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Integrating Flood Early Warning System (FEWS) for Optimizing Small Hydropower Sites: A West Java Case Study

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Abstract: This study explores potential locations of small hydropower (SHP) in a specific region by aligning Tropical Rainfall Measuring Mission (TRMM) rainfall data with ground station records. It refines river discharge time series using the Delft Flood Early Warning System (DELFT-FEWS) model and observed data, it also provides invaluable data and insights into water bodies' hydrological patterns and behavior, allowing for accurate forecasting of potential floods and water discharge fluctuations. Developing hydropower would be simpler if a nationally integrated system could monitor river discharge at any time by stakeholders. Calculations of dependable discharge Q90 enhance SHP feasibility assessments through flow duration curves. Integrating dependable discharges with head values estimates potential hydropower. The study identifies optimal sites aligning with substations and residential areas, emphasizing enhanced power transmission efficiency—the Total SHP Potential calculation results of 32.5 MW in 18 locations in West Java. Implementing an FEWS holds significant advantages for the sustainability of hydropower projects.

Keywords: hydropower; rainfall-runoff; ground check; dependable discharges; electric substation

1. Introduction

Hydropower has emerged as a beacon of sustainable energy transformation amid these dynamic energy shifts. It fulfills the three pillars of Trilema Energy—supply security, affordability, and environmental sustainability[1)]. Hydropower stands at the forefront of renewable energy technologies, poised to revolutionize global electricity generation[2–4)]. Hydropower, being a renewable energy source derived from the energy of flowing or falling water, such as rivers and dams, capitalizes on the natural replenishment of water resources, seamlessly harmonizing with sustainability concepts. Hydropower plants have lower greenhouse gas emissions than fossil-fuel-based counterparts[5,6)]. Underscore its environmental compatibility, positioning it as a pivotal component in the battle against climate change[7–10)].

Small hydropower (SHP) presents a compelling alternative to large hydropower, boasting a smaller environmental footprint, community integration potential, faster implementation, lower capital costs, flexibility in site selection, reduced regulatory complexities, and adaptability through modular design[11)]. The phrase "small hydro" is used in a variety of contexts around the world due to energy capacity; the upper limit is often between 10 and 30 MW. Although it is uncommon to impose a minimum limit, the US National Hydropower Association does so with a 5 MW minimum[12)].

It is common practice to do the SHP resource assessment in stages[13)]. Geographic Information System (GIS) modeling initially depicts river network gradients and discharge data[13–15)]. The model considers a Digital Elevation Model (DEM) of the study region and historical river discharge site data as inputs. Hydrological modeling for predicting river discharge in catchment areas encompasses a range of methods, including empirical approaches leveraging observed relationships between rainfall and run-off, as conducted by Jones *et al.*, 2019 [16)], statistical techniques utilizing historical data analysis conducted by Fitzgerald *et al.*, 1983 and by Palomino Cuya *et al.*, 2013, [15,17)], physically-based models employing fundamental hydrological principles, as conducted by Eini *et al.,* 2019[18)], conceptual models simplifying catchment processes conducted by Suprit *et al.,* 2012[19)], distributed models providing spatially distributed insights conducted by Mernild *et al.,* 2008[20)], hybrid models amalgamating various methods conducted by Samantaray *et al.,* 2023[21)], and emerging technologies like artificial intelligence and machine learning conducted by Astray *et al.,* 2016[22)]. The choice of method is influenced by factors such as data availability, catchment characteristics, modeling objectives, and desired prediction accuracy, often leading to a combined approach to ensure comprehensive and accurate discharge predictions. Most of the aforementioned techniques are used when determining the value of water outflow. Perhaps developing hydropower would be simpler if a nationally integrated system could monitor river discharge at any time by stakeholders.

DELFT-FEWS is an application developed by Deltares, Netherlands. DELFT-FEWS was initially developed in response to developments in forecasting and flood early warning, providing a sophisticated collection of generic modules designed for building systems tailored to the specific needs of each agency[23)]. Over the past ten years of development, the flexible nature of the system has been engaged to include applications for water resources, drought forecasting, water quality forecasting, and control in time series. This application has never been used to calculate river-dependable discharge before identifying potential hydropower sites.

Various studies have identified hydropower sites in West Java, Indonesia, ranging from international cooperation projects to private consultant studies, contributing to a growing understanding of the region's potential[24)]. While West Java holds substantial renewable energy potential, tapping into it efficiently requires overcoming data challenges and bridging gaps between potential and utilization.

The following are some of the contributions that this study makes to fill the voids seen in the existing literature: First, using GIS software with a higher resolution DEMNAS (Indonesian National Digital Elevation Model) 8m x 8m for better quality head data and second, developing a FEWS through the use of dependable discharge data calculation to evaluate the ROR SHP potential of West Java.

2. Material and Methods

2.1. Study Area

West Java is a province in Indonesia, situated on the island of Java, with Bandung as its capital city. The geographic coordinates of West Java are between 5°50′-7°50′ South latitude and 104°48′-108°48′ East longitude. The province comprises nine cities and eighteen regencies. It is home to 154 watersheds, six river basins, and 2,265 rivers. The highest temperature recorded in West Java is 34 degrees Celsius on the North Coast, while the lowest is 9 degrees Celsius at the summit of Mount Pangrango. The average annual rainfall across the province is 332.8 mm[25)].

2.2. The Electrical Production of a small hydropower plant

Estimating available water resources at the site is usually the first step in assessing hydropower resources [26)]. Hydropower plants harness the kinetic energy inherent in the movement of water to produce electrical energy. The energy is contingent upon the discharge volume and the head of the flowing water [27)]. The following equation can be utilized to estimate the hydro potential of the runoff river system at a specified location[28)].

$$P = Q \, x \, H \, x \, g \, x \, \eta \qquad (1)$$

In the context of the preliminary assessment, the formula for calculating power capacity (P) involves the dependable discharge (Q), head (H), gravity (g), and total efficiency (η), where system losses, including head, turbine, and generator losses, are combined to yield a plant efficiency of 60%.

2.3.Discharge estimation: WFLOW - DELFT – FEWS

DELFT-FEWS can manage and combine hydrological and climatological data from various sources, both from instrumentation in the field and from satellites, radar, and numerical weather prediction results in various formats. The ready-to-use data will be used automatically by the hydrologic and hydrodynamic models integrated into the system, and the output will be returned through DELF-FEWS for display [29)].

2.3.1. Preparing data

Rainfall is the main input for determining the total amount of water leaving the atmosphere. Soil type determines the degree of soil penetration and saturation, directly determining runoff formation and accumulation. Evapotranspiration determines the amount of water that returns to the atmosphere at different rates at each location due to wind speed, solar radiation, and air temperature. The catchment area's morphology and slope pattern determine the flow's direction and velocity. Plant water demand factors determine the amount of water plants consume during growth. Land use and land cover also determine crop water requirements and how rainfall is converted into runoff. Table 1 is some of the data used in the calculation of WFLOW-FEWS.

Table 1. WFLOW-FEWS input data

Data input	Sources	Format	Res	Type
Rainfall	TRMM	Raster	28 km	.map
Topography	SRTM	Raster	90 m	.tif/.asc
Land Cover	GlobCover	Raster	300 m	.tif
Soil Type	FAO	Vector	9.28 km	.shp.tif
Evaporation	CGIAR	Raster	1 km	.tif

2.3.2. Rainfall model correction

Corrections to the rainfall model are made by conducting field measurements with ground stations, and model settings are carried out to obtain a corrected rainfall model.

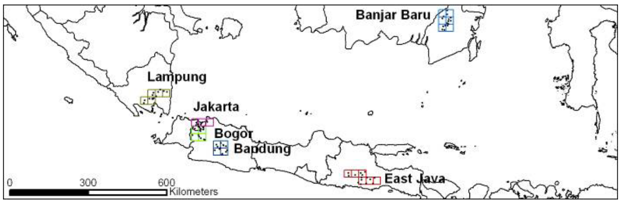

Fig 1: Location of the Rain ground stations in making corrections to the TRMM model (MPWH 2017)

The correction of rainfall modeling by integrating ground station data is significant in hydrological and meteorological studies. Rainfall is fundamental in various hydrological models, climate studies, flood forecasting, and water resource management. However, the accuracy of rainfall estimates obtained solely from remote sensing or numerical models can be compromised due to factors like spatial variability, topography, and local meteorological conditions. By incorporating ground station data, which offers direct and localized measurements, the accuracy and reliability of rainfall modeling are significantly improved. This correction process not only refines precipitation estimates but also enhances the precision of downstream hydrological predictions, flood forecasts, and water availability assessments.

2.3.4. WFLOW-FEWS process

The operational framework of DELFT-FEWS is elucidated, detailing its functional dynamics through a conceptual representation. The framework involves two key processes: the FEWS and application stages. The FEWS process includes importing, validating, interpolating, and processing dynamic and static datasets. It incorporates historical and forecast data modeling, integrating auxiliary models like WFLOW, Sobek, RTC, and Ribasim. The application stage involves utilizing the refined FEWS model for various domains such as water availability assessments, flood forecasting, drought monitoring, and reservoir operation management. This comprehensive approach addresses diverse hydrological challenges. Additionally, a hydrological and hydraulic model of the river is built for flood forecasting, simulating rainfall into runoff, and determining water levels and inundation. Integrating these processes in the DELFT-FEWS system provides a versatile solution to hydrological challenges and applications.

The calculation of river discharge resulting from rainfall runoff is performed using the WFLOW model [30,31], calibrated using field-measured data of river flow discharge at the water gauge post. The importance of correcting rainfall-runoff modeling using ground station data cannot be overstated in hydrological analysis and water resource management.

Accurate runoff estimation, the water flowing into rivers and streams from rainfall, is crucial for flood prediction, reservoir management, and overall water availability assessments. While hydrological models provide a valuable tool for understanding these processes, their accuracy heavily relies on precise input data. Incorporating ground station data, which directly measures local river discharge, ensures a more realistic representation of runoff patterns within the modeling framework. Figure 2 is the river ground station used for calibration on Java Island.

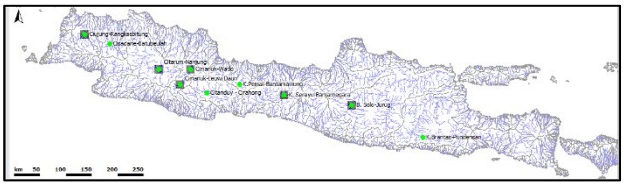

Fig 2: Location of the river ground station (observation discharge)

2.3.5. Statistical Dependable Discharge

The Flow Duration Curve (FDC) method is a valuable hydrological tool used to assess the dependable discharge of a river or stream[32]. It provides insights into the frequency and duration of different flow rates, helping characterize a river's flow regime. FDC is generated by graphing the cumulative percentage of time flow rates equal to or greater than specific values against the corresponding flow rates. The reliable discharge refers to the rate of flow that is either equal to or surpassed for a specific percentage of time. As an illustration, it is worth noting that in Indonesia, the accepted and reliable measure for the release of water in hydropower systems is commonly referred to as Q90[33]. The discharge value that can be relied upon with a 90% confidence level is the flow rate equaled or exceeds 90% of the time. This dependable discharge is a key parameter in water resources planning, as it helps in designing infrastructure, such as dams and water supply systems, that can reliably meet water demands under varying conditions.

2.4. Gross Head Estimation

The river must be divided into smaller segments to establish upstream and downstream points and improve the precision of head value calculations. The grid with 1 km square is used to segment the river. The extracted elevation values from the DEM map will rely heavily on the specified spots. To get gross head value, do the following equation :

$$Head = UE - DE \quad (2)$$

Where: UE = Upstream Elevation and DE = Downstream Elevation

2.5. Site Verification

The mapping verification aims to evaluate the precision of sites representative of earlier studies and existent sites, whether they have a functioning hydropower facility or are still in the planning stages. The information utilized is visible in Table 2.

Table 2. Information for validating hydro energy potential.

Type of data	Source
Hydro Inventory Study 1997	Obtained from the Japan International Cooperation Agency (JICA) and PLN [34]
Electricity Business Plan (RUPTL) 2019-2028	Provide by State Electricity Company (PLN) [35]
Location Pre-FS and FS	Data collected by the State Electricity Company (PLN) [34]
Location Pre-FS	Acquired from a Consultant [34]
Field Measurement	Direct measurement conducted by the National Research and Innovation Agency (BRIN)
Existing Hydro Power Plant	Sourced from the Directorate General of Electricity, Ministry of Energy and Mineral Resources [36]

3. Results and discussions

3.1.Correction rainfall TRMM model

The process of correction by fitting rainfall modeling using TRMM data, along with data from six ground stations in Lampung, Banjar Baru, Jakarta, Bogor, Bandung, and East Java, is visually depicted in Figure 3. This comprehensive approach integrates TRMM satellite data and ground station measurements from multiple regions, encompassing Lampung, Banjar Baru, Jakarta, Bogor, Bandung, and East Java. The black line is the ground measurement data compared to the TRMM model data in the form of red dots, and then the correction fitting process is carried out to produce a new model in the form of a red line. The convergence of these datasets contributes to a robust and geographically diverse understanding of rainfall patterns and trends, enhancing the accuracy and applicability of the rainfall modelling process for these regions.

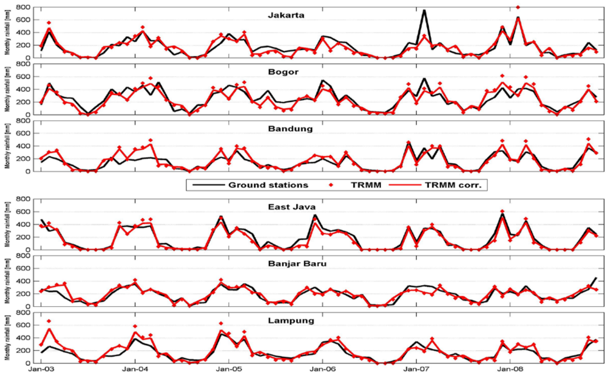

Fig 3: Fitting process rainfall modeling (TRMM) with a ground station

3.2.Correction WFLOW- FEWS model

Once the WFLOW FEWS simulation process has been executed, a time series of river discharge values will be yielded. However, adjustments must be made based on real-time river observation data obtained from ground stations to ensure the accuracy and reliability of the model's outcomes. This crucial step involves aligning the simulation outputs with the actual measurements to enhance the precision of the model's predictions.

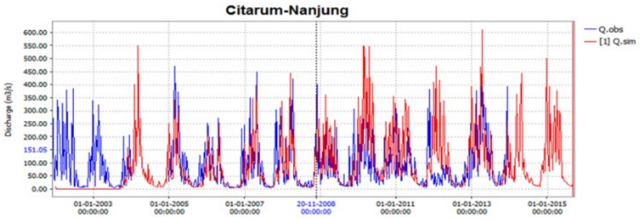

Fig 4: Fitting process of simulated river discharge with observation in Citarum-Nanjung station.

Data from six particular ground stations was used to attain this alignment for corrective purposes. These stations are: Bengawan Solo - Jurug Station, Cimanuk - Leuwidaun Station, Cimanuk - Wado Station, Citarum - Nanjung Station, Ciujung - Rangkasbitung Station, and K.

Serayu - Banjarnegara Station. The model's accuracy is enhanced by incorporating data from these stations, leading to more reliable and meaningful results.

Figure 4 visualizes the fitting process between the model-generated results and the actual observations at Citarum-Nanjung Station. Citarum-Nanjung is one of the ground stations located in one of the largest watersheds in West Java. This graphical representation clearly illustrates how the model is adjusted to match the observed data closely. This iterative process of fine-tuning the model with ground station data validates and improves its predictive capabilities, ultimately contributing to a more comprehensive and accurate understanding of river discharge dynamics in the studied regions.

3.3.Statistical dependable discharge Q90

Obtaining accurate discharge data involves rigorous statistical calculations applied to the entire river streamlines. Figure 5 illustrates one example of a time series graph depicting the flow discharge over time at a specific location along the Cimanuk – Leuwidaun River, facilitating the identification of trends and fluctuations. The time series graph allows for a comprehensive understanding of the temporal variations in flow discharge. By tracking the changes over time, patterns such as seasonal trends, periodic fluctuations, or abrupt changes become apparent. This insight is crucial for water resource management, environmental planning, and predicting the river's behavior under different conditions.

Additionally, Figure 6 presents a flow duration curve derived from statistical analysis, offering insights into the distribution of flow discharge values across different time intervals. This curve aids in understanding the proportion of time-specific discharge levels that are exceeded or equaled. Both visualizations contribute to a comprehensive understanding of the river's hydrological characteristics, supporting informed decision-making in water resource management, hydrological planning, and environmental impact assessment. These tools, backed by robust statistical calculations, are valuable for researchers, hydrologists, and water resource managers, enhancing their understanding of river behavior and optimizing water-related strategies for sustainable development.

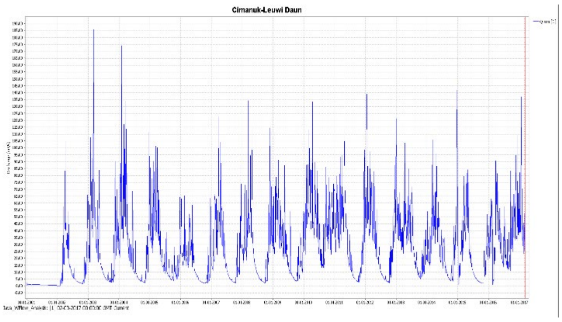

Fig 5: Flow Rate annual time series

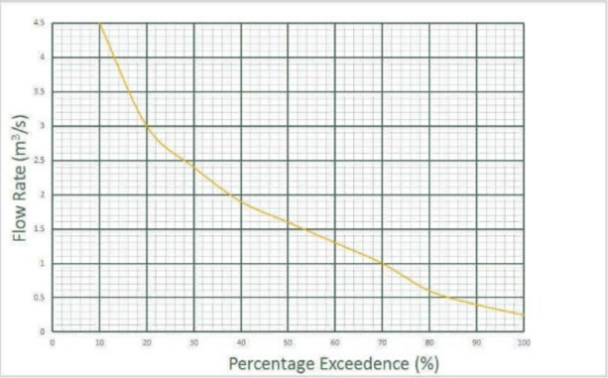

Fig 6: flow duration curve

3.4.Site verification

The assessment process for hydropower potential involves qualitative verification, ensuring congruence between modelling results and verification studies. This verification substantiates the hydropower potential of specific locations within a 1 km radius, as determined by the segmentation grid resolution. While a direct comparison of generation capacities is hindered by the lack of precise data on head, discharge, and efficiency values in each verification study, 99 of the model-derived points align notably well with 79 elements scrutinized in the verification study. This alignment underscores the reliability and applicability of the modelling outcomes in identifying sites with inherent hydropower potential. Figure 7 visually presents the distribution pattern of verification sites compared to potential sites identified through modelling, reinforcing the geographic alignment between the two. The qualitative verification process and alignment between modelling and verification outcomes support the assertion of significant hydropower promise in the identified locations.

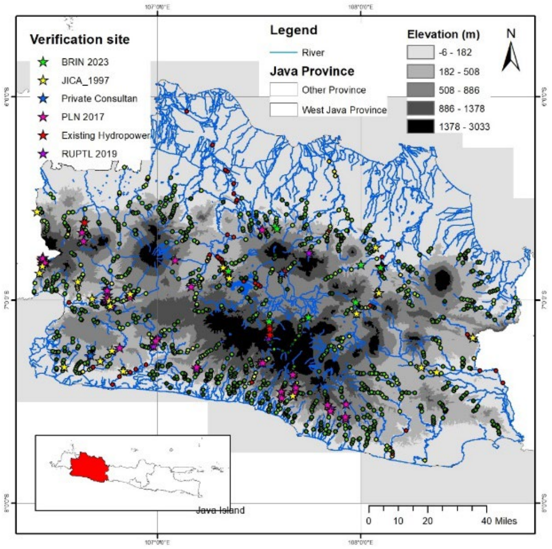

Fig 7: Distribution of verification site among the potential site

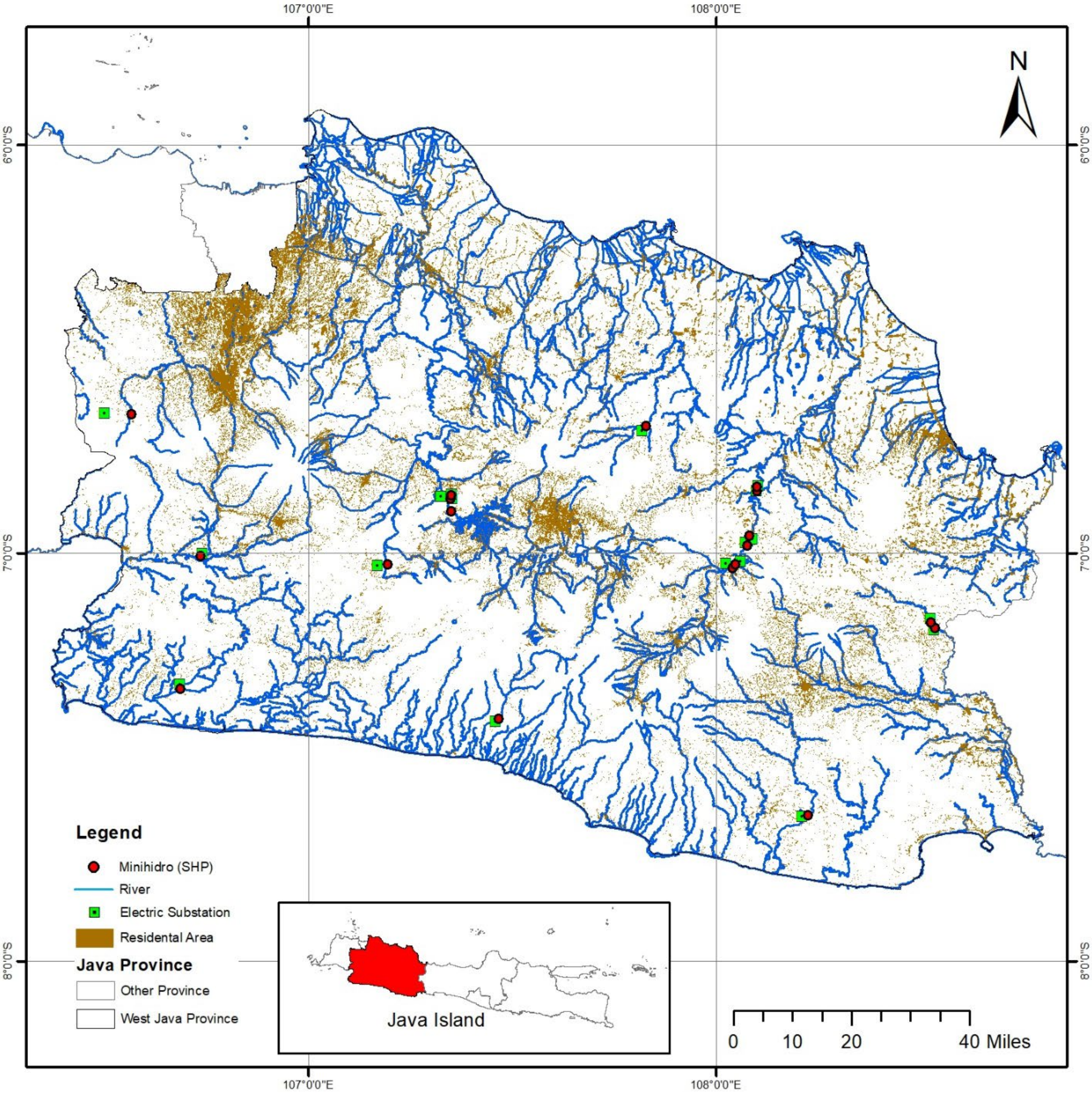

Fig 8: Distribution site SHP potential, electric substation, and residential area

Despite qualitative alignment, the absence of specific data limits direct capacity comparisons, suggesting that further research addressing data limitations can enhance the comprehensive understanding of hydropower potential in these locations.

3.5.SHP Potential

Table 3 presents the SHP potential across nine watersheds, showcasing the distribution of SHP sites and their corresponding total power capacity in kilowatts (kW). The Cimanuk watershed leads with six SHP sites, contributing significantly to a total power capacity of 12,576 kW.

The Citarum watershed also shows promise, generating 9,921 kW from four SHP sites. Other watersheds like Citanduy exhibit potential with two SHP sites, respectively. Watersheds such as Cipunagara, Cikaso,

Cilaki, Cimandiri, Cisadane, and Ciwulan offer smaller but noteworthy contributions to overall SHP capacity. These findings underscore the diverse levels of small hydropower potential across watersheds, suggesting a role in regional energy strategies and sustainable development. Figure 8 illustrates the distribution of SHP potential near electric substations and residential areas, with detailed distances provided in Tables 4 and 5.

There are numerous advantages to locating a power plant, electric substation, and nearby residential area. First, it increases the efficacy of power transmission by decreasing the distance electricity must travel, resulting in less energy loss and greater operational efficiency. In addition, this configuration can result in cost savings due to reduced infrastructure needs, as shortened transmission lines are less expensive to construct and maintain, according to Mendu et al. (2020)[37]. In addition, proximity to an electric substation expedites response times during power outages, minimizing resident disruptions. This configuration also enables voltage regulation, which ensures a stable power supply with fewer fluctuations.

Table 3. Total SHP in watershed group

No	Watershed Name	Amount Site	Total power(kW)
1	Cikaso	1	1,146
2	Cilaki	1	1,051
3	Cimandiri	1	1,284
4	Cimanuk	6	12,576
5	Cipunagara	1	1,545
6	Cisadane	1	1,244
7	Citanduy	2	2,584
8	Citarum	4	9,921
9	Ciwulan	1	1,149
	Total	18	32,500

Table 4. Distance potential site to an electric substation

No	**Distance to an electric substation**	**Amount**
1	< 1 km	8
2	1 – 2 km	6
3	2- 4 km	3
4	> 4 km	1

Table 5. Distance potential site to the residential area

No	**Distance to Residential Area**	**Amount**
1	< 1 km	14
2	1 – 2 km	3
3	> 2 km	1

Based on the 1997 hydro inventory study summarized in the World Bank Report [24]West Java is reported to have 4 out of 17 potential small hydropower locations, whereas the rest are large hydropower. However, if the location is seen in detail, many miss the existence of the river channel. This problem is likely due to the huge difference in DEM data resolution, so this study has a better value.

Moreover, it can ease the integration of alternative renewable energy sources like solar and wind farms into the infrastructure. Nonetheless, managing potential drawbacks, such as environmental impacts, safety concerns, land use considerations, and regulatory obstacles, is essential. Achieving a harmonious coexistence between power infrastructure and residential areas requires thorough planning and implementation of safety measures.

Implementing a Floods Early Warning System (FEWS) holds significant advantages for the sustainability of hydropower projects. Firstly, FEWS provides invaluable data and insights into water bodies' hydrological patterns and behavior, allowing for accurate forecasting of potential floods and water discharge fluctuations. Hydropower planners and operators can mitigate risks associated with extreme weather events by harnessing this predictive capability, ensuring infrastructure safety and nearby communities. This method has been done by Alasali et al. (2021), who discuss a Sustainable Early Warning System utilizing rolling forecasts based on Artificial Neural Networks (ANN) and Golden Ratio Optimization methods to predict real-time water levels and flash floods accurately[38]. This system aims to efficiently provide reliable information and warnings about potential flood events, reducing damages due to flash floods. Moreover, the ability of FEWS to forecast water discharge in various streams enables the identification of optimal locations for hydropower development. By analyzing the hydrological characteristics of different sites, such as flow rates and head potential, FEWS helps pinpoint areas with the highest merit for hydropower generation. This targeted approach minimizes environmental disruption by focusing development on sites with the greatest energy output while minimizing ecological impact.

Furthermore, integrating FEWS into hydropower planning and management enhances operational efficiency and resource utilization. Hydropower facilities can optimize generation schedules and adapt to changing environmental conditions by leveraging real-time data on water levels and flow dynamics. This dynamic response maximizes energy output and ensures the sustainable utilization of water resources, promoting long-term viability and resilience in hydropower operations.

4. Conclusion

Incorporating FEWS into hydropower development and management represents a crucial step towards enhancing sustainability in the sector. By providing advanced forecasting capabilities and optimizing site selection and operational efficiency, FEWS facilitates the responsible harnessing of hydropower resources while minimizing environmental impact and maximizing long-term sustainability.

The study calculates head values based on river segmentation and elevation data. Intersecting dependable discharges with head values yields potential hydropower generation estimates. The outcomes are categorized by hydropower classes, emphasizing significant potential in the Cimanuk and Citarum watersheds and various other watersheds with a total SHP Potential of 32.5 MW in 18 locations in West Java.

For further hydropower development, you can use this application (DELFT-FEWS) to get reliable discharge values for each river by contacting the Balai Hidrologi dan Lingkungan Keairan at the address Jl. Ir. H. Juanda No.193, Dago, Coblong District, Bandung City, West Java

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Abbreviations

DELFT	Deltares Research Institute
DEM	Digital Elevation Models
DEMNAS	National Digital Elevation Model
FDC	Flow Duration Curves
FEWS	Floods Early Warning System
GIS	Geographic Information System
GW	Giga Watt
JICA	Japan International Cooperation Agency
kW	Kilo Watt
MEMR	Ministry of Energy and Mineral Resources
MPWH	Ministry of Public Works and Housing
MW	Mega Watt
PLN	National Electricity Company in Indonesia
RE	Renewable Energy
REGP	Regional Energy General Plan
RoR	Run-of-River
SHP	Small Hydropower Plant
TRMM	Tropical Rainfall Measuring Mission

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