area, poor SNR for the users farthest

to base station, signaling overhead that causes battery drain.

Refs. [18] - [20] used the fractional frequency reuse (FFR) method to perform interference management in femtocell network. In [18], the authors investigated the FFR method on an ultra-dense network (UDN) in the 26 GHz band. Ref. [19] proposed FFR with three sectors and three layers (FFR-3SL) to reduce co-channel interference (CCI) in heterogeneous networks. In [20] the FFR method was designed by properly dimensioning the center and edge of the cell, dividing and

assigning the available total bandwidth between the two areas appropriately.

Meanwhile, in [18] the FFR method was used as a solution of interference management on the millimeter wave UDN network for the 26 GHz band. Dense small cell networks with short user distances and high-level sectorization (HOS) were the focus of [18]. Although the FFR methods are popular methods to avoid interference problems by differentiating the cell-edge and center cell of a cell, it is not preferable methods for the femtocell-macrocell networks, especially for the femtocells that are deployed randomly and densely. For FFR methods there will be inefficiencies of the frequency bandwidth usage. It is because the FFR method divides the frequency bandwidth allocations among the different type of cells.

Our current paper aims to solve interference problems arising on femtocells deployed densely on the macrocell of wireless cellular networks by proposing a relay-based clustering method. More specific, we are targeting to reduce the effect of cross-tier interferences. This paper is an extension of a paper that has been presented in [21], where the relay-based clustering method was used for interference management in the femtocell-macrocell network. In that previous paper, the observed macrocells were divided into six sectors. In each sector, it was deployed by thirty-three femtocells. It is different from [21], in this current paper femtocells presents at two scenarios i.e., femtocells are deployed in the whole cell edge area of macrocells and the femtocells are deployed in the cell edge of macrocells in the sectorized macrocells consisting of six sectors. Our target is that relay-based clustering method is used to mitigate the interference of the femtocells being in the cell edge area. In summary, our current paper position to the previously mentioned literatures is shown in Table I.

The contribution of this paper is an interference management method using a relay-based clustering method in mitigating cross-tier interferences coming from Macrocell User Equipment (MUEs) in neighboring macrocells to the certain numbers of observed HeNBs. In our previous paper [21], the highest SINR value after applying the relay-based clustering method was 30 dB, while in this current paper it will be shown that the highest SINR value achieves 40 dB. This is because in the paper [21] the analysis focus is only on two sectors out of six sectors for sectorized cells. One sector of two sectors from the observed macrocell was very close to the edge of another macrocell. Meanwhile, another sector of those two sectors is very close to the cell edge of other different neighboring macrocell, considering three macrocells layout. Therefore, the interferences that occur at the HeNB is very large because femtocells are very close to the MUEs in the neighboring macrocell. In addition to the aforementioned scenario, in this current paper femtocells are deployed randomly and densely in the whole cell edge area of macrocell, not only concentrating on certain sectorized cell. By this setting, the interference coming from the MUEs in neighboring macrocells is not as large as the previous case. Note that our previous work is also included in this paper for the comparison purposes.

The rest of this paper is organized as follows. Section II describes the methods used to achieve the goal of this research including system model, the network

scenarios that are going to be implemented in the simulation experiment, and the simulation parameters. Section III presents the simulation results and its discussion. Finally, we conclude the paper in section IV.

TABLE I. RESEARCH POSITION BASED ON METHOD AND RESEARCH RESULTS

Ref.	Method	Result
[5]	Resource allocation method to reduce co-tier interference	Proposed scheme achieves substantial throughput and improves Packet Loss Rate (PLR) performance
[6]	Semi-clustering of victim-cell (SCVC) Method to reduce co-tier interference	Average percentage of throughput reaches 185%
[7]	Interference identification and resource management method to reduce inter-femtocell interference	Throughput is increased by 20.64%
[8]	Cluster-based resource allocation method to reduce co-tier interference	Proposed resource allocation algorithm can reduce the lower interference between FUEs
[9]	Resource allocation method to reduce cross-tier interference	Total capacity of the proposed scheme decreased from 41% to 4%
[10]	Joint clustering and resource allocation to reduce intra-tier interference	Simulation results shown that the proposed method can increase the throughput of femto user (FU)
[21]	Relay-based clustering method to mitigate cross-tier interference	Simulation results shown that the proposed method can improve the performance of the femtocell access point (FAP) located on the cell edge

II. METHOD

This paper applies modeling and simulation as its research methodology to achieve its goal. The goal is the proposed method being capable to improve the performance of femtocells appearing at the cell edge of macrocell. To achieve the effectiveness of proposed solution, the design of two system models is carried out in which it is also applied as the simulation scenarios. The first considered system is a conventional system, where in this system there is no method of interference management applied. The second system is a system that applies the relay-based clustering method to mitigate cross-tier interference coming from the MUEs to the HeNB on the cell edge area of macrocell. For both systems, it is considered two scenarios of the femtocells deployments. First, femtocells are randomly and densely deployed in the whole cell edge area of macrocell i.e., macrocell uses omnidirectional antenna. Secondly, femtocells are deployed in the cell edge area of sectorized macrocell consisting of six sectors of macrocell. Therefore, there are four scenarios in total that are considered. Detail discussions for these system models of the considered simulation scenarios will be explained in the following two Subsections II (A) and (B).

A. System Model

Figure 1 shows a two-tier network of femto-macrocells in which we refer this network as a heterogeneous wireless cellular network. We consider three macrocells of OFDMA-based cellular networks. The total system bandwidth is divided into three frequency spectrums (three frequency bands). One macrocell out of three macrocells, i.e., macrocell A is deployed a number of femtocells in its cell edge area. Each of three macrocells is allocated a different frequency band in which it is referred as reuse factor of 3, whereas the femtocells in macrocell A will be assigned the same frequency band as used in the two neighboring macrocells (reuse factor of 2).

Femtocells are densely deployed in the whole cell edge area of macrocell A, as mentioned earlier. Meanwhile, for other two macrocells there are no femtocells deployed. However, these two neighboring macrocells are deployed a number of macro user equipment (MUEs). When the femtocell user equipment (FUE) sends the signal i.e., in uplink mode to Home enhanced Node B (HeNB) and at the same time the MUEs in the neighboring macrocell also communicate to Node B (eNB) i.e., in uplink mode as well, thus the observed HeNB suffers cross-

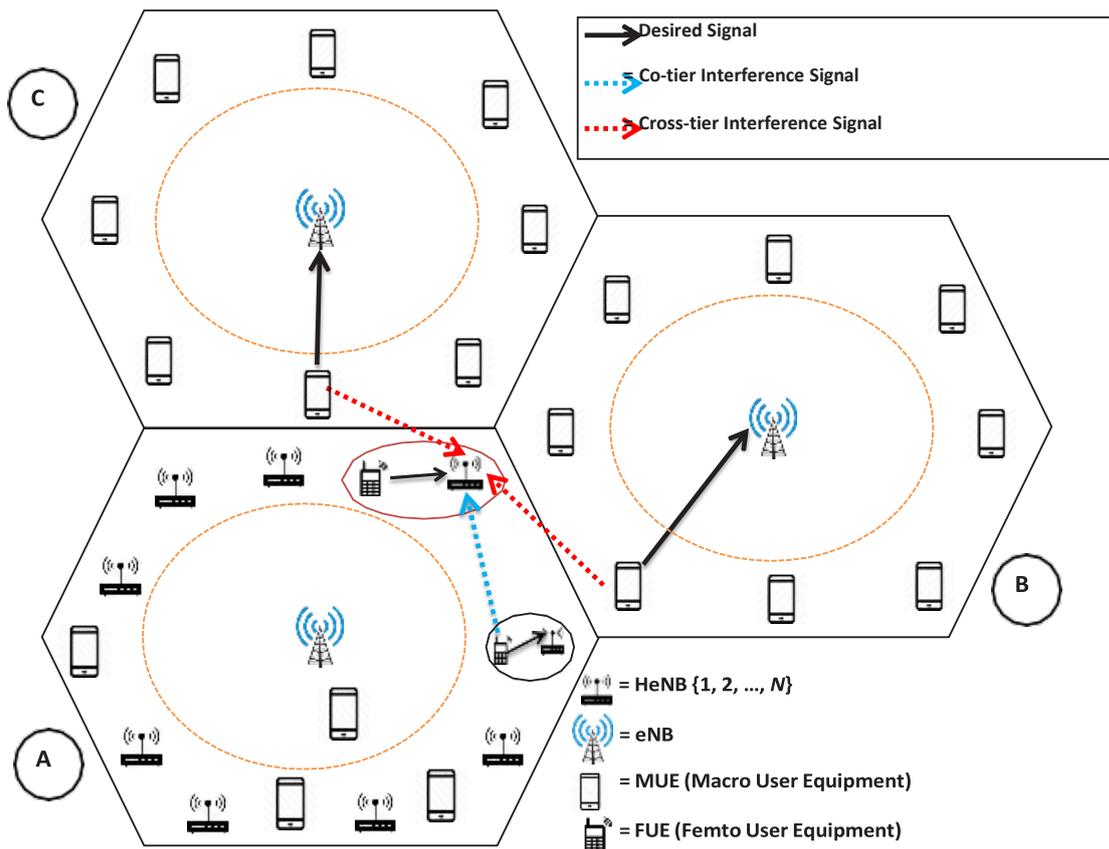


Figure 1. Conventional system model

tier interferences from MUEs as shown by the red line in Figure 1. This interference occurs because the femtocells likely use the same radio resources as used for two neighboring macrocells. Note that in our system model, we define cell edge area of macrocell by dividing a macrocell area into two areas by drawing an orange dashed circle (as shown in Figure 1) inside the macrocell area. It is virtually dividing macrocell areas into the inner cell area and outer cell area/cell edge area of macrocell. By this scenario setting, this can make the performance of the femtocells even worse, especially when it is very close to the cell edge area of the neighboring macrocells.

Besides getting cross-tier interferences, HeNB also suffers co-tier interference caused by other FUEs, because HeNBs share the same radio resources. In Figure 1, the co-tier interference is indicated by a blue line. The scenario that has been described in Figure 1 is also referred to as the first scenario in this paper for the conventional system.

The relay node functions as receiver and forwarder of the signals from the MUE to the eNB. The signal power transmitted by the MUE to the eNB via the relay node is not necessarily as large as without a relay node. Then, interferences caused by the MUE in the neighboring macrocells to the HeNB can be minimized. More detailed descriptions of the system using the relay-based clustering method is described in the following and it is illustrated in Figure 2.

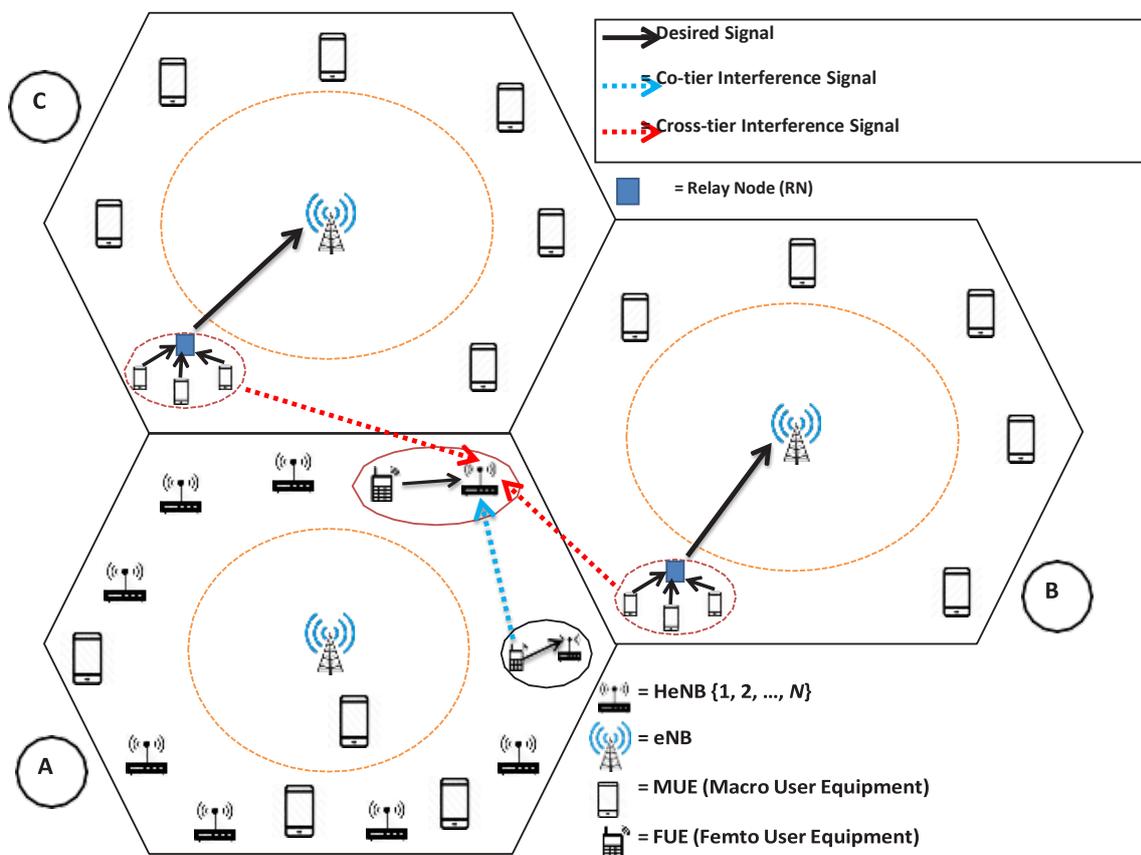


Figure 2. System with relay-based clustering method

In our previous paper [21] the relay-based clustering method was applied to mitigate the interference of femtocells deployed in macrocells which have been divided into six sectors. Furthermore, the focus of analysis in the paper [21] was only on two sectors of the observed macrocell area, namely sectors 1 and 2. Those two sectors are neighborhood of other two different macrocells accordingly. Each sector was deployed by thirty-three femtocells. Besides that, in this current paper, relay-based clustering is applied when femtocells are deployed in the whole cell edge area of the macrocell i.e., macrocell uses omnidirectional antenna.

There are some steps to apply the relay-based clustering method in the system. First, a number of relays is deployed statically (in fixed position) at two neighboring macrocells. In this paper, the relay nodes are placed on the positions of circle that indicate the border of the inner and outer macrocells (orange dashed circle). Those relay nodes that are deployed will recruit its corresponding members to be served consisting of several MUEs based on their closest distance to the certain relay node. It is assumed that one relay node can recruit a maximum of three MUEs. With this setting, the MUE does not need to transmit as a large amount of power to the eNB as the system without relay node, such that interference from neighboring macrocells' MUE to the observed HeNB can be minimized. The illustration of this second scenario can be seen in Figure 2.

As mentioned earlier, the goal of this research is to overcome the problem of interference in femtocells that its

Figure 3. Conventional system model with sectorized macrocell consisting of six sectors [21]

relay node is deployed statically (in fixed position) in the neighboring macrocell area (macrocells B and C), but in this scenario the relay node is used to mitigate cross-tier interference on the femtocells that are deployed in sectors 1 and 2 of the cell edge of macrocell A's area. Note that we have presented the scenarios in Figures 3 and 4 in [21]. It is presented and discussed in this paper for the comparison purposes.

B. Channel Model

In order to simulate the considered system models, it is necessary to describe the channel models that are applied. The channel models are very important to get the simulation successful. The signal that is sent from the transmitter will get attenuated to the receiver because the signal is propagated on the transmission media. The signal strength that is received at the receiver side can be calculated by considering the propagation model that is assumed. In this paper, we consider two channel models including macrocells and femtocells in urban areas. The channel model that is used in urban macrocells is based on the standard 3GPP TR 36.814 version 10.2.0 [22]. Meanwhile, the channel model that is used for the femtocells in urban area is based on the 3GPP TR 36.922 version 10.0.0 Release 10 standards [23]. For the channel model that is used in urban femtocells, it can be calculated using (1) [23].

$$L_{femto} (dB) = 15.3 + 37.6 \log_{10}(x) \quad (1)$$

Channel model used in urban macrocell can be calculated using (2) as the following [22].

position is in the cell edge area. Hence, we also consider the

$$L \left(\frac{x}{\beta} \right) = 127 + 30 \log \left(\frac{x}{\beta} \right) + L \tag{2}$$

scenario for femtocells deployed inside a macrocell that has

$$L_{\beta} = 10 \log \beta$$

been divided into six sectors in Figure 3. Since our goal is to improve the femtocells performances in the cell edge area of macrocell, we focus our analysis in sectors 1 and 2. It is because the femtocells deployed in sectors 1 and 2 of the macrocell are the areas that are most affected by interferences. Femtocells located in these two sectors are very close to the MUE which is also on the cell edge area of the neighboring macrocell.

Figure 3 is a conventional system scenario based on sector division, which means that this scenario has not applied any method. In this scenario, it can be expected that the performance of the femtocell is greatly decreased because it is affected by interference from the MUE in neighboring macrocells. To overcome this interference problem, we propose a scenario for the system with a relay-based clustering method as shown in Figure 4. Similar to the scenario in Figure 2, the

where x in both (1) and (2) denotes the distance between the user to the HeNB or to eNB in meters, respectively, meanwhile L_{β} represents the penetration loss in which its value in this paper is assumed to be 6 dB [24].

C. Signal-to-Interference-plus-Noise-Ratio Analysis

For the model system that was described previously, in order to evaluate the signal quality of the observed HeNB at the femtocell, it can be determined from the Signal-to-Interference-plus-Noise-Ratio (SINR) value. SINR is the ratio of the desired signal coming from the FUE to the observed HeNB to the interference signal from the MUEs and other FUEs who are using the same radio resources as the observed HeNB used plus noise power. The SINR can be calculated using (3) as the following.

$$SINR = \frac{P_{rx}}{\sum_{x=1}^n I_{co_tier} + \sum_{m=1}^m I_{cross_tier} + N} \tag{3}$$

when the number of femtocells is one femtocell. Then, the number of femtocells is increased by the factor of 1 until two where P_{rx} is the desired power from FUE to observed HeNB (in milli Watt), I_{co_tier} is the interference signal from other FUEs to observed HeNB (in milli Watt) with n is number of co-tier interferences, I_{cross_tier} is the interference signal from MUEs to observed HeNB (in milli Watt) with m is number of cross-tier interferences, and N is the Noise Power in the system (in milli Watt).

The desired signal (P_{rx}) from the served FUE or the co-tier interference signals caused by other FUEs (as co-tier interferences) can be calculated using (4).

hundred femtocells. Beside the SINR values, the performance parameters which are considered and collected are throughput and Bit Error Rate (BER). The cumulative probability of SINR and throughput values are described on the form of Cumulative Distribution Function (CDF) graph. Meanwhile, the cumulative probability of the bit error rate (BER) is illustrated on the Complementary Cumulative Distribution Function (CCDF) graph. The simulation program was run and the performance parameters were measured and averaged for two hundred observed femtocells. The simulation program was run for

$$\begin{aligned}
 &P_{rx} \\
 &(dBm) = P_{fue} \\
 &(dBm) - L_{femto} \\
 &(dB)
 \end{aligned} \tag{4}$$

twenty times as mentioned earlier. Then, the results for averaged performance parameter values of two hundred where P_{fue} is the transmit power that is transmitted from the desired FUE or other FUEs (as interference) in dBm. The cross-tier interference signals from the MUE can be calculated by using (5).

femtocells were averaged for twenty simulation times. These simulation parameters mentioned above are summarized in Table II.

$$\begin{aligned}
 &I_{cross_tier} \\
 &= P_{mue}(dBm) - L \\
 ¯o (dB)
 \end{aligned} \tag{5}$$

III. RESULTS AND DISCUSSION

As previously described, the simulation experiments in this where P_{mue} is the transmit power that is transmitted by MUE to the eNB or the observed HeNB in dBm.

D. Simulation Parameters

As in the system models previously discussed, this paper considers three macrocells of OFDMA-based wireless cellular network, which each macrocell is assigned different radio resources or frequency reuse factor is equal to 3. The radius of each macrocell and femtocell are set to 1000 m and 30 m, respectively [25].

It is assumed that femtocells can serve just one femtocell user equipment (FUE) at one time duration for the sake of simplicity analysis. Two hundred femtocells are densely and randomly deployed increased in step of 1 from one until two hundred femtocells in the whole coverage area of macrocell, especially the macrocell edge area. We deploy 200 femtocells because with this number of femtocells it is enough to form the UDN network in which it is the focus of our study as well. According to Ref. [26] UDN is defined as the density of access points (APs) which are more than the number of users. The maximum powers that are transmitted by both FUE and MUE without relay node are set to 23 dBm both [10]. The total bandwidth for the system is set to 10 MHz

[27]. All systems apply the modulation scheme of 16 Quadrature Amplitude Modulation (16 QAM). The inner and outer macrocell areas are bordered with a virtual circle of 750 m radius. A number of relay nodes is placed on this virtual circle which is equal to sixteen relay nodes. These sixteen relay nodes are determined and calculated to cover the border line of inner and outer areas of macrocell.

As relay nodes are deployed, MUEs belong to the member of a certain relay node do not need to transmit the signal as large as the system without relay node. Since the distance between relay node to the border of macrocell is quarter of macrocell radius, the transmit power of MUEs with relay nodes is set to

0.25 of MUEs' transmit power [28] without relay node, i.e., 50 mW (17 dBm). The simulation program was run for twenty times and the simulation results are averaged from these twenty times of simulation run. It is because the simulation experiment involves the random variables in the collected performance parameters, thus the results that are obtained are expected to be close to the expected values.

In the simulation experiments, firstly the SINR values are collected from the simulation to determine the signal quality

paper considers four scenarios. The first scenario is a conventional system or a system that does not apply the relay-based clustering method as shown in Figure 1. A number of femtocells are densely and randomly deployed in the whole cell edge area of macrocell A. Meanwhile, in macrocells B and C, the femtocells are not deployed, but within those two macrocells are deployed a number of macrocell user equipment (MUEs) at the cell edge area. We divide the cell area into two areas to describe the cell edge area (outer cell) and the center area (inner cell) of the cell as shown with orange dashed circle at the Figures 1 and 2.

The second scenario in the simulation system can be seen in Figure 2, which in this scenario the system is designed to improve conventional system using the relay-based clustering method. A number of relay nodes are deployed on macrocells B and C, with the expectation that the presence of relay nodes can mitigate the effect of cross-tier interferences coming from

TABLE II. SIMULATION PARAMETERS

No.	Parameters	Value
1.	Radius of macrocell [25]	1000 m
2.	Radius of circle to border of the inner and the outer of macrocells	750 m
3.	Radius of femtocell [25]	30 m
4.	Number of macrocells and eNBs	3
5.	Number of femtocells in the first and second scenarios	20 0
6.	Total number of MUEs in macrocells B and C (for the Scenario in Figures 1 and 2)	10 0
7.	Total number of MUEs in each sector of macrocells B and C (for the Scenario in Figures 3 and 4)	33

8.	Number of relay nodes	16
9.	Maximum number of users in a relay node	3
10.	Total system bandwidth [27]	10 MHz
11.	Transmit power of FUE for the systems with and without relay node [10] Transmit power of MUE for the system without relay node [10]	23 dBm
12.	Transmit power of MUE for the system with relay node [28]	23 dBm
13.		17 dBm
14.	Simulation times	20
15.	<u>Modulation scheme</u>	<u>16 QAM</u>

the MUEs to the HeNB. In the simulation, the maximum number of relay node members is set to three MUEs, taking into account the relay node recruits its members based on the shortest distance.

Figure 3 depicts third scenario for the simulation system. Femtocells are deployed in macrocells that have been divided into six sectors. To study the effectiveness of our proposed relay-based clustering method in the sectorized macrocell in the third scenario, we designed a fourth scenario in our simulation experiment which is depicted in Figure 4. This fourth scenario represents our focus on the effectiveness of proposed relay-based clustering method in reducing the effect of cross-tier interferences on the cell edge area.

The four scenarios described above are simulated using MATLAB software by writing the simulation program codes, with the simulation results presented in the graphical forms. Then, in the simulation results we will compare the system performance results of the system designed, namely the conventional system and the system that applies the relay-based clustering method. The system performances in Figures 1 and 3 are compared to the system performances in Figure 2 and 4, respectively.

We have carried out the simulation experiments extensively and then the simulation results are obtained. The simulation results are presented in Figures 5-8 of this section which we compare the results of the four designed system scenarios. In the simulation results, we will compare the CDF values of SINR and the throughput of each system. CDF indicates the cumulative probability of random variables which is less than or equal to a certain value, i.e., a constant value. In our case the random variables that are measured in CDF are the SINR and throughput.

Figure 5 shows the results for SINR as the number of femtocells is increased. In Figure 5 the x -axis indicates number of femtocells and the y -axis represents the SINR values for both conventional system and the system with relay-based clustering method. In general, the SINR performance of femtocells decreases as the number of femtocells increases for both systems. This SINR result implies that the performance of femtocells decreases as a result of the number of cross-tier and co-tier interferences increases. The interferences are originating from MUEs and other FUEs that use the same radio resources. The SINR values for the system that apply the relay-

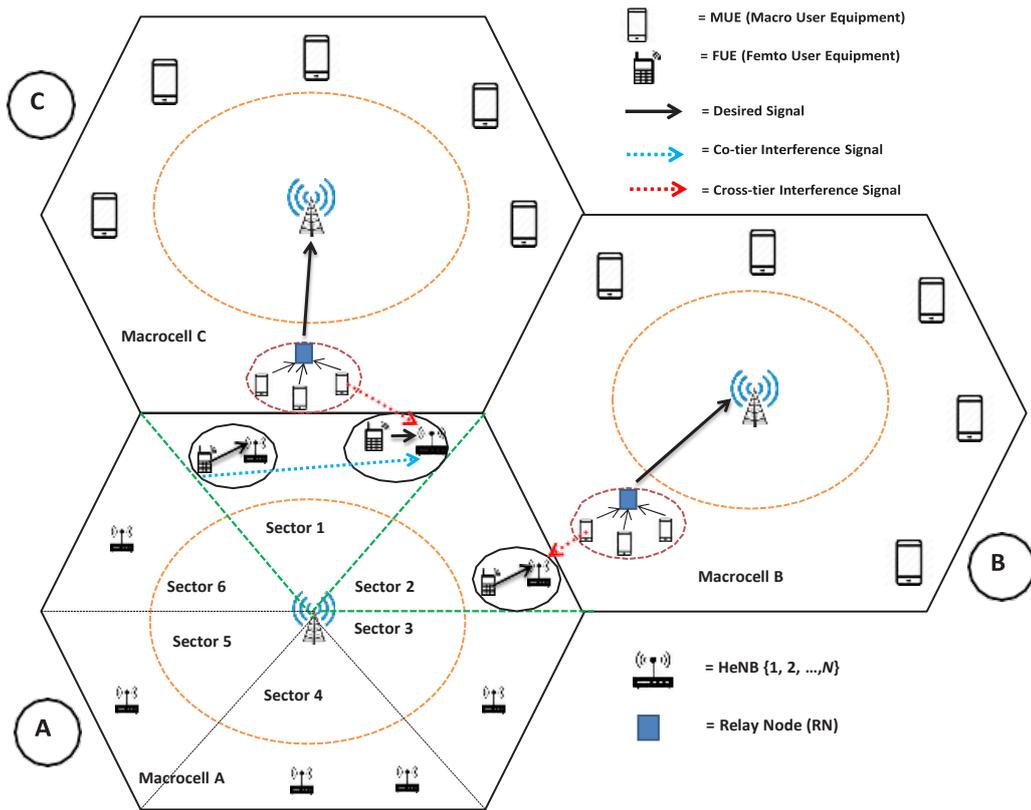
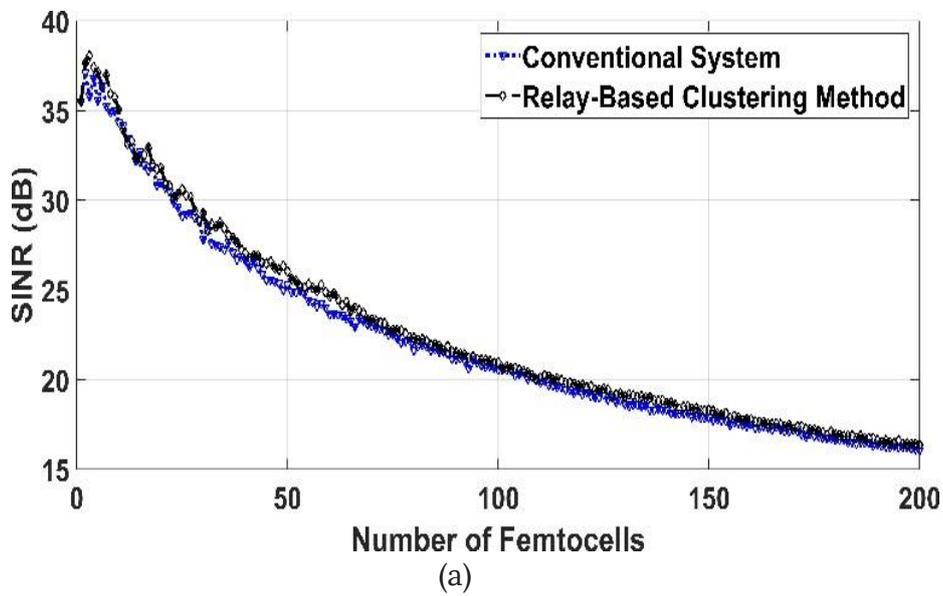


Figure 4. System with relay-based clustering method in the sectorized macrocell consisting of six sectors [21]



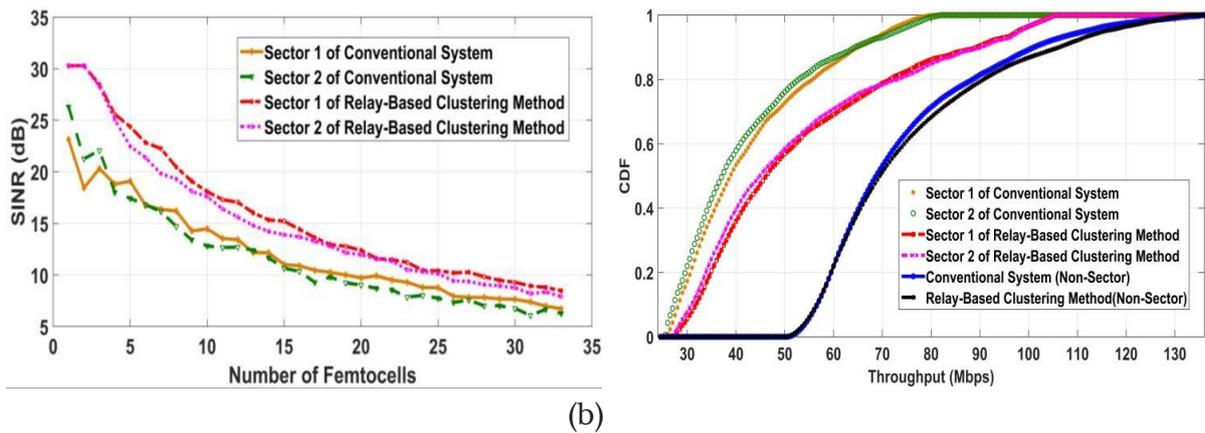


Figure 5. Simulation results for SINR performance: (a) comparison of conventional system and system with relay-based clustering method and (b) comparison of conventional system and system with relay-based clustering method based with sector division [21]

based clustering method outperforms the conventional system. It is because the transmit power of MUEs which caused the cross-tier interferences is decreased by the present of relay nodes. However, when we compare the SINR results for the proposed method in Figures 5 (a) and (b) we can see that the SINR values of our proposed method in Figure 5(a) is greater than the SINR values in Figure 5(b). It is because the femtocells deployed in sectors 1 and 2 within the cell edge of macrocell coverage area are located very close to the MUE on the cell edge of the neighboring macrocell. Consequently, the femtocells in sectors 1 and 2 are exposed to greater interferences than the femtocells that are randomly deployed in the whole cell edge area of macrocell, scenario in Figure 1.

Figure 6 depicts the results for CDF of SINR which is a comparison of the CDF of SINR for all four scenarios of both systems; the conventional system and the system that applies the relay-based clustering method. Suppose we target a SINR value of 20 dB which is excellent target. It can be seen that the probability of SINR not reaching the target when femtocells are deployed in the whole coverage cell edge area of macrocell for conventional system and system with relay-based clustering method are 46% and 44%, respectively. It relates to the SINR value below or equal to 20 dB. Meanwhile, the probability of SINR not reaching the target for conventional systems in sectors 1 and 2 are both 87%. Furthermore, the probability of SINR not reaching the target for systems that use the relay-based clustering method in both sectors 1 and 2 are 72% and 75%, respectively. Optimistically, it can be said that our proposed system can improve the SINR performance up to 15%. It is achieved when we compare the CDF of SINR between sectors 1 in the conventional system and the system with relay-based clustering method. In general, it can be said from the

Figure 6. The comparison of cumulative distribution function (CDF) of SINR for conventional system and system with relay-based clustering method results of the SINR probability that our proposed relay-based clustering method can improve the performance of femtocells located on the cell edge area of macrocells. We choose the

value of 20 dB for SINR target because 20 dB for SINR is an excellent signal measurement level for the cellular communication systems defined by the vendors [29].

In ref. [30], the system that applies the power control method has a probability of the SINR value not reaching the target or below or equal to 20 dB reaching 65%. While ref. [31], the applied power control method considered partial pathloss compensation to calculate the minimum transmit power, thus inter-cell interference can be reduced. Simulation results in ref.

[31] showed that the smaller the pathloss compensation value, the higher the SINR value. Thus, it can be understood that the relay-based clustering method outperforms conventional system and system that applied power control. In [18], to reduce cross-tier interference, a FFR method was applied. Furthermore, ref. [18] uses FFR on a millimeter wave network, where the outer cell and inner cell bandwidths were distinguished. The authors' goal was to reduce interference for cell edge users. Their simulation results showed that the applied FFR technique produced the lowest SINR of -4 dB and the highest SINR of 15 dB. In [32], the authors combined two methods, namely FFR and relay methods. Both methods were used to reduce interference for cell side users. The simulation results showed that the CDF of SINR value at 20 dB reaches 98% when the inner region radius was 0.5 km.

Based on the results of the studies above, it can be seen that femtocell performance can be improved, not only using techniques to reduce cross-tier interference, but also requires a technique to reduce co-tier interference. Due to the very close density of femtocells, dynamic frequency adjustment is to be required. Thus, the co-tier interference that occurs among femtocells can be reduced. However, it is not the focus of our current paper, since our target is to reduce the effect of cross-tier interferences by using relay-based clustering method, but at the same time the co-tier interference is still taken into account. We leave this theme as future works.

Figure 7 is a comparison of the CDF of throughput for both the conventional system and the system that applies the relay-based clustering method. When we notice the throughput target of 70 Mbps, the probability value of throughput below or equal to 70 Mbps for conventional system when femtocells are deployed in the whole coverage cell edge area of macrocell reaches 0.54 or 54%. Meanwhile, after applying the relay-based clustering method the probability of throughput value below or equal to 70 Mbps reaches 0.51 or 51%. In the meantime, the probability of throughput below or equal to 70 Mbps for

Figure 7. The comparison of cumulative distribution function (CDF) of throughput for conventional system and system with relay-based clustering method

conventional systems in both sectors 1 and 2 is 94%. In addition, the probability of throughput below or equal to 70 Mbps for systems using the relay-based clustering method in both sectors 1 and 2 reaches 79%. As we can see, the improvement of throughput for the conventional system is 15% by applying the proposed relay-based clustering method.

In ref. [33], interference management was carried out using interference identification and resource management techniques to reduce inter-femtocell interferences. The interference identification method produces patterns that are

received by the user using Universal Serial Radio Peripheral (USRP) software. The simulation results in their study showed that the proposed method was able to increase throughput by 20.64%. Meanwhile, ref. [8] proposed a cluster-based resource allocation method to reduce interference among Femtocell Access Points (FAPs). Meanwhile, in our current work our goal is to reduce cross-tier interferences coming from MUEs in neighboring macrocells. It has different scope compared to ref.

[8] in which their method can just reduce co-tier interference. The simulation results in [8] showed that as the number of FAPs increases, the data rate decreases. It is because the interferences among the closest FAPs increases. In addition to resource allocation methods, ref. [34] also reduced co-tier interference using greedy and graph-based technique (GBT) algorithms. Their simulation results showed that the greedy algorithm has the disadvantage of being inefficient in assigning random sub-bands.

From comparing with some of the results above, it can be said that the method that we propose in our current paper can only reduce cross-tier interference, while refs. [8], [31], [32] proposed the methods that can reduce co-tier interference only. As previously mentioned, to get optimal results on dense femtocell performance, a method that can reduce both interferences (co-tier and cross-tier) simultaneously is needed. However, it is not the focus of our paper, but it can be explored further as future works.

Figure 8 is a comparison of the CCDF of BER for both the conventional system and the system that applies the relay-based clustering method. CCDF means the cumulative probability of random variable that is greater than a certain value or a constant. We notice in Figure 8 that the probability of BER values above

0.01 for conventional systems when femtocells are deployed in the whole coverage cell edge area of macrocell is 0.71 or 71%. Meanwhile, after applying the relay-based clustering method the probability of BER values above 0.01 reaching 0.68 or 68%. In contrast, the probability of BER values above 0.01 for the conventional system when the femtocells are deployed in

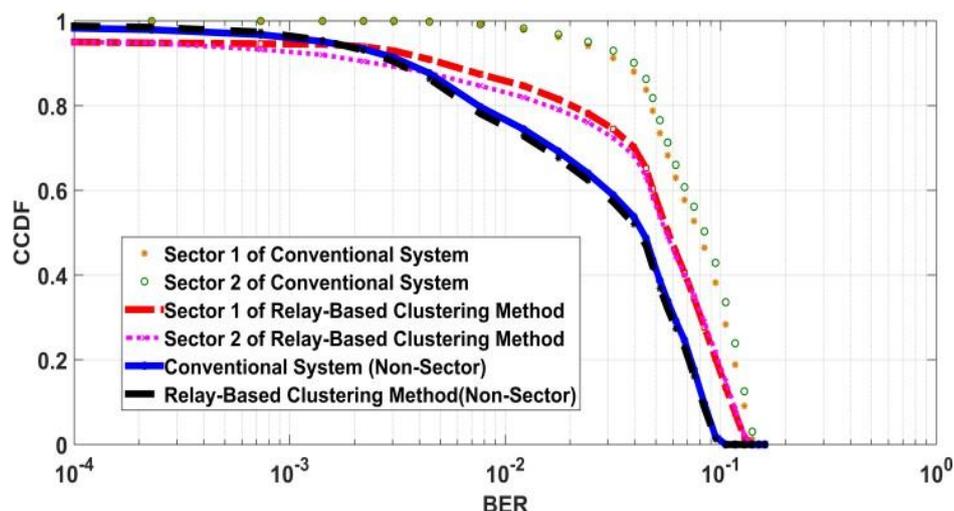


Figure 8. The comparison of complementary cumulative distribution function (CCDF) of bit error rate (BER) for conventional system and system with relay-based clustering method

macrocell sectors 1 and 2 is 97% both. After applying the relay-based clustering method, the probability of BER in sectors 1 and 2 becomes 86% and 83%, respectively. From these BER results, it can be said that the probability of errors that occurs in the system that applies the relay-based clustering method was smaller than the conventional system. The improvement achieves 14% in the case of sectorized macrocell at sector 2.

In ref. [27], cooperative relay method was used to reduce cross-tier interference for femtocells at the cell edge area. However, in their paper, the authors added a pre-coder and decoder algorithm for FAP, MUE, and cell-edge user (CUE) to minimize the number of mean square errors (MSE). The advantage of the cooperative relay technique over the relay technique that they proposed was that the cooperative technique made it possible to collect information about neighboring femtocells and allocated them by considering their effect on the neighbors.

The simulation results in [27] showed that the BER value was very minimum when the estimated value was added to the zero forcing (ZF) value. Although the application of ZF can reduce interference, but it increases noise power. Table III summarizes the comparisons of the results for the previous results on the literatures related to our discussion in this section. Based on the simulation results that have been described previously, it showed that the system that applies the relay-based clustering method outperforms the conventional system.

However, in the scenario where the femtocells are deployed in the whole coverage cell edge area of macrocell (scenarios in Figures 1 and 2), the differences in the probability of the SINR, throughput, and BER values between the two systems were not significant. It is because the power transmitted from the Macrocell User Equipment (MUEs) passing through the relay is only contributing to the reduction of the cross-tier interferences.

In our system scenarios, it is identified that the cross-tier interference was not dominant cause of interferences in our three macrocells layout with densely deployed femtocells (UDN). In our simulation scenarios, since we have considered femtocell densely deployed in macrocell that creates UDN, the higher contribution to the interference total in the system was caused by other femtocells (co-tier interferences). However, in the scenario of sectorized macrocell with femtocells deployed in it (scenarios in Figures 3 and 4), the improvements were significant.

It can be said that our results have good improvement to mitigate the cross-tier interferences even with UDN scenario. Our proposed system is superior even under UDN scenario. Our proposed relay-based clustering method promises as a solution to mitigate the cross-tier interference in UDN scenario. In addition, all performance parameters' results show the consistency of simulation experiments.

IV. CONCLUSION

This paper analyzes the interference that occurs in the femtocell-macrocell network, especially femtocells located at the cell edge area of macrocell. We propose the use of relay-based clustering method to reduce the effect of cross-tier

interferences caused by the users located in the cell edge area of neighboring macrocells. We use MATLAB programming code software to examine the scenarios that have been designed. Extensive simulation experiments have been carried out. The performance parameters have been collected in term of SINR, throughput and BER. The simulation results show that the relay-based clustering method can improve the performance of femtocells located in the cell edge area. It can be proven that the presence of relay nodes distributed in neighboring macrocells can reduce cross-tier interference that comes from macro user equipment (MUE). The power transmitted by the

TABLE III. COMPARISON OF PREVIOUS RESEARCH RESULTS

Ref.	Method	Result
[30]	Power control method	Probability of the SINR value was not reaching the target or below or equal to 20 dB reaching 65%
[31]	Power control method considering partial pathloss compensation	Simulation shows that the smaller the pathloss compensation value, the higher the SINR value
[18]	Fractional frequency reuse (FFR) method to reduce cross-tier interference	FFR technique produced the lowest SINR of -4 dB and the highest SINR of 15 dB
[32]	FFR and relay methods	CDF of SINR value at 20 dB reaches 98% when the inner region radius was 0.5 km
[33]	Interference identification and resource management techniques to reduce inter-femtocell interferences	Proposed method was able to increase throughput by 20.64%
[8]	Cluster-based resource allocation method to reduce interference among Femtocell Access Points (FAPs)	Simulation results showed that as the number of FAPs increases, the data rate decreases, because the interference between the closest FAPs increases
[34]	Greedy and graph-based technique (GBT) algorithms to reduce co-tier interference	The greedy algorithm has disadvantage of being inefficient in assigning random subbands
[27]	Cooperative relay method was used to reduce cross-tier interference for femtocells in the cell edge area	BER value was very minimum when the estimated value was added to the zero forcing (ZF) value. However, the application of ZF can reduce interference but increase noise power

MUE to the eNB via the relay node is reduced, thus the cross-tier interference to the observed femtocell can be minimized. This is implied in the results of SINR, throughput, and BER parameters that were obtained in the simulation. The optimistic simulation

results for the sectorized macrocells scenario show that Signal-to-Interference-plus-Noise-Ratio (SINR) of femtocells for the conventional system that does not reach the targeted SINR of 20 dB is 87%. Meanwhile, after applying the relay-based clustering method, SINR value of femtocells below or equal to 20 dB reaches 72%. Optimistic results for throughput and Bit Error Rate (BER) show improvement of 15% and 14%, respectively. Our system contributes a solution to mitigate the cross-tier interferences in the scenario of femtocells densely deployed in the macrocell cellular networks (Ultra Dense Networks/UDN). As our proposed relay-based clustering method focuses on the reduction of cross-tier interference effects, it can be suggested to study or to propose a scheme which is taking into account simultaneously both co-tier and cross-tier interferences as well as considering delay parameter as a consequence to apply relay node. We leave this theme as future works.

ACKNOWLEDGEMENT

This work was supported for the funding by University of Lampung (Unila), Indonesia through the scheme of Graduate Research (Penelitian Pascasarjana) of DIPA BLU Unila 2021.

REFERENCES

- L. Zhang, T. Jiang, and K. Luo, "Dynamic Spectrum Allocation for the Downlink of OFDMA-Based Hybrid-Access Cognitive Femtocell Networks," *IEEE Transactions on Vehicular Technology*, Vol. 65, No. 3, pp. 1772-1781, March 2016, doi: 10.1109/TVT.2015.2414424.
- H. Holma, A. Toskala, K. Ranta-aho, and J. Pirskanen, "High-Speed Packet Access Evolution in 3GPP Release 7 [Topics in Radio Communications]," *IEEE Communications Magazine*, Vol. 45, No. 12, pp. 29-35, Dec. 2007, doi: 10.1109/MCOM.2007.4395362.
- O. A. Akinlabi and M. Joseph, "Signal Behaviour in an Indoor Environment: Femtocell over Macrocell," 2016 IEEE 16th International Conference on Environment and Electrical Engineering (EEEIC), June 2016, pp. 1-5, doi: 10.1109/EEEIC.2016.7555864.
- C. Liu, P. Huang, L. Xiao, and A. Esfahanian, "Inter-Femtocell Interference Identification and Resource Management," *IEEE Transactions on Mobile Computing*, Vol. 19, No. 1, pp. 116-129, Jan. 2020, doi: 10.1109/TMC.2019.2892138.
- Y. L. Lee, J. Loo, T. C. Chuah, and A. A. El-Saleh, "Fair Resource Allocation with Interference Mitigation and Resource Reuse for LTE/LTE-A Femtocell Networks," *IEEE Transactions on Vehicular Technology*, Vol. 65, No. 10, pp. 8203-8217, Oct. 2016, doi: 10.1109/TVT.2016.2514535.
- I. Shgluof, M. Ismail, and R. Nordin, "Semi-Clustering of Victim-Cells Approach for Interference Management in Ultra-Dense Femtocell Networks," *IEEE Access*, Vol. 5, pp. 9032-9043, April 2017, doi:10.1109/ACCESS.2017.2695518.
- C. Liu, P. Huang, L. Xiao, and A. Esfahanian, "Inter-Femtocell Interference Identification and Resource Management," *IEEE Transactions on Mobile Computing*, Vol. 19, No. 1, pp. 116-129, Jan. 2020, doi: 10.1109/TMC.2019.2892138.

- H. Zhang, D. Jiang, F. Li, K. Liu, H. Song, and H. Dai, "Cluster-Based Resource Allocation for Spectrum-Sharing Femtocell Networks," *IEEE Access*, Vol. 4, pp. 8643-8656, Dec. 2016, doi: 10.1109/ACCESS.2016.2635938.
- Sung-Yeop Pyun, Woongsup Lee, and Ohyun Jo, "Uplink Resource Allocation for Interference Mitigation in Two-Tier Femtocell Networks", *Mobile Information Systems*, Vol. 2018, pp. 1-6, Dec. 2018, doi: 10.1155/2018/9093139.
- J. Dai and S. Wang, "Clustering-Based Interference Management in Densely Deployed Femtocell Networks," *Digital Communications and Networks*, Vol. 2, No. 4, pp. 175-183, Nov. 2016, doi: 10.1016/j.dcan.2016.10.002.
- Y.-J. Liang, "Dynamic Resource Allocation in Mobile Heterogeneous Cellular Networks," *Wireless Networks*, Vol. 25, pp. 1605-1617, Nov. 2017, doi: 10.1007/s11276-017-1617-8.
- T. LeAnh, N. H. Tran, S. Lee, E. Huh, Z. Han, and C. S. Hong, "Distributed Power and Channel Allocation for Cognitive Femtocell Network Using a Coalitional Game in Partition-Form Approach," *IEEE Transactions on Vehicular Technology*, Vol. 66, No. 4, pp. 3475-3490, April 2017, doi: 10.1109/TVT.2016.2536759.
- N. Sharma, D. Badheka, and A. Anpalagan, "Multi-objective Subchannel and Power Allocation in Interference-Limited Two-Tier OFDMA Femtocell Networks," *IEEE Systems Journal*, Vol. 10, No. 2, pp. 544-555, June 2016, doi: 10.1109/JSYST.2014.2308438.
- Z. Liu, Y. Yuan, H. Yuan, and X. Guan, "Power Allocation Based on Proportional-Integral Controller in Femtocell Networks with Consideration of Maximum Power Constraint," *IEEE Systems Journal*, Vol. 13, No. 1, pp. 88-97, March 2019, doi: 10.1109/JSYST.2018.2794508.
- B. Yuksekkaya and C. Toker, "Power and Interference Regulated Water-Filling for Multi-Tier Multi-Carrier Interference Aware Uplink," *IEEE Wireless Communications Letters*, Vol. 7, No. 4, pp. 494-497, Aug. 2018, doi: 10.1109/LWC.2017.2788883.
- A. Kalaycıoğlu and A. Akbulut, "Simulated Annealing Based Femtocell Power Control in Heterogeneous LTE Networks," *International Journal of Communications*, Vol. 11, pp. 27-33, 2017.
- A. Bezzina, M. Ayari, R. Langar, and L. A. Saidane, "A fair Cluster-Based Resource and Power Allocation Scheme for Two-tier LTE Femtocell Networks," *Global Information Infrastructure and Networking Symposium (GIIS)*, Porto, Portugal, Oct. 2016, pp. 1-6, doi:10.1109/GIIS.2016.7814945.
- N. Al-Falahy and O. Y. K. Alani, "Network Capacity Optimisation in Millimetre Wave Band Using Fractional Frequency Reuse," *IEEE Access*, Vol. 6, pp. 10924-10932, Oct. 2017, doi: 10.1109/ACCESS.2017.2762338.
- S. A. Khan, A. Kavak, S. A. Çolak, and K. Küçük, "A Novel Fractional Frequency Reuse Scheme for Interference Management in LTE-A HetNets," *IEEE Access*, Vol. 7, pp. 109662-109672, Aug. 2019, doi: 10.1109/ACCESS.2019.2933689.
- J. García-Morales, G. Femenias, and F. Riera-Palou, "Statistical Analysis and Optimization of a Fifth-Percentile User Rate Constrained Design for FFR/SFR-Aided OFDMA-Based Cellular Networks," *IEEE Transactions on Vehicular Technology*, Vol. 67,

- No. 4, pp. 3406-3419, April 2018, doi: 10.1109/TVT.2017.2782943.
- S.N. Hasim, M. Susanto, H. Fitriawan, and F. Hamdani, "Interference Management with Relay-Based Clustering Method on Ultra Dense Networks of Femto-Macrocellular Network," 2021 International Conference on Converging Technology in Electrical and Information Engineering (ICCTEIE), Oct. 2021, Bandar Lampung, Indonesia (in press).
- M. Susanto, R. Hutabarat, Y. Yuniati, and S. Alam, "Interference Management Using Power Control for Uplink Transmission in Femtocell-Macrocell Cellular Communication Network," 2017 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering, July 2017, pp. 245-250, doi: 10.1109/QIR.2017.8168490.
- M. Susanto, D. Fauzia, Melvi, and S. Alam, "Downlink Power Control for Interference Management in Femtocell-Macrocell Cellular Communication Network," 2017 15th International Conference on Quality in Research (QiR): International Symposium on Electrical and Computer Engineering, July 2017, pp. 479-484, doi: 10.1109/QIR.2017.8168533.
- M. Khatun, C. Guo, D. Matolak, and H. Mehrpouyan, "Indoor and Outdoor Penetration Loss Measurements at 73 and 81 GHz," 2019 IEEE Global Communications Conference (GLOBECOM), Dec. 2019, pp. 1- 5, doi: 0.1109/GLOBECOM38437.2019.9013945.
- A. Abdelnasser, E. Hossain, and D. I. Kim, "Clustering and Resource Allocation for Dense Femtocells in a Two-Tier Cellular OFDMA Network," IEEE Transactions on Wireless Communications, Vol. 13, No. 3, pp. 1628-1641, March 2014, doi: 10.1109/TW.2014.011614.131163.
- M. Kamel, W. Hamouda, and A. Youssef, "Ultra-Dense Networks: A Survey," IEEE Communications Surveys & Tutorials, Vol. 18, No. 4, pp. 2522-2545, Fourth quarter 2016, doi: 10.1109/COMST.2016.2571730.
- A. D. Mafuta, T. Walingo, and F. Takawira, "Interference Management in LTE-Advanced Cooperative Relay Networks: Decentralized Transceiver Design with Channel Estimation," IEEE Access, Vol. 7, pp. 131078-131093, Aug. 2019, doi: 10.1109/ACCESS.2019.2935990.
- S. P. Padhy, S. Sethi, and A. Tripathy, "Performance Evaluation of Relays Used for Next Generation Wireless Communication Networks," 2018 International Conference on Applied Electromagnetics, Signal Processing and Communication (AESPC), March 2020, pp. 1-4, doi: 10.1109/AESPC44649.2018.9033327.
- CableFree, "LTE RSRQ to SINR: LTE Metrics including RSRP, RSRQ and SINR," cablefree.net. <https://www.cablefree.net/wirelesstechnology/4glte/lte-rsrq-sinr/> (Accessed Dec. 15, 2021).
- W. Yao, J. Li, B. Tan, and S. Hao, "Interference Management Scheme of Ultra Dense Network Based on Clustering," IEEE 2nd Information Technology, Networking, Electronic and Automation Control Conference (ITNEC), Dec. 2017, pp. 374-377, doi: 10.1109/ITNEC.2017.8284755.
- S. Ali Saad, M. Ismail, R. Nordin, and A. Uddin, "A Fractional Path-Loss Compensation

- Based Power Control Technique for Interference Mitigation in LTE-A Femtocell Networks,” *Physical Communication*, Vol. 21, pp. 1-9, Dec. 2016, doi: 10.1016/j.phycom.2016.02.003.
- M. Abd-elnaby and A. Mohammed, “A Self-Organized Dynamic Resource Allocation Scheme Using Enhanced Fractional Frequency Reuse in LTE-Advanced Relay Based Networks,” *IET Communications*, Vol. 48, pp.174-186, July 2016, doi: 10.1049/iet-com.2015.0859.
- C. Liu, P. Huang, L. Xiao, and A. Esfahanian, “Inter-Femtocell Interference Identification and Resource Management,” *IEEE Transactions on Mobile Computing*, Vol. 19, No. 1, pp. 116-129, Jan. 2020, doi: 10.1109/TMC.2019.2892138.
- A. Adekunle and A. Gbenga-Ilori, “Minimizing Interference in Ultra- Dense Femtocell Networks Using Graph-Based Frequency Reuse Technique,” *FUOYE Journal of Engineering and Technology (FUOYEJET)*, Vol. 5, No. 1, pp. 55-59, March 2020, doi: 10.46792/fuoyejet.v5i1.456.

ANALISA DAMPAK MASUKNYA PHOTOVOLTAIC (PV) DALAM SKALA BESAR TERHADAP PERFORMA SISTEM TENAGA LISTRIK

Ubaidah¹, Khairudin², Dikpride Despa³, Lukmanul Hakim⁴

Jurusan Teknik Elektro Universitas Lampung, Bandar Lampung
Jl. Prof. Sumantri Brojonegoro No.1 Bandar Lampung 35145

¹ubaidah.te@gmail.com

²khairudin@eng.unila.ac.id

³despa@eng.unila.ac.id

⁴plgsekip@eng.unila.ac.id

Intisari

Photovoltaic (PV) merupakan salah satu pembangkit renewable energy yang sifatnya intermittent dimana ketersediaannya tidak selalu ada ketika diperlukan. Banyaknya jumlah PV yang masuk ke sistem tenaga listrik sangat berpengaruh terhadap kemampuan generator konvensional dalam mengejar ketertinggalan daya akibat menurunnya daya output PV atau pada saat daya output PV tidak tersedia. Hal ini disebabkan oleh karakteristik ramping rate setiap jenis generator berbeda-beda. Untuk mengatasi ketertinggalan daya pada sistem tenaga listrik, maka perlu membatasi banyaknya PV yang diperbolehkan terpasang pada sistem interkoneksi tenaga listrik.

Pada penelitian ini, data pembangkit dan beban yang digunakan berdasarkan data kelistrikan Lampung. Pembangkit yang digunakan adalah PLTA, PLTU, PLTP, PLTD, PLTMG dan PLTG. Berdasarkan hasil simulasi, banyaknya PV yang diperbolehkan terpasang maksimal 30% dari total pembangkitan pada konfigurasi pembangkitan tertentu. Apabila jumlah PV melebihi batas maksimal tersebut, maka akan terjadi ketidaksetimbangan daya antara pembangkit dan beban. Jika konfigurasi pembangkit dengan kapasitas generator besar dan memiliki ramping rate tinggi memungkinkan pembangkit PV yang terpasang ke interkoneksi tenaga listrik lebih dari 30% dari total pembangkitan.

Kata kunci – Duck curve, photovoltaic, ramping rate, ketidaksetimbangan daya.

Abstract

Photovoltaic (PV) is a renewable energy generator that produces electrical energy at a certain time or also called intermittent.. A large number of PV penetrations into the system significantly affects the ability of conventional generators to catch up with power due to decreased PV output power or when PV output power is not available. This is due to the different characteristics of the lean rate of each type of generator. To overcome the power imbalance in the electric power system with various compositions, it is necessary to limit the number of PV that is allowed to be installed in the electrical power interconnection system.

In this study, the generator and load data were used collectively from the Indonesian National Great Company. The power plants used are hydropower plant, steam power plant, geothermal power plant, diesel power plant, gas engine power plant, and gas power plant. Based on the simulation results, the number of PV that is allowed to be installed is a maximum of 30% of the total generation in a certain generation configuration. If the amount of PV exceeds the maximum limit, there will be a power imbalance between the generator and the load. If the generator configuration has a large generator capacity and has a high lean rate, PV plants can be connected to the electrical power interconnection of more than 30% of the total generation.

Keywords Duck curve, photovoltaic, ramping rate, power imbalance.

VI. PENDAHULUAN

Saat ini, teknologi generasi Photovoltaic (PV) berkembang sangat pesat. [1] Ditinjau dari segi sumber dayanya bahwa PV termasuk pembangkit listrik dengan renewable energy [2] memungkinkan untuk dijadikan salah satu pilihan pembangkit listrik dengan skala besar [3]. Namun, hal ini dikhawatirkan dapat menyebabkan ketidakstabilan system tenaga. [4]

PV merupakan yang memanfaatkan radiasi matahari. dengan daya output fluktuatif mengikuti kondisi cuaca yang ada. Selain itu, PV dapat menghasilkan daya pada saat siang hari saja. [5] Sehingga pada saat menjelang sore PV sudah tidak produktif lagi. Akibatnya daya beban yang sebelumnya dipenuhi oleh PV farm harus ditanggung oleh generator konvensional. [6] Sedangkan setiap jenis generator mempunyai karakteristik ramping rate yang berbeda. [7] Apabila generator konvensional tidak dapat mengejar kekurangan pada system, maka akan terjadi ketidaksetimbangan. Hal ini tidak boleh terjadi karena sangat berpengaruh terhadap kualitas dan stabilitas system tenaga. Seperti peristiwa di California yang kemudian disebut duck curve phenomenon, yaitu terjadinya peningkatan penggunaan PV setiap tahun dimulai pada 2012 sampai 2020 [8]. Pada siang hari daya beban ditanggung oleh PV, kemudian pada saat menjelang sore hari daya yang dihasilkan PV berkurang yang menyebabkan generator harus mengejar ketertinggalan daya. Toleransi banyaknya PV yang diperbolehkan pada system adalah lebih kecil dari 30% [9] Semakin banyak PV yang masuk pada system, maka ramp rate yang dibutuhkan generator untuk memenuhi kebutuhan permintaan beban juga semakin besar. [10] Hal ini perlu dipertimbangkan agar system dapat bertahan dalam keadaan setimbang.

Pada studi ini, menganalisa dampak masuknya PV dalam skala besar terhadap performa system kelistrikan Lampung serta memberikan rekomendasi dampak penambahan PV dalam skala besar pada sistem kelistrikan Lampung.

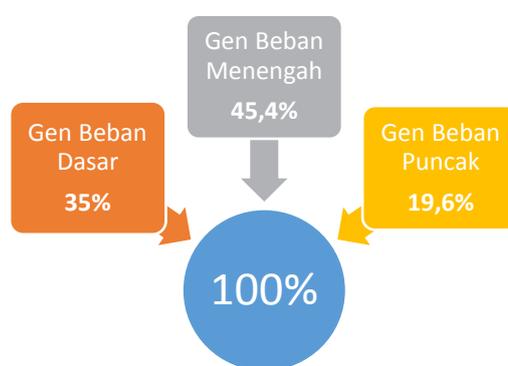
VII. MODEL SISTEM

B. Komposisi pembangkit

Sistem kelistrikan Lampung secara garis besar terdapat 7 pembangkit, yaitu PLTU, PLTP, PLTA, PLTG, PLTD, PLTMG dan PLTS dengan total pembangkitan 1,1 GW [11]. Pada penelitian ini pembagian jenis peran pembangkit adalah sebagai berikut:

Tabel 1. Pembagian Jenis Peran Pembangkit

Jenis Peran	Pembangkit
Beban Dasar	PLTA, PLTP
Beban Menengah	PLTMG, PLTU
Beban Puncak	PLTG, PLTD

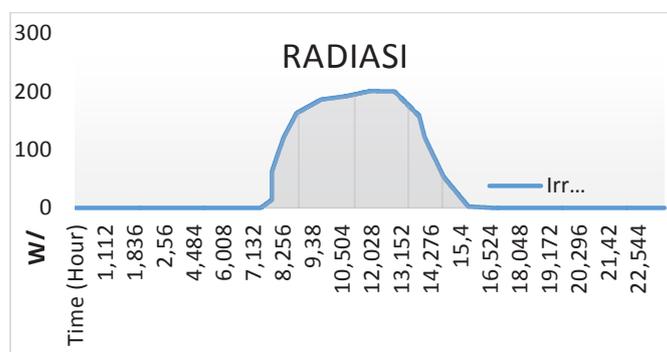


Gbr 1. Pembagian Presentase Pembangkit

Skenario yang diujikan adalah dengan menambahkan PV secara bertahap dari 20%, 25%, 30%, 35% dan 40% dari total pembangkitan yang ada. Pada penelitian ini, ditinjau pada hari cerah tanpa mempertimbangkan *shadding*.

C. Radiasi

Berikut merupakan data radiasi di Lampung pada bulan Januari 2020 dengan pembagian waktu 1 jam: 150 titik.



Gbr 2. Data Radiasi

VIII. METODOLOGI ANALISIS

Apabila daya beban dan daya pembangkit tidak setimbang, maka dapat mempengaruhi kualitas dan keandalan sistem tenaga listrik, sesuai dengan persamaan swing berikut ini:

$$P_m = P_e \quad (1)$$

$$\Delta P = d\omega / dt \cdot H_{\text{system}}$$

$$d\omega / dt = 1 / H_{\text{system}} (P_m - P_e)$$

Dimana,

$d\omega / dt$ = frekuensi anguler terhadap waktu

H_{system} = inersia konstan system

P_m = daya mekanik

P_e = daya elektrik

Seperti yang kita ketahui, jika terdapat pembangkit PV maka persamaan (1) diturunkan menjadi

$$P_g + P_{pv} - P_{loss} - P_L = 0 \quad (2)$$

Apabila PV tiba-tiba tidak menghasilkan daya, maka persamaan menjadi

$$P_g - P_{loss} - P_L = 0 \quad (3)$$

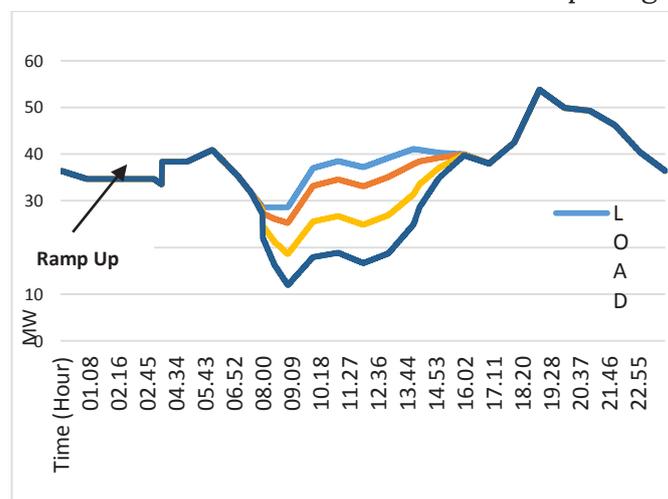
Dengan tidak adanya daya yang dihasilkan oleh PV P_{pv} dan daya beban P_L bernilai sama atau bahkan cenderung mengalami pertambahan, maka daya yang ditanggung oleh generator P_g akan semakin besar. [12] Sedangkan setiap generator mempunyai karakteristik ramping rate yang berbeda. Ramping rate sendiri adalah ukuran seberapa cepat suatu pembangkit dapat mengubah daya selama beroperasi dalam mengejar perubahan daya beban. [13]

$$\text{Ramp rate} = (\Delta P_{\text{Net}}) / \Delta t \quad (4)$$

Berdasarkan persamaan (4), jika daya yang dibutuhkan tidak terpenuhi dengan ramping rate generator yang ada, maka akan terjadi ketidak setimbangan system tenaga listrik.

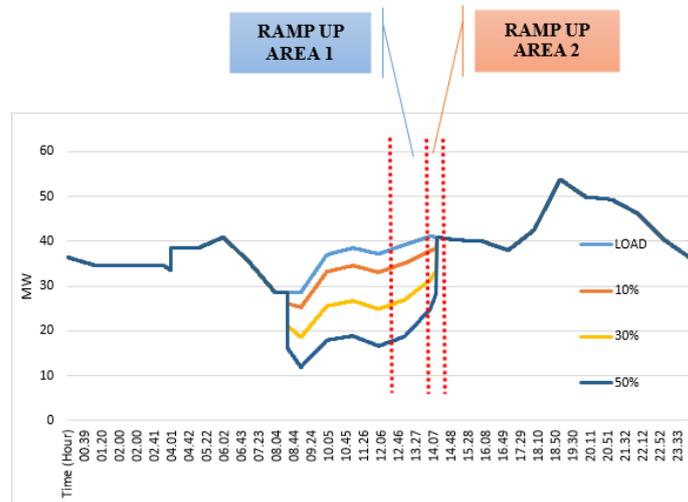
IX. HASIL SIMULASI

Setelah dilakukan simulasi dengan berbagai skenario, saat radiasi matahari mulai meredup daya yang dihasilkan oleh PV menurun, akibatnya generator harus mengejar kekurangan daya untuk memenuhi kebutuhan beban. dilihat pada gambar berikut



Gbr 3. Kurva beban yang ditanggung oleh generator konvensional

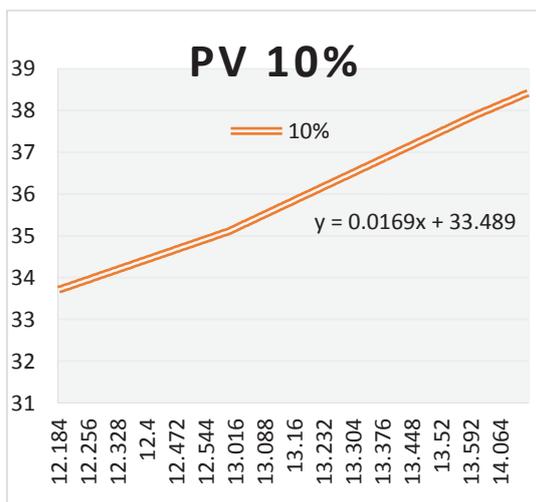
Pada kenyataannya radiasi efektif yang dapat menghasilkan daya sebesar 120,15 W/m² yang ditunjukkan pada gambar berikut ini. Sehingga kurva beban menjadi seperti gambar berikut



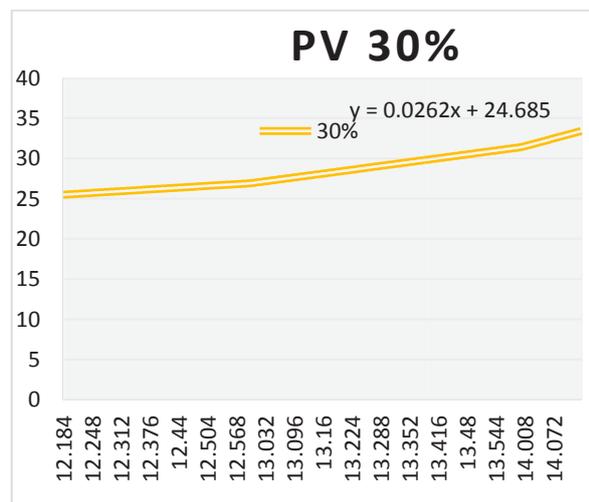
Gbr 4. Kurva beban dengan radiasi efektif

D. Ramp up Area 1

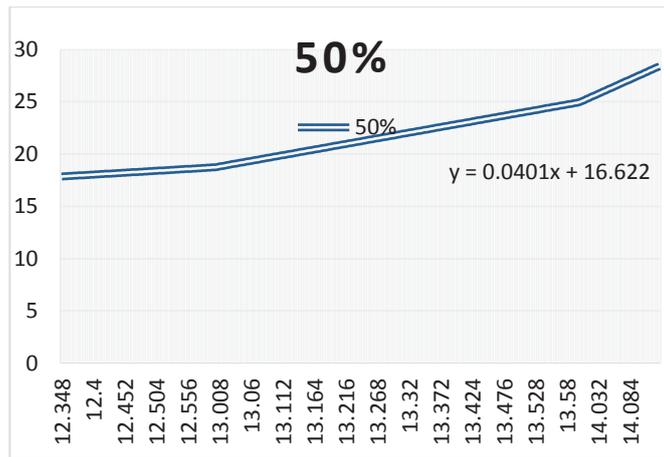
Bagian ini dimulai pada saat radiasi mulai mengalami penurunan, berikut merupakan hasil simulasi dari berbagai skenario besarnya PV yang dimasukkan ke system tenaga listrik. Batas maksimal ramping rate dapat ditanggung oleh generator konvensional adalah sebesar 3,017 MW/menit, berdasarkan simulasi pada area I ramping rate generator masih mampu melayani kebutuhan beban.



(a)



(b)

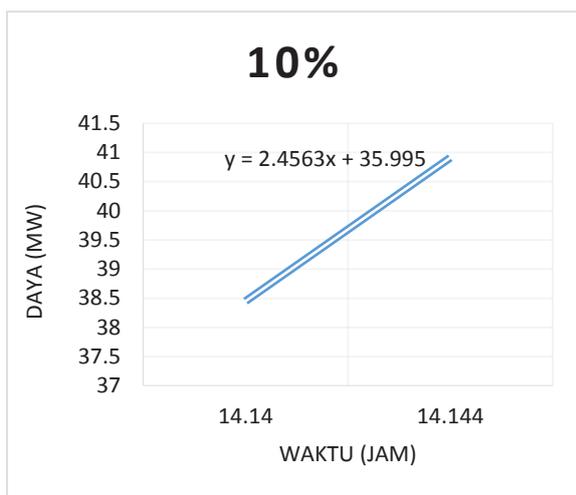


(c)

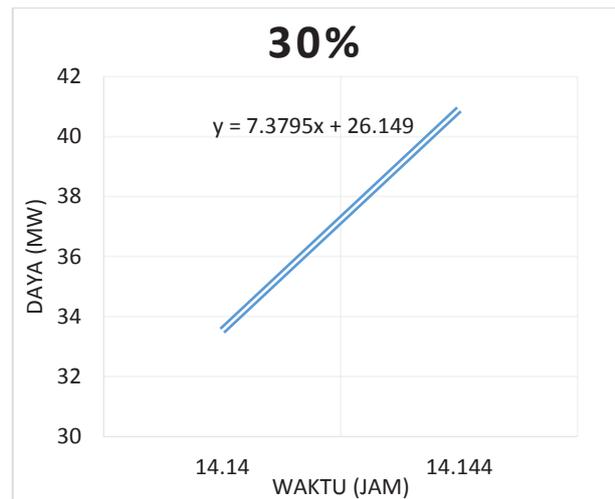
Gbr 5. Presentase PV 10%, 30% dan 50% Area I

E. Ramp Up Area II

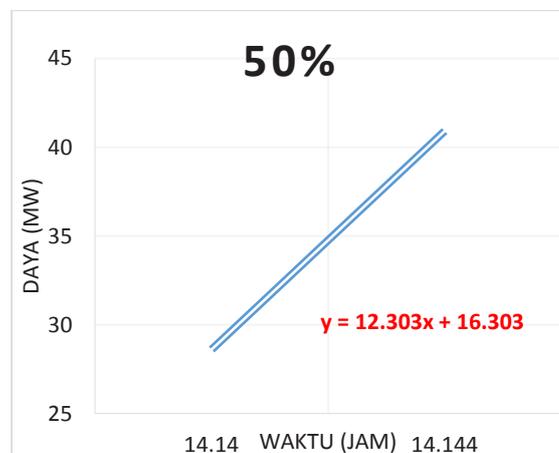
Bagian ini daya yang dihasilkan oleh PV mengalami penurunan drastis selama 48 detik. Dengan batas maksimal ramping rate yang dapat ditanggung oleh generator konvensional adalah sebesar 10,712/menit atau setara dengan 8,5696/48 detik. Berikut merupakan grafik pada Area II.



(a)



(b)



(c)

Gbr 6. Presentase PV 10%, 30% dan 50% Area II

Berdasarkan hasil simulasi pada gambar 8, batas maksimum diperbolehkan PV disistem adalah sebesar 30%, jika lebih maka generator konvensional yang ada tidak dapat memenuhi kebutuhan beban. Hal ini menyebabkan ketidak setimbangan system yang mengakibatkan pergeseran frekuensi, tegangan, arus dari nilai nominalnya. Sehingga jika tidak ditangani dengan baik maka dapat mengakibatkan black out.

X. PENUTUP

Berdasarkan hasil simulasi yang telah dilakukan dengan berbagai skenario komposisi pembangkit, dapat disimpulkan bahwa maksimum pembangkitan yang berasal dari PV dalam suatu sistem kelistrikan atau sistem interkoneksi yang ada di Lampung adalah 30% dari total pembangkit.

Apabila komposisi pembangkitan yang berasal dari PV lebih dari 30%, maka sistem kehilangan kemampuan untuk mencapai kesetimbangan antara pembangkitan dan beban.

UCAPAN TERIMA KASIH

Terimakasih kepada seluruh staf dan rekan Laboratorium Sistem Tenaga Elektrik (STE) yang telah mendukung kegiatan penelitian ini.

REFERENSI

- D. L. V. S. Y. M. and D. K. , "Smoothing control strategy of wind and photovoltaic output power fluctuation by considering the state of health of battery energy storage system," *IET Renew. Power Gen*, vol. 13, no. 4, pp. 578-586, 2019.
- T. K. C. C. C. L. and C. H. , "Transformer management system for energy control of customer demand response and PV systems," *IEEE Trans. Ind. Appl*, vol. 55, no. 1, pp. 51-59, 2019.
- F. B. R. Y. a. T. k. S. L. Wang, "Real-time coordinated voltage control of PV inverters and energy storage for weak networks with high PV penetration," *IEEE Trans. Power Syst*, vol. 33, no. 3, pp. 3383-3395, 2018.
- Q. Wang, Q. Yuan and . Y. Tang, "A Demand Response Strategy in High Photovoltaic Penetration Power Systems Considering the Thermal Ramp Rate Limitation," *IEEE*, vol. XX, pp. 1-9, 2017.
- A.-W. M. J. B. B. and A. A. K. , "Effect of Solar Radiation on Photovoltaic Cell," *International Research Journal of Advanced Engineering and Science*, vol. 3, no. 3, pp. 47-51, 2018.
- K. Prabha, *Power System Stability and Control*, New Jersey: Pentice Hall, 1993.
- M. A. Gonzalez-Salazar and T. K. , "Review of the operational flexibility and emissions of gas- and coal-fired power plants in a future with growing renewables," *Renewable and Sustainable Energy Reviews*, pp. 1-17, 2017.
- B. JONES-ALBERTUS, "ENERGI.GOV," *ENERGY EFFICIENCY & RENEWABLE ENERGY*, 12 October 2017. [Online]. Available: <https://www.energy.gov/eere/articles/>

[confronting-duck-curve-how-address-over-generation-solar-energy](#) . [Accessed 31 July 2021].

- A. Hoke and R. Butler, "Maximum Photovoltaic Penetration Levels on Typical Distribution Feeders," NREL, pp. 1-14, 2012.
- Q. H. and N. Zhang, "Probabilistic duck curve in high PV penetration power system: Concept, modeling, and empirical analysis in China," ELSEVIER, vol. 242, pp. 205-215, 2019.
- D. ESDM, PETA PENYEBARAN PEMBANGKIT LISTRIK PROVINSI LAMPUNG (Triwulan I Tahun 2019), Bandar Lampung: Pemerintah Provinsi Lampung, 2019.
- J. Glover and M. Sarma, Power System Analysis Fifth Edition, USA: Nelson Education, 2012.
- J. Marcos and O. Storke, "Storage requirements for PV power ramp-rate control," ELSEVIER, vol. 99, pp. 28-35, 2014.

KAJIAN KINERJA DAN KEBERLANJUTAN SPAM PERDESAAN DI LAMPUNG SELATAN

Yeddy Andriansyah^{a*}, Endro P. Wahono^b, Ahmad Zakaria^c

^a Mahasiswa Magister Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1 Bandar Lampung, 35145, Indonesia

^b Jurusan Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1 Bandar Lampung, 35145, Indonesia

^c Jurusan Teknik Sipil, Universitas Lampung, Jl. Soemantri Brojonegoro No. 1 Bandar Lampung, 35145, Indonesia

ABSTRAK

Kinerja dan keberlanjutan Sistem Penyediaan Air Minum (SPAM) merupakan faktor yang sangat menunjang kepada keberlangsungan atau kontinuitas penyediaan air minum pada sarana yang telah dibangun dari bantuan pemerintah. Pengukuran kinerja dan keberlanjutan pada suatu sarana SPAM menjadi komponen evaluasi terukur yang harus dilakukan oleh lembaga pengelola atau pihak lainnya sebagai dasar dari pengambilan keputusan untuk meningkatkan operasional dan pemeliharaan sarana. Penelitian mengenai kinerja dan keberlanjutan SPAM menjadi penting dengan menghitung indikator-indikator yang memberikan suatu klasifikasi pada nilai kinerja dan keberlanjutan SPAM. Pada penelitian ini metode perhitungan Angka Kebutuhan Nyata Operasional dan Pemeliharaan (AKNOP) irigasi digunakan untuk melakukan pengukuran kinerja dan keberlanjutan SPAM pada beberapa lokasi penelitian yaitu beberapa desa yang telah mendapatkan Program Penyediaan Air Minum dan Sanitasi Berbasis Masyarakat (PAMSIMAS) di Kabupaten Lampung Selatan Provinsi Lampung dengan jumlah sampel sebanyak 15 desa. Peneliti menempatkan posisi Pakem (Panitia Kemitraan) Program PAMSIMAS Kabupaten Lampung Selatan sebagai pewawancara.

5. Pendahuluan

Lajunya pertumbuhan pembangunan khususnya permukiman dan perumahan, memicu pertumbuhan kebutuhan air bersih di berbagai daerah di Indonesia. Ketersediaan air bersih terutama air minum adalah hal yang paling pokok dalam suatu proses pembangunan di suatu daerah dan merupakan salah satu komponen yang paling penting dalam proses penanggulangan kemiskinan.

Pembangunan konstruksi prasarana dan sarana air bersih dalam suatu proses pengembangan sistem air bersih di suatu kawasan adalah kegiatan utama yang harus dilaksanakan. Sedangkan kegiatan pemeliharaan dan rehabilitasi masih dianggap kegiatan sekunder yang terkadang masih belum diutamakan dan cenderung terabaikan.

Salah satu masalah dalam memelihara keberlanjutan sarana dan prasarana air bersih di suatu kawasan terutama di perdesaan adalah masih minimnya peran

masyarakat dalam kegiatan operasi dan pemeliharaan sarana dan prasarana tersebut [1]. Program pembangunan di desa seringkali tidak melihat kebutuhan, dan keterlibatan masyarakat di desa, dan masyarakat tidak diberi kapasitas yang cukup untuk melakukan pengelolaan mandiri, seperti melakukan operasi dan pemeliharaan. [2].

Salah satu program andalan pemerintah untuk memenuhi kebutuhan layanan dasar yang tidak terlayani oleh sistem publik pada wilayah perdesaan adalah Program Penyediaan Air Minum Dan Sanitasi Berbasis Masyarakat (PAMSIMAS) [3]. Pada prinsipnya Program Pamsimas bertujuan untuk meningkatkan jumlah fasilitas air bersih bagi warga masyarakat kurang mampu yang di wilayah perdesaan dan peri urban atau daerah pinggiran yang tidak dapat dicapai oleh Perusahaan Daerah Air Minum (PDAM).

Keberfungsian suatu fasilitas PAMSIMAS di suatu desa telah dapat diidentifikasi menjadi merah, kuning, dan hijau, namun metode yang dipakai untuk menentukan keberfungsian tersebut merupakan metode yang masih belum begitu baku dan masih sulit jika pengukuran keberfungsian tersebut dilakukan oleh masyarakat desa, lembaga pengelola dalam hal ini Kelompok Pengelola Sistem Penyediaan Air Minum dan Sanitasi (KP-SPAMS).

Salah satu metode penilaian sejenis pada dasarnya telah diciptakan untuk menilai kinerja dan fungsi suatu jaringan tetapi bukan untuk SPAM melainkan irigasi. Metode ini dilaksanakan untuk menghitung Angka Kebutuhan Nyata Operasi dan Pemeliharaan (AKNOP) di suatu jaringan irigasi. Metode ini diciptakan berdasarkan Permen PU&PR No.12/ PRT/M/2015 [4].

Melihat struktur analisis pengukuran dari AKNOP terdapat kemiripan dengan pengukuran analisis keberlanjutan PAMSIMAS, maka penelitian ini bermaksud mengembangkan suatu metode baku untuk menilai kinerja dan keberlanjutan SPAM Perdesaan khususnya Program Pamsimas.

Penelitian ini dilakukan di Kabupaten Lampung Selatan, Provinsi Lampung. Pemilihan lokasi ini berdasarakan kepada pertimbangan keterjangkauan lokasi penelitian oleh peneliti, sehingga akan sangat membantu dari segi efektifitas waktu dan efisiensi biaya penelitian.

6. Metode Penelitian

Penelitian ini berisi rangkaian proses atau langkah-langkah dalam rangka mengembangkan suatu produk atau metode baru atau menyempurnakan produk atau metode yang telah ada agar menghasilkan suatu keluaran yang lebih baik. Secara umum prosedur dalam penelitian kajian kinerja dan keberlanjutan SPAM perdesaan ini dapat dilihat pada bagan alir berikut:



Gambar 2.1. Bagan Alir Prosedur Penelitian
(Sumber: Hasil Penelitian, Juni 2018)

Beberapa penelitian mengenai pengukuran kinerja keberlanjutan untuk Program PAMSIMAS telah banyak dilakukan. Dan masih perlu diciptakan suatu metode yang baku untuk menilai keberfungsian Program PAMSIMAS, untuk menjamin kinerja dan keberlanjutannya di suatu kawasan.

Studi literatur dilaksanakan untuk mencari referensi baik dari buku-buku literatur maupun dari penelitian-penelitian yang telah dilaksanakan sebelumnya. Dalam penelitian ini kegiatan mempelajari struktur dan mekanisme metode AKNOP irigasi berdasarkan PU&PR No.12/ PRT/ M/ 2015 adalah termasuk dalam studi literatur ini. Kemudian juga dilakukan pendekatan penelitian dan perbandingan metode lainnya seperti metode penilaian pengukuran kinerja PDAM, yang sangat menginspirasi dari penelitian ini dalam metode perhitungannya.

Adapun metode pengumpulan data dalam penelitian ini adalah terbagi menjadi pengumpulan data primer dan data sekunder, di mana data primer didapat dari wawancara dan observasi, sedangkan data sekunder yaitu data dari Sistem Informasi Manajemen (SIM) PAMSIMAS [5].

Proses adopsi dan modifikasi adalah proses menyesuaikan komponen dan mekanisme metode AKNOP irigasi dengan metode penilaian keberfungsian PAMSIMAS, yaitu dengan menetapkan konversi pada komponen yang dinilai pada metode AKNOP, kepada komponen yang relevan pada program PAMSIMAS, hal itu dilakukan agar terjadi suatu proses modifikasi model yang tepat saat metode perhitungan AKNOP tersebut diterapkan pada perhitungan pengukuran kinerja Program PAMSIMAS.

Komponen yang dihitung dalam metode AKNOP irigasi adalah sebagai berikut:

- 1) Prasarana fisik
- 2) Produktivitas tanam
- 3) Sarana penunjang
- 4) Organisasi personalia
- 5) Dokumentasi

6) Kondisi kelembagaan P3A

Dari penilaian tersebut diatas akan diformulasikan sebagai konversi yang dapat dikemukakan dalam penelitian ini dengan formulasi penilaian PAMSIMAS (adopsi dan modifikasi AKNOP irigasi) adalah sebagai berikut:

- 1) Prasarana fisik
- 2) Produktivitas kegiatan
- 3) Sarana penunjang
- 4) Organisasi pendamping program
- 5) Dokumentasi
- 6) Kondisi kelembagaan KP-SPAMS

Dapat dicermati bahwa terjadi konversi pada komponen 2 (dua) dan komponen 6 (enam), yang mana semula “Produktivitas tanam” berubah menjadi “Produktivitas kegiatan”, lalu “Kondisi kelembagaan P3A’ berubah menjadi “Kondisi kelembagaan KP-SPAMS”.

Setelah dilakukan proses adopsi dan modifikasi secara menyeluruh, melalui penilaian dari lembar pertanyaan yang akan disampaikan kepada lembaga pengelola SPAM di desa yang menjadi sampling penelitian, maka dilakukan skoring pembobotan persentase untuk mengelompokkan kategori kondisi keberlanjutan sarana, dengan demikian maka didapatlah suatu model penilaian PAMSIMAS yang baru.

Walaupun demikian, metode yang baru ini harus terlebih dahulu diterapkan pada PAMSIMAS yang ada di lapangan. Apabila metode yang baru ini dapat menggambarkan keadaan PAMSIMAS yang sebenarnya maka metode ini dapat dipakai sebagai metode yang baku. Apabila kejadian yang terjadi adalah sebaliknya maka perlu diadakan koreksi pada struktur dan mekanisme metode yang baru sampai metode yang baru ini dapat menggambarkan kondisi keberfungsian PAMSIMAS yang sebenarnya.

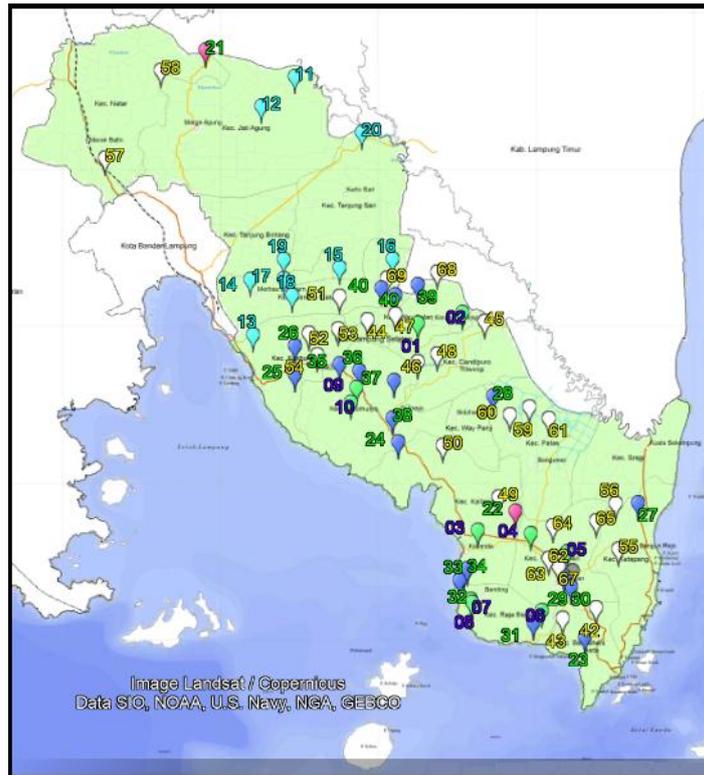
7. Hasil dan Pembahasan

7.1 Pengumpulan Data Sekunder

Terdapat dua jenis data yang diambil di dalam penelitian ini, yaitu data primer dan data sekunder. Data sekunder diambil dari SIM Pamsimas (<http://mis.pamsimas.org>), yaitu Data Keberlanjutan SIM Pamsimas, untuk kemudian diolah menjadi informasi dasar sebagai data pembanding dari data primer. Adapun data yang diambil adalah data pada modul keberlanjutan (modul 7.3), dengan detail data sebagai berikut:

- 1) Opsi Sarana Air Minum
- 2) Status keberfungsian
- 3) Iuran pemanfaat
- 4) Jumlah Sambungan Rumah (SR)

Kabupaten Lampung Selatan telah menjalankan PAMSIMAS mulai dari tahun 2014, dan masih akan menerima program reguler dari pemerintah dan pemerintah kabupaten sampai dengan tahun 2021. Saat peneilitian ini berlangsung, Kabupaten Lampung Selatan telah menyelesaikan 69 desa (Juni 2019), secara umum para pelaku program biasa menyebutnya desa pasca atau desa keberlanjutan.



Gambar 3.1. Peta Sebaran Lokasi Pamsimas Kabupaten Lampung Selatan
(Sumber: <http://sim.pamsimas.org>, Juni 2019, diolah)

A. Data Keberlanjutan Desa Tahun Anggaran 2014

Berdasarkan data yang diolah di Bulan Juni Tahun 2019 terhadap desa TA 2014 (10 desa), maka didapat data keberlanjutan desa pasca sebagai berikut.

Tabel 3.1. Kondisi Desa Pasca TA 2014

No.	Periode Laporan Desa, Kecamatan	Mar 16				Jun 16			
		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
				Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
1	Sukabanyar, Kec. Sidomulyo	H	2	60	0	H	2	60	0
2	Sidomulyo, Kec. Sidomulyo	H	2	70	8	H	2	83	8
3	Beringin Kencana, Kec. Candipuro	H	2	0	40	H	2	0	40
4	Banyumas, Kec. Candipuro	H	2	30	0	H	2	30	0
5	Kesugihan, Kec. Kalianda	H	2	0	63	H	2	0	63
6	Kerinjing, Kec. Rajabasa	H	2	0	30	H	2	0	30
7	Rajabasa, Kec. Rajabasa	H	2	0	75	H	2	0	75
8	Banding, Kec. Rajabasa	H	2	0	120	H	2	0	120
9	Gayam, Kec. Penengahan	H	2	0	30	H	2	0	30
10	Taman Baru, Kec. Penengahan	H	3	0	65	H	2	0	65
Total Pemanfaat (SR)				160	431			173	431
Total Akumulasi Pemanfaat (SR)				160	431			173	431

Sep 16				Des 16				Mar 17				Jun 17			
Keberfungsian	Iuran	Jml SR													
		Dgn WM	Tanpa WM												
H	2	60	0	H	2	60	0	H	2	60	0	H	2	0	60
H	2	83	8	H	2	83	8	H	2	83	8	H	2	0	45
H	2	0	40												
H	2	30	0	H	2	30	0	H	2	30	0	H	2	0	27
H	2	0	63	H	2	0	63	H	2	0	63	H	2	63	0
H	2	0	30	H	1	0	30	H	2	0	30	H	2	50	0
H	2	0	75	H	2	0	75	H	2	0	75	H	2	90	0
H	2	0	120	H	2	0	120	H	2	0	120	H	2	120	0
H	2	0	30	H	2	0	30	H	2	0	30	H	2	0	88
H	2	0	65	H	2	0	65	H	2	0	65	H	2	70	0
		173	431			173	431			173	431			393	260
		599	431			653	431			173	431			393	260
Sep 17				Des 17				Mar 18				Jun 18			
Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
		Dgn WM	Tanpa WM												
H	2	0	60	K	2	58	4	H	2	60	4	H	2	60	4
H	2	0	45	K	2	105	2	H	2	105	2	H	2	105	2
H	2	0	40	H	3	0	40	H	3	0	50	H	3	50	0
H	2	0	65	H	2	128	0	H	2	128	0	H	2	128	0
H	2	63	0	K	2	90	21	K	2	90	21	K	2	90	21
H	2	50	0	H	2	0	50	H	2	0	50	H	2	0	160
H	2	90	0	H	2	0	90	H	2	0	92	H	2	0	92
H	2	120	0	H	3	155	20	H	3	155	20	H	3	160	0
H	2	0	88	K	2	0	88	K	2	0	88	K	0	0	88
H	2	70	0	K	0	0	88	K	0	0	88	K	1	0	88
		393	298			536	403			538	415			593	455
		393	298			536	403			538	415			593	455
Sep 18				Des 18				Mar 19				Jun 19			
Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
		Dgn WM	Tanpa WM												
H	2	60	4	H	2	60	4	H	2	60	0	H	2	70	0
H	2	105	2	H	2	105	2	H	2	106	1	H	2	115	1
H	3	50	0	H	2	50	0	H	3	70	0	H	3	95	0
H	2	128	0	H	2	128	0	H	2	128	0	H	2	257	0
K	2	90	21	H	2	90	21	H	2	90	21	H	2	111	21
H	2	0	160	H	2	0	160	H	2	0	192	H	2	0	192
H	2	0	92												
H	3	160	0	H	2	160	0	H	3	160	0	H	3	160	0
K	0	0	88	H	0	0	88	H	2	0	93	H	2	0	96
K	1	0	88	H	1	0	88	H	1	88	0	H	2	88	0
		593	455			593	455			702	399			896	402
		593	455			593	455			702	399			896	402

(Sumber: sim.pamsimas.org, data SIM Keberlanjutan, Modul 7.3.)

Keterangan Tabel:

- H = Hijau, Berfungsi Baik;
K = Kuning, Berfungsi Sebagian;
M = Merah, Tidak Berfungsi.

B. Data Keberlanjutan Desa Tahun Anggaran 2015

Berdasarkan data yang diolah di Bulan Juni Tahun 2019 terhadap desa TA 2015 (10 desa), maka didapat data keberlanjutan desa pasca sebagai berikut.

Tabel 3.2. Kondisi Desa Pasca TA 2015

Periode Laporan		Sep 16				Des 16			
No.	Desa, Kecamatan	Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
				Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
1	Sumber Jaya, Kec. Jati Agung	H	2	37	0	H	2	37	0
2	Sinar Rejeki, Kec. Jati Agung	H	2	42	0	H	2	42	0
3	Malang Sari, Kec. Tanjung Sari	H	2	107	0	H	2	107	0
4	Rangai Tri Tunggal, Kec. Katibung	H	2	10	0	H	2	10	0
5	Karang Raja, Kec. Merbau Mataram	H	2	50	0	H	2	50	0
6	Suban, Kec. Merbau Mataram	H	2	19	0	H	2	50	0
7	Triharjo, Kec. Merbau Mataram	H	2	86	0	H	2	87	0
8	Panca Tunggal, Kec. Merbau Mataram	H	2	15	0	H	2	15	0
9	Pujirahayu, Kec. Merbau Mataram	H	2	40	0	H	2	40	0
10	Karang Jaya, Kec. Merbau Mataram	H	2	20	0	H	2	42	0
Total Pemanfaat (SR)					426	0		480	0
Total Akumulasi Pemanfaat (SR)					1025	431		1133	431

Mar 17				Jun 17				Sep 17				Des 17			
Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
		Dgn WM	Tanpa WM			Dgn WM	Tanpa WM			Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
H	2	37	0	H	2	22	0	H	2	31	0	H	2	35	0
H	2	42	0	H	2	73	0	H	2	40	0	H	1	40	0
H	2	107	0	H	2	80	0	H	2	103	0	H	2	109	1
H	2	10	0	H	2	10	0	H	2	10	0	M	0	0	0
H	2	50	0	H	2	60	0	H	2	60	0	K	2	60	0
H	2	50	0	H	2	60	0	H	2	60	0	H	2	60	0
H	2	87	0	H	2	87	0	H	2	90	0	H	2	165	0
M	2	15	0	M	0	0	0	M	0	0	0	M	0	0	0
H	2	40	0	H	2	35	0	H	2	35	0	H	2	140	0
H	2	42	0	H	2	42	0	H	2	42	0	H	2	42	0
		480	0			469	0			471	0			651	1
		653	431			862	260			864	298			1187	404

Mar 18				Jun 18				Sep 18				Des 18			
Keberfungsian	Iuran	Jml SR													
		Dgn WM	Tanpa WM												
H	2	36	1												
H	1	40	2	H	2	40	2	H	2	40	2	H	2	40	2
H	2	116	1	H	2	116	1	H	2	129	0	H	2	129	0
M	0	0	0	M	0	0	0	M	0	0	0	H	2	30	0
K	2	62	0	K	2	71	0	K	2	71	0	H	2	71	0
H	2	86	0												
H	2	165	0												
M	0	0	0	M	0	0	0	M	0	0	0	H	0	70	0
H	2	140	0												
H	2	44	0	H	2	47	0	H	2	47	0	H	2	47	0
		689	4			701	4			714	3			814	3
		1227	419			1294	459			1307	458			1407	458

Mar 19				Jun 19			
Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
		Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
H	2	36	1	H	2	40	1
H	2	40	2	H	2	43	2
H	2	129	0	H	2	129	0
H	1	30	0	H	2	50	0
H	2	71	0	H	2	71	0
H	2	86	0	H	2	105	0
H	2	168	0	H	2	174	0
H	1	70	0	H	2	90	0
H	2	140	0	H	2	140	0
H	2	47	0	H	2	47	0
		817	3			889	3
		1519	402			1785	405

(Sumber: sim.pamsimas.org, data SIM Keberlanjutan, Modul 7.3.)

C. Data Keberlanjutan Desa Tahun Anggaran 2016

Berdasarkan data yang diolah di Bulan Juni Tahun 2019 terhadap desa TA 2016 (2 desa), maka didapat data keberlanjutan desa pasca sebagai berikut.

Tabel 3.3. Kondisi Desa Pasca TA 2016

Periode Laporan		Mar 18				Jun 18			
No.	Desa, Kecamatan	Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
				Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
1	Sukadamai, Kec. Natar	H	2	111	0	H	2	160	0
2	Kekiling, Kec. Penengahan	H	2	25	0	H	1	35	0
Total Pemanfaat (SR)				136	0				
Total Akumulasi Pemanfaat (SR)				1363	419	1489 459			

Sep 18				Des 18				Mar 19				Jun 19			
Keberfungsian	Iuran	Jml SR													
		Dgn WM	Tanpa WM												
H	2	160	0												
H	2	35	0	H	2	35	0	H	2	40	0	H	2	40	0
		195	0			195	0			200	0			200	0
		1502	458			1602	458			1719	402			1985	405

D. Data Keberlanjutan Desa Tahun Anggaran 2017

Berdasarkan data yang diolah di Bulan Juni Tahun 2019 terhadap desa TA 2017 (19 desa), maka didapat data keberlanjutan desa pasca sebagai berikut.

Tabel 3.4. Kondisi Desa Pasca TA 2017

Periode Laporan		Mar 18				Jun 18			
No.	Desa, Kecamatan	Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
				Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
1	Babatan, Kec. Katibung	H	2	37	0	H	2	37	0
2	Sumberagung, Kec. Way Sulan	H	2	30	0	H	2	30	0
3	Karang Pucung, Kec. Way Sulan	H	2	80	0	H	2	128	0
4	Talang Way Sulan, Kec. Way Sulan	H	2	0	0	H	2	45	0
5	Batu Balak, Kec. Rajabasa	H	2	0	0	H	1	10	0
6	Canggung, Kec. Rajabasa	H	2	54	0	H	2	53	1
7	Betung, Kec. Rajabasa	H	2	60	0	H	2	60	0
8	Kota Guring, Kec. Rajabasa	H	2	20	120	H	2	20	120
9	Munjuk Sempurna, Kec. Kalianda	H	2	56	0	H	1	56	0
10	Kelawi, Kec. Bakauheni	H	2	110	0	H	2	110	0
11	Taman Sari, Kec. Ketapang	H	2	37	0	H	2	37	0
12	Tanjung Jaya, Kec. Palas	H	2	87	0	H	2	87	0
13	Tanjung Heran, Kec. Penengahan	H	2	50	0	H	1	50	0
14	Pisang, Kec. Penengahan	H	2	40	0	H	1	40	0
15	Bandar Dalam, Kec. Sidomulyo	H	2	40	0	H	2	40	0
16	Campang Tiga, Kec. Sidomulyo	H	2	45	0	H	1	45	0
17	Sidorejo, Kec. Sidomulyo	H	2	50	0	H	1	50	0
18	Sukamaju, Kec. Sidomulyo	H	2	54	0	H	2	50	4
19	Sido Mekar, Kec. Katibung	H	2	0	0	H	0	27	0
Total Pemanfaat (SR)				850	120			975	125
Total Akumulasi Pemanfaat (SR)				2213	539			2464	584

Sep 18				Des 18				Mar 19				Jun 19			
Keberfungsian	Iuran	Jml SR													
		Dgn WM	Tanpa WM												
H	2	37	0	H	2	37	0	H	2	70	0	H	2	85	0
H	2	30	0	H	2	30	0	H	2	100	0	H	2	100	0
H	2	128	0	H	2	128	0	H	2	157	0	H	2	186	0
H	2	45	0	H	2	45	0	H	2	60	0	H	2	65	0
H	1	10	0	H	1	10	0	H	1	66	0	H	2	66	0
H	2	53	1	H	2	53	1	H	2	125	0	H	2	127	0
H	2	60	0	H	2	60	0	H	2	77	0	H	2	78	0
H	2	20	120	H	2	20	120	H	2	72	68	H	2	72	68
H	1	56	0	K	1	56	0	H	1	66	0	H	2	66	0
H	2	110	0	H	2	110	0	H	2	185	0	H	2	252	0
H	2	37	0												
H	2	87	0	H	2	87	0	H	1	87	0	H	2	92	0
H	1	50	0	H	1	50	0	H	1	50	0	H	2	52	0
H	1	40	0	H	1	40	0	H	1	40	0	H	2	48	0
H	2	40	0	H	2	40	0	H	2	50	0	H	2	50	0
H	1	45	0	H	1	45	0	H	1	45	0	H	2	45	0
H	1	50	0	H	1	50	0	H	1	50	0	H	2	50	0
H	2	50	4	H	2	50	4	H	1	50	4	H	2	50	4
K	0	27	0	K	0	27	0	H	1	27	0	H	2	31	0
		975	125			975	125			1414	72			1552	72
		2477	583			2577	583			3133	474			3537	477

(Sumber: sim.pamsimas.org, data SIM Keberlanjutan, Modul 7.3.)

E. Data Keberlanjutan Desa Tahun Anggaran 2018

Berdasarkan data yang diolah di Bulan Juni Tahun 2019 terhadap desa TA 2018 (28 desa), maka didapat data keberlanjutan desa pasca sebagai berikut.

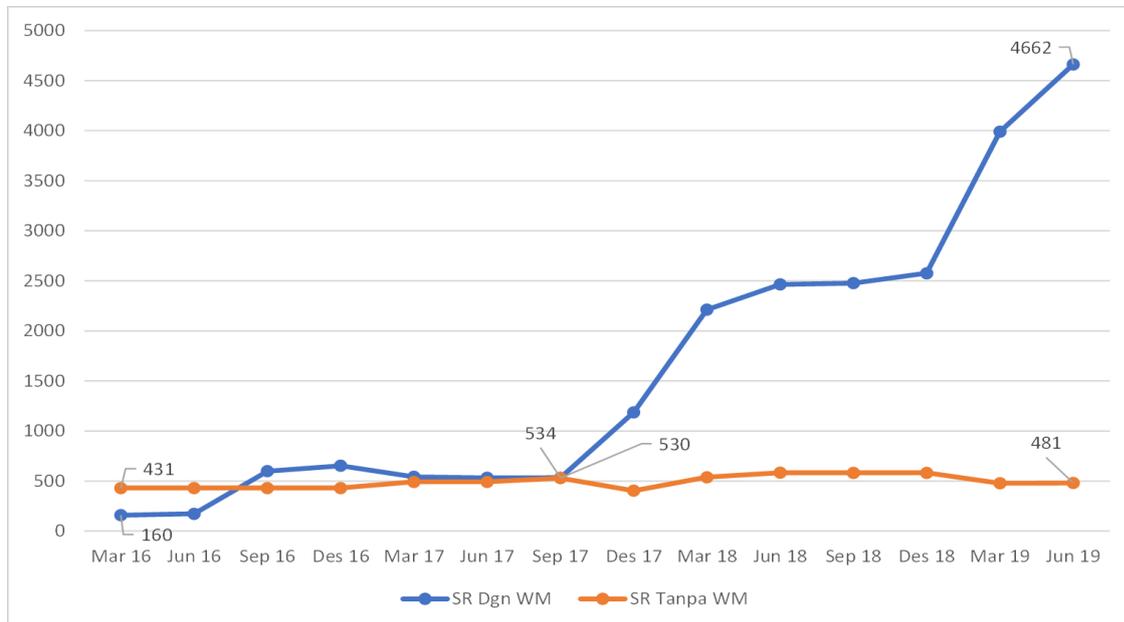
Tabel 3.4. Kondisi Desa Pasca TA 2018

Periode Laporan		Mar 19				Jun 19			
No.	Desa, Kecamatan	Keberfungsian	Iuran	Jml SR		Keberfungsian	Iuran	Jml SR	
				Dgn WM	Tanpa WM			Dgn WM	Tanpa WM
1	Pardasuka, Kec. Katibung	H	2	32	0	H	2	55	0
2	Banjarsari, Kec. Way Sulan	H	2	21	0	H	2	32	0
3	Karya Mulya Sari, Kec. Candipuro	H	2	7	0	H	2	23	0
4	Taman Agung, Kec. Kalianda	H	3	20	0	H	3	26	0
5	Bali Agung, Kec. Palas	H	3	10	0	H	3	26	0
6	Kemukus, Kec. Ketapang	H	2	19	3	H	2	23	3
7	Rawa Selapan, Kec. Candipuro	H	2	25	0	H	2	30	0
8	Pemanggilan, Kec. Natar	H	2	24	0	H	2	42	0
9	Neglasari, Kec. Katibung	H	2	20	0	H	2	40	0
10	Tanjungagung, Kec. Katibung	H	3	19	0	H	3	19	0
11	Sukabaru, Kec. Penengahan	H	3	15	0	H	3	30	0
12	Sukajaya, Kec. Penengahan	H	3	15	0	H	3	20	0
13	Mekarsari, Kec. Way Sulan	H	2	37	0	H	2	60	0
14	Batuliman Indah, Kec. Candipuro	H	2	21	0	H	2	28	0
15	Sidoasri, Kec. Candipuro	H	2	4	0	H	2	15	0
16	Bumi Daya, Kec. Palas	H	2	70	0	H	2	70	0
17	Mekar Mulya, Kec. Palas	H	2	29	0	H	2	29	0
18	Way Gelam, Kec. Candipuro	H	3	40	0	H	3	40	0
19	Gedungharta, Kec. Penengahan	H	3	29	0	H	3	29	0
20	Tetaan, Kec. Penengahan	H	3	22	0	H	3	22	0
21	Pancasila, Kec. Natar	H	2	21	0	H	2	30	0
22	Bangun Rejo, Kec. Ketapang	H	2	38	1	H	2	51	1
23	Tajimalela, Kec. Kalianda	H	3	48	0	H	3	48	0
24	Totoharjo, Kec. Bakauheni	H	2	146	0	H	2	156	0
25	Hata, Kec. Bakauheni	H	3	50	0	H	3	50	0
26	Ruang Tengah, Kec. Penengahan	H	3	10	0	H	3	29	0
27	Banjarmasin, Kec. Penengahan	H	3	27	0	H	3	27	0
28	Sukajaya, Kec. Katibung	H	2	38	0	H	2	75	0
Total Pemanfaat (SR)				857	4			1125	4
Total Akumulasi Pemanfaat (SR)				3990	478			4662	481

(Sumber: sim.pamsimas.org, data SIM Keberlanjutan, Modul 7.3.)

F. Resume Data Keberlanjutan Periode Juni 2019

Berikut ini disajikan beberapa grafik yang merupakan informasi yang diperoleh dari data pada pembahasan sebelumnya.



Gambar 3.2. Peta Sebaran Lokasi Pamsimas Kabupaten Lampung Selatan
(Sumber: <http://sim.pamsimas.org>, Juni 2019, diolah)

Dari grafik tersebut diperoleh informasi bahwa di Bulan Maret 2016 dari SPAM terbangun di 10 desa, adalah sebanyak 591 SR (160 SR dengan Water Meter (WM) dan 431 SR tanpa WM). Kemudian terjadi penambahan baik SPAM terbangun maupun penambahan SR, maka diperoleh jumlah pemanfaat di Bulan September 2017 dari SPAM terbangun di 20 desa yaitu menjadi 1,064 SR (534 SR dengan WM dan 530 SR tanpa WM).

Lalu terjadi penambahan pemanfaat pada saat penelitian dilakukan di Bulan Juni 2019 dari SPAM terbangun di 69 desa yaitu menjadi 5,143 SR (4,662 SR dengan WM dan 481 SR tanpa WM). Dengan demikian diperoleh rata-rata SR adalah 74.50 SR dimana rata-rata 67.56 SR dengan WM dan rata-rata 6.97 SR tanpa WM per desa. Hal ini masih jauh dari harapan dimana kapasitas sistem rencana desain SPAM terbangun rata-rata adalah sebanyak 209.17 SR, berarti baru mencapai pertumbuhan SR sebesar 35.63%, masih terdapat idle capacity sebesar 64.37%.

7.2 Pengumpulan Data Primer

Data primer didapatkan melalui survey ke beberapa lokasi penelitian, dengan melakukan penilaian berupa wawancara dan observasi. Responden yang dimintai menjawab lembar penilaian adalah KP-SPAMS, agar diperoleh nilai objektivitas yang lebih baik. Adapun penilaian dilakukan oleh personel Panitia Kemitraan (Pakem) dan Tim Fasilitator Masyarakat (TFM), sedangkan peneliti berfokus kepada persiapan lembar pertanyaan, dan menjelaskan jika terdapat pertanyaan yang sulit dipahami maksudnya oleh pewawancara, atau sulit dicerna oleh responden.

Tabel. 3.5. Pewawancara dan Jumlah Responden

No	Pewawancara	Jumlah Responder (KP-SPAMS)	Keterangan
1	Panitia Kemitraan	13	Lembar Penilaian
2	Fasilitator Masyarakat	2	Lembar Penilaian

(Sumber: Hasil penelitian)

Populasi di dalam penelitian ini merupakan wilayah yang akan diteliti oleh peneliti, menurut Sugiyono (2011:80) “Populasi adalah wilayah generalisasi yang terdiri atas subyek/objek yang mempunyai kualitas dan karakteristik tertentu yang ditetapkan oleh peneliti untuk dipelajari dan kemudian ditarik kesimpulannya.” [6]. Hal tersebut menjadi acuan bagi peneliti untuk menetapkan populasi. Populasi yang akan digunakan adalah sebagai penelitian ini adalah desa TA 2015 (10 desa) dan desa TA 2018 (28 desa), sehingga total populasi adalah sebanyak 38 desa.

Sampel merupakan bagian dari populasi yang akan diteliti oleh peneliti. Menurut Sugiyono (2011:81) “Sampel adalah bagian dari jumlah dan karakteristik yang di miliki oleh populasi tersebut.”. Teknik pengambilan sampel dalam penelitian ini menggunakan teknik *Purpose Sampling* yaitu penentuan responden sebagai sampel dengan menggunakan pertimbangan tetentu.

Menurut Arikunto (2006:112), mengatakan bahwa jika jumlah subjek cukup besar dapat diambil sampel antara 10-15% atau 15-25% atau lebih [7], maka di dalam penelitian ini 15 desa sampling dari 38 jumlah total desa pasca TA 2015 dan TA 2018 atau sebesar 39,47%.

Adapun alasan pertimbangan pengambilan sampel pada penelitian ini adalah sebagai berikut:

- 1) Dari 28 desa Tahun Anggaran 2018 diambil sample sebanyak 13 desa, alasannya karakterisk sampel adalah agar dapat diukur penilaian selama 7 bulan setelah sarana dibangun atau yaitu operasional dari bulan Januari 2019 s/d Juli 2019, dimana wancara 13 desa dilakukan oleh Pakem dan didampingi TFM;
- 2) Dari 10 desa TA 2015 sebanyak 2 desa, yaitu Desa Sumber Jaya Kecamatan Jati Agung dan Desa Sinar Rejeki Kecamatan Jati Agung, alasannya karakterisk sampel adalah agar dapat diukur penilaian selama 43 bulan setelah sarana dibangun atau operasional dari bulan Januari 2016 s/d Juli 2019, wawancara pada kedua desa tersebut dilakukan oleh TFM.

7.3 Kajian Aspek Penilaian Kinerja AKNOP Modifikasi

Pembahasan ini merupakan penjelasan dan perhitungan aspek-aspek penilaian kinerja yang akan diukur, dengan modifikasi dari metode perhitungan AKNOP untuk irigasi. Dari mulai pembagian aspek fisik dan non fisikm lalu pembobotan yang diperhitungkan pada seluruh aspek tersebut, sampai dengan nantinya akan diukur skoring klasifikasi nilai kinerja SPAM.

Adapun aspek-aspek kinerja SPAM yang akan dinilai dan juga pembobotannya adalah sebagaimana berikut:

- | | |
|----------------------------------|----------------|
| 1) Prasarana fisik | = 45%..... (a) |
| 2) Produktivitas kegiatan | = 15% |
| 3) Sarana penunjang | = 10% |
| 4) Organisasi pendamping program | = 15% |
| 5) Dokumentasi | = 5% |
| 6) Kondisi kelembagaan KP-SPAMS | = 10% |

Jumlah = 100%

(Sumber: Data Primer diolah, Juni 2019)

Setelahnya nanti dilakukan pengukuran melalui penilaian yang dilakukan oleh penilai kepada responder (KP-SPAM), maka akan dibuat pengelompokan klasifikasi skoring kinerja keberlanjutan SPAM dengan nilai skoring sebagaimana berikut.

- 90.00% – 100% = Kinerja SPAM Sangat Baik
- 75.00% – 89.99% = Kinerja SPAM Baik
- 55.00% – 74.99% = Kinerja SPAM Kurang Baik
- < 54.99% = Kinerja SPAM Buruk

(Sumber: Data Primer diolah, Juni 2019)

Berikut di bawah ini adalah akan ditampilkan simulasi perhitungan analisis dan penjelasannya pada salah satu sample, yaitu Lokasi: Desa Bumi Daya; Kecamatan Palas; tanggal penilaian 7 Agustus 2019; penilai Subagio (Pakem).

1. Prasarana Fisik

Metode perhitungan penilaian kinerja pada aspek prasarana fisik adalah dengan cara menghitung nilai kerusakan dari indikator penilaian yang ditetapkan, untuk kemudian dilakukan formulasi dengan bobot indeks untuk menghitung indeks kinerja, sehingga dari formulasi bobot indeks dan bobot aspek sarana fisik akan diperoleh nilai yang menjadi hasil pengukuran kinerja. Aspek penilaian fisik dibagi menjadi 4 komponen, yaitu:

- 1) Aspek unit air baku, bobot komponen 35%..... (b)
- 2) Aspek unit produksi, bobot komponen 10%
- 3) Aspek unit distribusi, bobot komponen 30%
- 4) Aspek unit pelayanan, bobot komponen 25%

A. Unit Air Baku

Adapun berdasarkan jenis opsi sumber air baku yang digunakan pada sarana SPAM terbangun, maka aspek penilaian untuk kinerja unit air baku dibagi lagi menjadi 4 opsi, yaitu: 1) sumur bor; 2) mata air; 3) intake; 4) sumur gali. Kemudian dari masing-masing opsi tersebut akan dihitung nilai kerusakan pada kondisi komponen dari air baku, dalam hal ini diberikan contoh untuk komponen air baku pada opsi sumur bor, diantaranya: 1) kondisi sumber dan sumur bor; 2) sumber energi; 3) pompa; dan 4) bak penampung.

Kemudian indikator penilaian adalah keterangan yang menggambarkan kondisi saat dilakukan pemeriksaan atau wawancara, semisal diambil contoh indikator-indikator penilaian untuk aspek sarana fisik pada opsi sumur bor dan pada komponen kondisi sumber dan sumur bor, yaitu:

- a. Ketersediaan debit sumber, apakah sesuai dengan rencana desain? (bobot indikator = 0.50) (c)
- b. Kualitas sumber air baku, apakah tidak berwarna, tidak berasa, tidak berbau? (bobot indikator = 0.30)
- c. Perlindungan tutup casing sumur bor, apakah terlindungi gangguan luar? (bobot indikator = 0.10)
- d. Tutup plat manhole, apakah tertutup, dikunci gembok? (bobot indikator = 0.05)
- e. Pipa pengambilan (Inlet), apakah tidak rusak dan tidak ada kebocoran? (bobot indikator = 0.05)

Cara menjawab pertanyaan-pertanyaan indikator penilaian tersebut adalah cukup dengan mengisi ceklis pada lembar penilaian yang telah disediakan, pada kolom kondisi, lalu pilih salah satu apakah: **N**=normal; **R**=rusak ringan; **S**=rusak sedang; dan **B**=rusak berat.

Sehingga diperoleh nilai aspek aspek prasarana fisik dengan rumus sebagaimana berikut.

$$\text{Nilai Aspek} = \text{Kondisi} \times \text{Indeks Kinerja}$$

di mana,

Kondisi = kerusakan dengan bobot $N = 1$, $R = 0.75$,
 $S = 0.5$, $B = 0.25$;

Indeks Kinerja = bobot aspek x bobot komponen x bobot indikator penilaian.

Untuk contoh diatas, maka dapat dihitung indeks kinerja dari indikator ketersediaan debit sumber adalah sebagai berikut.

$$\begin{aligned} \text{Indeks kinerja} &= (a) \times (b) \times (c) \\ &= 0.35 \times 0.3 \times 0.50 = 0.0525 \dots\dots\dots d) \end{aligned}$$

Dan jika ceklis yang dipilih oleh penilai, yaitu sarana dengan kondisi Normal, maka Nilai Kinerja ketersediaan debit sumber adalah sebagai berikut.

$$\begin{aligned} \text{Nilai Aspek} &= \text{Bobot Kondisi (N)} \times (d) \\ &= 1.0 \times 0.0525 = 0.0525 \end{aligned}$$

Dari analisis hasil kuesioner diperoleh penilaian sub aspek unit air baku adalah sebesar 0.3290, kemudian nilai aspek tersebut dibagi dengan bobot sub aspek unit air baku yaitu 0.3500, maka diperoleh nilai 0.9400. Sehingga dapat disimpulkan bahwa nilai sub aspek unit air baku adalah sebesar 94.00%.

B. Unit Produksi

Perhitungan nilai kinerja SPAM sub aspek penilaian prasarana fisik berikutnya adalah nilai kinerja unit produksi. Seluruh sample tidak melakukan pembuatan sarana

untuk peningkatan kualitas air minum, hal ini dikarenakan hasil uji kualitas air dari laboratorium Kesehatan daerah menunjukkan hasil yang baik.

Kendati demikian, pembuatan sarana tersebut semestinya dibuat, karena khawatir saat terjadi musim hujan terjadi perubahan kualitas air minum yang seharusnya dapat diantisipasi oleh sarana pada unit produksi dengan pengolahan air minum sederhana.

Dari analisis hasil kuesioner diperoleh penilaian sub aspek unit produksi adalah sebesar 0.0000, karena tidak ada unit layanan produksi pada SPAM terbangun di Desa Mekarmulya Kecamatan Palas. Sehingga dapat disimpulkan bahwa nilai sub aspek unit air baku adalah sebesar 0.00%.

C. Unit Distribusi

Selanjutnya adalah perhitungan nilai kinerja SPAM sub aspek penilaian prasarana fisik, yaitu nilai kinerja unit distribusi. Dari sample penelitian menunjukkan bahwa unit distribusi pada SPAM terbangun menggunakan sistem distribusi gravitasi, hal ini bertujuan agar biaya operasional lebih efisien.

Dari analisis hasil kuesioner diperoleh penilaian sub aspek unit distribusi adalah sebesar 0.3000, kemudian nilai aspek tersebut dibagi dengan bobot sub aspek unit distribusi yaitu 0.3000, maka diperoleh nilai 1.000. Sehingga dapat disimpulkan bahwa nilai sub aspek unit distribusi adalah sebesar 100%.

D. Unit Pelayanan

Perhitungan nilai kinerja SPAM sub aspek penilaian prasarana fisik berikutnya adalah nilai kinerja unit pelayanan. Dalam hal ini, seluruh sample menggunakan pelayanan dengan sistem sambungan rumah (SR), dan menggunakan *water meter*.

Kapasitas sistem rencana SPAM terbangun yang tertuang didalam RKM (Rencana Kerja Masyarakat) dirancang untuk jumlah pelayanan kurang lebih 200 SR, adapun kebijakan yang terdapat pada Program Pamsimas adalah bahwa 25% dari target SR tersebut harus sudah terpasang dan dimanfaatkan dan hal itu merupakan syarat serah terima pekerjaan.

Dari analisis hasil kuesioner diperoleh penilaian sub aspek unit pelayanan adalah sebesar 0.2500, kemudian nilai aspek tersebut dibagi dengan bobot sub aspek unit pelayanan yaitu 0.2500, maka diperoleh nilai 1.0000. Sehingga dapat disimpulkan bahwa nilai sub aspek unit pelayanan adalah sebesar 100%.

2. Produktivitas kegiatan

Berbeda dengan penilaian sebelumnya, nilai indikator yang digunakan dari aspek point 2 (dua) sampai dengan 6 (enam) adalah bukan dari kondisi kerusakan, akan tetapi yang dinilai adalah kondisi kesesuaian antara kenyataan yang ada dengan perencanaan sistem. Sehingga kelas indeks yang digunakan menggunakan simbol: **S** = sudah sesuai; **H** = hampir sesuai; **L** = lumayan sesuai; dan **T** = tidak sesuai.

Setelah mengukur nilai kinerja SPAM aspek penilaian prasarana fisik, maka selanjutnya adalah nilai kinerja unit non fisik, yaitu aspek produktivitas kegiatan. Produktivitas kegiatan ini mencakup berbagai sub aspek produktivitas yang diukur, diantaranya: 1) produktivitas pelayanan; 2) produktivitas operasional; dan 3) produktivitas keuangan.

Dari analisis hasil kuesioner diperoleh penilaian aspek produktivitas kegiatan adalah sebesar 0.1430, kemudian nilai aspek tersebut dibagi dengan bobot aspek produktivitas kegiatan yaitu 0.1500, maka diperoleh nilai 0.9536. Sehingga dapat disimpulkan bahwa nilai aspek produktivitas kegiatan adalah sebesar 95.36%.

3. Sarana penunjang

Pengukuran kinerja SPAM selanjutnya adalah aspek penilaian sarana penunjang. Dalam hal ini, sarana penunjang yang dimaksud adalah sarana yang digunakan oleh pengelola (KP-SPAMS) dalam melakukan pelayanan dan menjalankan operasional sarana SPAM terbangun, agar dapat memberikan pelayanan prima dan mampu memberikan kepuasan kepada pemanfaatnya.

Dari analisis hasil kuesioner diperoleh penilaian aspek sarana penunjang adalah sebesar 0.0880, kemudian nilai aspek tersebut dibagi dengan bobot aspek sarana penunjang yaitu 0.1000, maka diperoleh nilai 0.8800. Sehingga dapat disimpulkan bahwa nilai aspek sarana penunjang adalah sebesar 88.00%.

4. Organisasi pendamping program

Pengukuran kinerja SPAM selanjutnya adalah aspek penilaian organisasi pendamping program. Nilai yang diukur adalah frekuensi kunjungan pendamping (fasilitator program Pamsimas) dalam periode waktu tertentu.

Belum semua SPAM Perdesaan, khususnya di kabupaten wilayah penelitian yaitu Kabupaten Lampung Selatan, memiliki organisasi pendamping program seperti halnya program Pamsimas, terlebih jika pembangunan yang dilakukan adalah merupakan bantuan dari pemerintah yang bersifat proyek. Diharapkan kedepan Pemerintah Kabupaten Lampung Selatan melakukan pengelolaan SPAM terbangun, untuk memastikan keberlanjutan sarana tersebut.

Dari analisis hasil kuesioner diperoleh penilaian aspek organisasi pendamping program adalah sebesar 0.0900, kemudian nilai aspek tersebut dibagi dengan bobot aspek organisasi pendamping program yaitu 0.1500, maka diperoleh nilai 0.6000. Sehingga dapat disimpulkan bahwa nilai aspek organisasi pendamping program adalah sebesar 60.00%.

5. Dokumentasi

Pengukuran kinerja SPAM selanjutnya adalah aspek penilaian dokumentasi. Dalam hal ini, nilai yang diukur adalah tentang perihal kegiatan mencatat, melaporkan, mengarsipkan, serta mengumumkan seluruh kegiatan-kegiatan, terutama kegiatan yang dituntut transparansi dan akuntabilitas dari pemanfaat sarana SPAM.

Dari analisis hasil kuesioner diperoleh penilaian aspek dokumentasi adalah sebesar 0.0465, kemudian nilai aspek tersebut dibagi dengan bobot aspek dokumentasi yaitu 0.0500, maka diperoleh nilai 0.9300. Sehingga dapat disimpulkan bahwa nilai aspek dokumentasi adalah sebesar 93.00%.

6. Kondisi kelembagaan KP-SPAMS

Pengukuran kinerja SPAM selanjutnya adalah aspek penilaian kelembagaan KP-SPAMS. Dalam hal ini, nilai yang diukur adalah tentang perihal keaktifan pengurus KP-PAMS, maksudnya personel pada seluruh komponen struktur organisasi telah melakukan tugas dan fungsinya dengan baik.

Dari analisis hasil kuesioner diperoleh penilaian aspek kelembagaan KP-SPAMS adalah sebesar 0.0710, kemudian nilai aspek tersebut dibagi dengan bobot aspek kelembagaan KP-SPAMS yaitu 0.1000, maka diperoleh nilai 0.7100. Sehingga dapat disimpulkan bahwa nilai aspek kelembagaan KP-SPAMS adalah sebesar 71.00%.

7.4 Analisis Hasil Penilaian Kinerja Adopsi AKNOP

Setelah dilakukan pengukuran keseluruhan aspek, selanjutnya adalah melakukan analisis hasil penilaian kinerja adopsi AKNOP, yaitu dengan melakukan perkalian dengan bobot-bobot yang sudah ditetapkan. Adapun analisis atas contoh pengisian lembar penilaian di atas adalah sebagaimana berikut.

1) Nilai Aspek Prasarana Fisik =

$$\begin{aligned} & \text{Sub aspek unit air baku} \times \text{bobot kinerja unit air baku} + \\ & \text{Sub aspek unit produksi} \times \text{bobot kinerja unit produksi} + \\ & \text{Sub aspek unit distribusi} \times \text{bobot kinerja unit distribusi} + \\ & \text{Sub aspek unit pelayanan} \times \text{bobot kinerja unit pelayanan} \\ & = (0.9400 \times 0.35) + (0.00 \times 0.1) + (1.00 \times 0.30) + (1.00 \times \\ & \quad 0.25) = 0.8790 \end{aligned}$$

Maka, Nilai Kinerja Aspek Prasarana Fisik

$$\begin{aligned} & = \text{Nilai Aspek Prasarana Fisik} \times \text{Bobot Aspek Sarana Fisik} \\ & = 0.8790 \times 45\% \\ & = 0.3956 \end{aligned}$$

2) Nilai Kinerja Produktivitas Kegiatan

$$\begin{aligned} & = \text{Nilai Aspek Produktivitas Kegiatan} \times \text{Bobot Aspek} \\ & \quad \text{Produktivitas Kegiatan} \\ & = 0.9536 \times 15\% \\ & = 0.1430 \end{aligned}$$

3) Nilai Kinerja Sarana Penunjang

$$\begin{aligned} & = \text{Nilai Aspek Sarana Penunjang} \times \text{Bobot Aspek} \\ & \quad \text{Sarana Penunjang} \\ & = 0.8800 \times 10\% \\ & = 0.0880 \end{aligned}$$

4) Nilai Kinerja Organisasi Pendamping Program
 = Nilai Aspek Pendamping Program x Bobot Aspek
 Pendamping Program
 = $0.6000 \times 15\%$
 = 0.0900

5) Nilai Kinerja Dokumentasi
 = Nilai Aspek Dokumentasi x Bobot Aspek Dokumentasi
 = $0.9300 \times 5\%$
 = 0.0465

6) Nilai Kinerja Kondisi kelembagaan KP-SPAMS
 = Nilai Aspek Kondisi kelembagaan KP-SPAMS x Bobot
 Aspek Kondisi kelembagaan KP-SPAMS
 = $0.7100 \times 10\%$
 = 0.0710

Dengan demikian diperoleh jumlah persentase Nilai Kinerja SPAM = 83.41%

Dengan melihat standar kinerja sebagaimana berikut,

- 90.00% – 100% = Kinerja SPAM Sangat Baik
- 75.00% – 89.99% = Kinerja SPAM Baik
- 55.00% – 74.99% = Kinerja SPAM Kurang Baik
- < 54.99% = Kinerja SPAM Buruk

Maka dapat disimpulkan bahwa Nilai Kinerja Keberlanjutan SPAM Adopsi AKNOP pada contoh tersebut termasuk **Kinerja SPAM Baik**, hal ini ditunjukkan pada tabel di bawah.

Tabel. 3.6. Form Lembar Resume Pengukuran Kinerja SPAM

PENILAIAN KINERJA DAN KEBERLANJUTAN SPAM
PERDESAAN

Desa : Bumi Daya
Kecamatan : Palas
Program : Pamsimas
Tanggal Penilaian : 07 Agustus 2019
Penilai : Subagio

Resume

No.	Aspek Penilaian Kinerja	Skoring	Bobot	Nilai
1.	Prasarana Fisik	0.8790	45.00%	0.3956
2.	Produktivitas Kegiatan	0.9536	15.00%	0.1430
3.	Sarana penunjang	0.8800	10.00%	0.0880
4.	Organisasi pendamping program	0.6000	15.00%	0.0900
5.	Dokumentasi	0.9300	5.00%	0.0465
6.	Kondisi kelembagaan KP-SPAMS	0.7100	10.00%	0.0710
Jumlah				0.8341

Persentase Kinerja SPAM = 83.41%

Standar Kinerja SPAM Adopsi AKNOP

90.00% – 100%	Kinerja SPAM Sangat Baik
75.00% – 89.99%	Kinerja SPAM Baik
55.00% – 74.99%	Kinerja SPAM Kurang Baik
< 54.99%	Kinerja SPAM Buruk

Dengan melihat nilai skoring tersebut maka Nilai Kinerja SPAM Adopsi AKNOP di Desa Bumi Daya Kecamatan Palas pada Bulan Agustus Tahun 2019, termasuk kepada:

Kinerja SPAM Baik

7.5 Uji Validitas dan Reliabilitas

Uji validitas dilakukan dengan membandingkan nilai r hitung dengan r tabel. Pada kasus ini jumlah sampel (n) = 56 dan alpha = 0,05 diperoleh r tabel = 0.264. Jika r hitung lebih besar dari r tabel maka pertanyaan atau indikator tersebut dinyatakan valid. Hasil pengujian validitas menggunakan program Excel.

Tabel. 3.7. Hasil Uji Validitas *Pearson Product Moment*

No. Pertanyaan	r perhitungan	r tabel	Keterangan
P1	0.89	0.264	Valid
P2	0.43	0.264	Valid
P3	0.91	0.264	Valid
P4	0.89	0.264	Valid
P5	0.28	0.264	Valid
P6	0.43	0.264	Valid
P7	0.81	0.264	Valid
P8	0.31	0.264	Valid
P9	0.34	0.264	Valid
P10	0.35	0.264	Valid
P11	0.31	0.264	Valid
P12	0.42	0.264	Valid
P13	0.30	0.264	Valid
P14	0.90	0.264	Valid
P15	0.43	0.264	Valid
P16	0.39	0.264	Valid
P17	0.32	0.264	Valid
P18	0.32	0.264	Valid
P19	0.32	0.264	Valid
P20	0.32	0.264	Valid
P21	0.55	0.264	Valid
P22	0.84	0.264	Valid
P23	0.55	0.264	Valid
P24	0.43	0.264	Valid
P25	0.61	0.264	Valid
P26	0.95	0.264	Valid
P27	0.95	0.264	Valid
P28	0.96	0.264	Valid
P29	0.70	0.264	Valid
P30	0.96	0.264	Valid
P31	0.96	0.264	Valid
P32	0.34	0.264	Valid
P33	0.34	0.264	Valid
P34	0.89	0.264	Valid
P35	0.77	0.264	Valid
P36	0.72	0.264	Valid
P37	0.95	0.264	Valid
P38	0.50	0.264	Valid
P39	0.32	0.264	Valid
P40	0.34	0.264	Valid
P41	0.34	0.264	Valid
P42	0.28	0.264	Valid
P43	0.32	0.264	Valid
P44	0.75	0.264	Valid
P45	0.95	0.264	Valid
P46	0.32	0.264	Valid
P47	0.29	0.264	Valid
P48	0.91	0.264	Valid
P49	0.28	0.264	Valid
P50	0.76	0.264	Valid
P51	0.36	0.264	Valid
P52	0.35	0.264	Valid
P53	0.76	0.264	Valid
P54	0.32	0.264	Valid
P55	0.40	0.264	Valid
P56	0.32	0.264	Valid

Uji Reliabilitas dipakai untuk menunjukkan sejauh mana suatu hasil pengukuran relatif konsisten apabila alat ukur yang digunakan berulang kali. Pengujian yang dipakai adalah dengan teori *Cronbach Alpha* dengan menggunakan program Excel, maka didapat nilai *Cronbach Alpha* sebesar 0.942, dapat disimpulkan bahwa pertanyaan yang diajukan adalah reliabel.

8. Kesimpulan

Berdasarkan hasil penelitian tentang Kajian Kinerja Dan Keberlanjutan SPAM Pedesaan di Lampung Selatan, dapat disimpulkan bahwa adopsi dan modifikasi struktur serta mekanisme metode penilaian kinerja pada jaringan irigasi (metode pengukuran AKNOP), telah menunjukkan hasil yang signifikan, di mana bisa dilihat dari hasil penelitian yang bersifat kuantitatif mampu mewakili klasifikasi kondisi SPAM terbangun. Yaitu dengan nilai kinerja: 1) 90.00% – 100% = Kinerja SPAM Sangat Baik; 2) 75.00% – 89.99% = Kinerja SPAM Baik; 3) 55.00% – 74.99% = Kinerja SPAM Kurang Baik; dan 4) 0% – 54.99% = Kinerja SPAM Buruk.

Struktur dan mekanisme metode yang baku untuk menilai kinerja, keberfungsian dan keberlanjutan Program Pamsimas pada penelitian ini adalah berupa angka-angka yang dihasilkan dari perhitungan bobot tertentu yang proporsional pada setiap pertanyaan yang mewakili pengukuran aspek-aspek pada lembar pengukuran saat proses pemantauan kondisi SPAM dan saat wawancara dengan pengelola. Adapun aspek yang diukur beserta bobotnya adalah: 1) Prasarana Fisik = 45%; 2) Produktivitas kegiatan = 15%; 3) Sarana penunjang = 10%; 4) Organisasi pendamping program = 15%; 5) Dokumentasi = 5%; dan Kondisi kelembagaan KP-SPAMS = 10%.

Penilaian Kinerja dan Keberlanjutan SPAM Pedesaan ini tentunya dapat membantu Pakem untuk menetapkan status kondisi SPAM pada desa tertentu, saat harus melakukan pemilihan desa yang tepat sasaran untuk digulirkan bantuan program-program lainnya pada desa-desa yang telah mendapatkan Program Pamsimas.

Daftar Pustaka

- Septiana, W. (2016). Peningkatan Partisipasi Masyarakat dalam Program Penyediaan Air Bersih di Dukuh Jurugan Desa Karangpatihan Kecamatan Pulung Kabupaten Ponorogo. *Skripsi. Institut Teknologi Sepuluh Nopember*. RP14-1501. Surabaya
- Djono, T.P.A (2011). Analisis Keberlanjutan Sistem Penyediaan Air Minum Pedesaan. *Tesis. Universitas Indonesia*. Jakarta.
- Andito, S. dan Doddy, A. I. (2020). Keberlanjutan Sistem Penyediaan Air Minum Pedesaan Berbasis Masyarakat. *Jurnal Litbang Sukowati*, Vol. 4, 2, Mei 2021, Hal 14-27.
- Menteri Pekerjaan Umum dan Perumahan Rakyat Republik Indonesia. (2015). *Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat No. 12/PRT/M/2015 Eksploitasi dan Pemeliharaan Jaringan Irigasi*. Kementerian PUPR. Jakarta. Website: <http://sim.pamsimas.org>
- Sugiyono. (2011). *Metode Penelitian Kuantitatif, Kualitatif dan R&D*. Alfabeta. Jakarta.
- Arikunto, S. (2006). *Prosedur Penelitian suatu Pendekatan Praktik*. Aneka Karya. Jakarta.