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DESIGN OF A WEB-BASED VILLAGE INCOME MAPPING SYSTEM USING HIERARCHICAL CLUSTERING IN CILETUH GEOPARK

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Abstract

Cikelat Village, located within the Ciletuh–Palabuhanratu UNESCO Global Geopark, has significant potential in agriculture, MSMEs, and tourism. However, the absence of a structured information system limits the optimal utilization of these resources. This study maps the income distribution of Cikelat residents using the Hierarchical Clustering method and designs a web-based information system as a decision-support tool. Data from 438 respondents were preprocessed, normalized, and analyzed using Ward's linkage and Euclidean distance, producing a dendrogram that identified three distinct socio-economic clusters: (1) Cluster 1 (212 respondents, 48.4%) – educated, self-employed residents with moderate income and high technology adoption; (2) Cluster 2 (131 respondents, 29.9%) – predominantly farmers with low income but positive perceptions of the Geopark's benefits; and (3) Cluster 3 (95 respondents, 21.7%) – low-income groups with limited education and technology use. ANOVA confirmed significant differences among clusters ($p < 0.05$). The system design follows the waterfall model and includes class diagrams and a prototype interface developed in Figma. Although still at the design stage, the proposed system provides a practical blueprint for future implementation and supports data-driven policymaking and sustainable rural development.

Keywords: *Information System, Hierarchical Clustering, Village Income, Ciletuh Geopark, Cikelat Village*

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1. INTRODUCTION

The Ciletuh–Palabuhanratu Geopark, located in Sukabumi Regency, West Java, Indonesia, was designated as a UNESCO Global Geopark in 2018 [1]. Covering approximately 126,100 hectares, the area is renowned for its breathtaking natural beauty, rich geological heritage, and biodiversity, as well as its cultural values [2]. As a destination that integrates conservation, education, and sustainable development, the geopark features unique landscapes, including steep cliffs, waterfalls, sandy beaches, and ancient rock formations millions of years old. It is also home to endemic flora and fauna and maintains a high cultural value through the preservation of local traditions and wisdom.

The Ciletuh Palabuhanratu Geopark spans eight districts, including Ciemas, Ciracap, Surade, Waluran, Simpenan, Cikakak, Palabuhanratu, and Cisolok, each with distinct geological features such as hills, waterfalls, beaches, and ancient rock formations [3]. Cikelat Village, located in Cisolok District, is one of the areas within the geopark. Despite its unique natural and cultural assets such as green rice fields, clear rivers, cool air, and preserved local culture the village remains less well-known compared to others in the geopark.

One of the village's former tourist attractions, the Cumintir Camping Ground, once attracted both local and non-local visitors. However, its operations ceased during the COVID-19 pandemic and have yet to resume. This site still holds substantial potential for redevelopment as a hub for ecotourism, environmental education, and community-based tourism, contributing to economic diversification. The village economy is supported by sectors such as micro, small, and medium enterprises (MSMEs), agriculture, plantations, and labor. According to 2025 data from the Cikelat Village Government, agriculture dominates with 1,350 households working as farmers, followed by 435 entrepreneurs, 358 traders, 4 fisherman, 36 drivers, and 357 jobless [4].

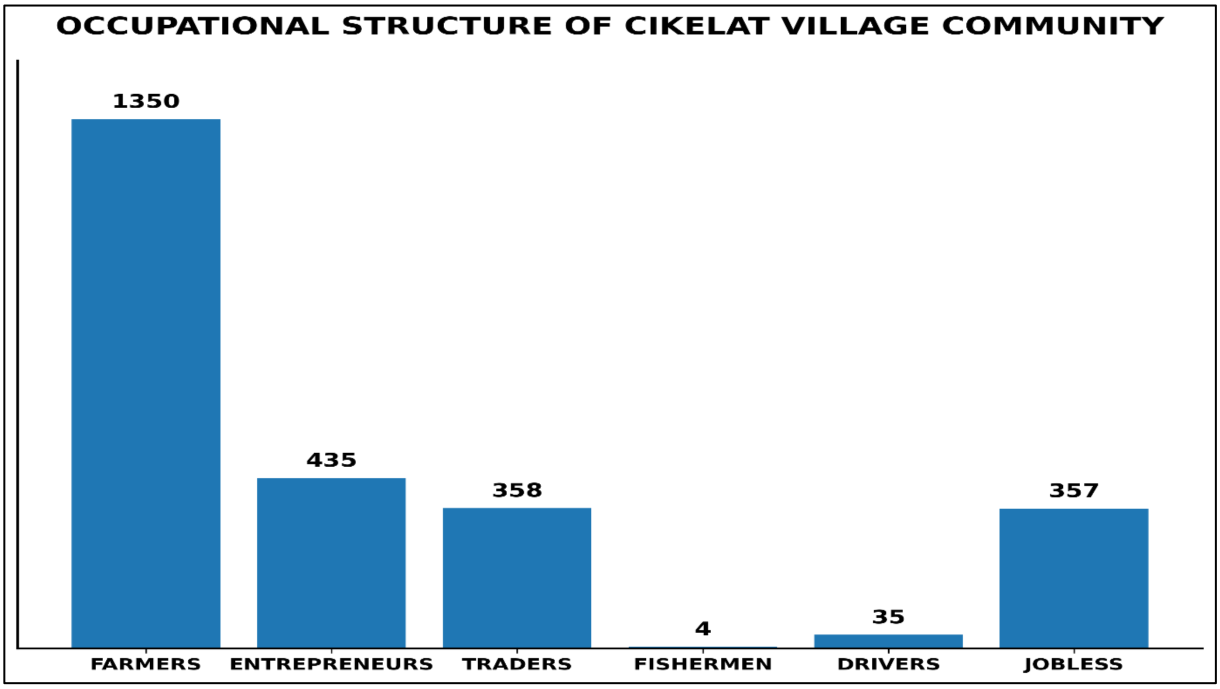

Figure 1.1 Employment Distribution in Cikelat Village

Given the village's untapped potential and the post-pandemic impact on residents' income, this study analyzes regional income distribution to formulate strategies for local economic improvement. The study applies the Hierarchical Clustering method, which groups data step-by-step based on characteristic similarities until a hierarchical structure is formed and visualized through a dendrogram. Compared to other clustering methods, Hierarchical Clustering offers advantages in exploring multivariate data without prior assumptions about the number of clusters. Unlike K-Means, which requires the number of clusters to be set in advance, this method allows for detailed observation of similarities and differences between groups [5].

Previous studies provide a crucial theoretical and methodological foundation for this work. Romshoo et al. (2024) used GIS and multi-criteria analysis to develop an Opportunity Index, classifying 348 villages in Pulwama, India, into five development categories based on social, economic, infrastructural, resource, and disaster vulnerability indicators, enabling targeted rural planning [6]. Zhang et al. (2022) evaluated rural life quality in 270 villages in Lin'an, China, using multidimensional big data indicators, grouping them into six development types to guide balanced regional policies [7]. Gajić et al. (2021) applied multivariate and cluster analysis to classify Serbian rural areas into six categories, facilitating more precise spatial planning [8]. Wang et al. (2023) employed GIS-based spatial analysis and the Pole Field Zone Network framework to identify development poles, spatial influence domains, and development zones in Yanchi County, China, informing revitalization strategies [9].

Other relevant works include Zhang et al. (2022), who combined weighting methods, hierarchical clustering, and spatial autocorrelation to evaluate and classify tourism resources in Hainan, China, into four spatial types, enabling tailored tourism development models [10]. Li et al. (2022) classified mountain villages in Yunnan, China, into five development categories based on topography, geological risk, and spatial indicators, formulating regulatory and public service strategies for each type [11]. Duarte-Duarte et al. (2021) used clustering to identify three tourism groups and propose two sample routes in Colombia, enhancing regional tourism planning [12]. Ma et al. (2022) assessed livability and population flow in 213 villages in Longxi County, China, categorizing them into four spatial reconstruction types to guide settlement restructuring [13]. These studies collectively demonstrate the effectiveness of clustering-based classification for spatial and socio-economic mapping. However, most of them focus only on analysis and classification, without providing a systematic design for practical implementation at the village level.

Building upon these foundations, this study aims not only to analyze socio-economic conditions but also to design a web-based information system to bridge the gap between academic analysis and practical policymaking. This research makes an academic contribution by combining socio-economic analysis with the design of a web-based information system in the specific context of a UNESCO Global Geopark. Previous studies, such as Romshoo et al. on rural planning in India [6], Zhang et al. on rural quality-of-life mapping in China [7], and Gajić et al. on rural classifications in Serbia [8], have demonstrated the effectiveness of clustering for socio-economic mapping. However, these studies did not integrate clustering analysis with the design of a decision-support system at the village level. The originality of this work lies in presenting a comprehensive blueprint for an income mapping information system tailored for Cikelat Village, which can later be implemented to support data-driven policymaking. This integration of clustering outcomes with system design distinguishes this research from prior works.

2. RESEARCH METHOD

2.1 Research Approach

This study employs a descriptive quantitative approach with a case study method in Cikelat Village. The descriptive quantitative approach aims to systematically present the characteristics of a phenomenon, variable, or population using numerical data, without testing causal relationships or hypotheses [14]. This method was selected because the collected data particularly community income are numerical and suitable for analysis using the Hierarchical Clustering method to identify patterns and groupings based on economic levels. The descriptive nature of this approach provides a clear depiction of the community's economic conditions without manipulating the data, while the case study method enables in-depth analysis within a single area, ensuring results that are relevant to local needs. Furthermore, this approach supports the design of a web-based information system to present the analysis results in an accessible format, serving as a decision-support tool for policymakers at the village level.

2.2 Types and Sources of Data

This study uses two complementary data types: primary and secondary data. Primary data were collected directly from respondents in Cikelat Village through field surveys using questionnaires, structured interviews, and direct observations [15]. The questionnaire gathered information on monthly income, occupation, education level, and main economic resources, serving as the main input for clustering analysis. Secondary data were obtained from pre-existing sources such as official village documents (profiles, development statistics, financial reports) and academic references, including journals, books, and prior studies relevant to village information systems and income analysis [16]. The integration of primary and secondary data provides a robust foundation for accurate analysis and the design of a relevant, well-targeted income mapping information system.

2.3 Data Collection Techniques

1. Observation. Field visits to Cikelat Village within the Ciletuh Geopark were conducted to directly observe economic conditions, local potentials, and relevant locations for income mapping, forming the basis for system design and clustering analysis.
2. Literature Review. A review of journals, articles, and prior studies on village information systems, local potential mapping, income analysis, and clustering methods was conducted to build the conceptual framework and ensure methodological relevance.
3. Interviews. Discussions with local officials, MSME actors, farmers, and tourism managers provided insights into economic challenges, untapped potentials, and expectations for the income mapping system.
4. Questionnaire. Questionnaires collected residents' data on economic conditions, income sources, and perceptions using a Likert scale. Respondents were informed of the study's purpose and assured confidentiality to ensure accuracy.

2.4 Data Analysis

The data analysis aimed to identify income patterns among Cikelat Village residents based on socioeconomic, environmental, and tourism-related factors. Hierarchical Clustering was applied to group residents with similar characteristics.

1. Data Description

The analyzed data came from questionnaires covering respondent characteristics such as age, gender, education, and occupation; household income sources and amounts, utilization of natural resources, perceived impacts of tourism, adoption of technology, alternative income sources including micro-enterprises and tourism-related activities, as well as community involvement and support for local economic policies.

2. Data Processing

Collected data were cleaned and transformed through:

1) Handling missing values.
2) Encoding categorical variables.
3) Normalizing numerical variables (e.g., income) using Min-Max Scaling [17].

$$X_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}} \quad (1)$$

3. Application of Hierarchial Clustering

The clustering process involved

1) Calculating Euclidean Distance between respondents [18].

$$d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2} \quad (2)$$

2) Applying Ward's Linkage to merge clusters on the smallest increase in Sum of Squared Errors (SSE) [19].

$$SSE = \sum_{j=1}^{p} \left(\sum_{i=1}^{n} X_{ij}^2 - \frac{1}{n} \sum_{i=1}^{n} X_{ij} \right)^2 \quad (3)$$

3) Visualizing results with a dendogram to determine the optimal number of clusters

4. Determanition of Clustering Number

The optimal cluster number was identified by examining dendrogram cut-off points indicating significant distance jumps and confirmed using the elbow method.

5. Interpretion and Visualizaton

Clusters were interpreted by analyzing average variable values and labeled as low-income, middle income, and high-income groups. Results were presented in the web-based information system through tables, graphs, and interactive maps to support policy-making and welfare monitoring.

2.4 Information System Design

Information system design is the process of planning, designing, and implementing a system to manage data and information effectively [20]. In this study, the design aims to develop a web-based application for presenting the income distribution of Cikelat Village in a structured and interactive manner. The system is based on data processed using the Hierarchical Clustering method, ensuring that the output is data-driven and supports targeted village policy-making.

1. System Development Method

The system development follows the Waterfall model, which, despite not reaching the implementation stage, provides a structured and systematic framework suitable for analysis and design. In this study, the applied stages include:

1) Requirement Analysis. Identifying user information needs, data types, and required features.
2) System Design. Creating diagrams and visual mockups such as Use Case Diagrams, Class Diagrams, and user interface prototypes.

2. Tools Used

The design process employed the following tools:

1) Figma. Figma used to design the user interface mockups for key web pages, including the homepage, income map, data filters, and cluster details. Chosen for its cloud-based, collaborative, and responsive design capabilities.
2) Draw.io Used to create system diagrams such as Use Case and Class Diagrams, offering flexibility and ease of use for system modeling needs.

3. System Design

The system design aims to provide a visual representation of the workflow and functionalities of the village income mapping information system

1) Use Case Diagram – Admin

This diagram illustrates the interaction between the admin and the system, including community data management, automated clustering, report generation, questionnaire management, and account settings. Include and extend relationships depict the connections between functions

2) Use Case Diagram – User

This diagram outlines the functions accessible to users, namely completing the questionnaire with NIK validation and viewing statistical summaries. Additional features, such as QR code scanning and data filtering, are indicated using extend relationships.

3) Class Diagram

The class diagram outlines the structure of the Cikelat Village income mapping system, showing key classes such as Admin, Community Data, Clustering, Statistics, and Reports. It defines their attributes, methods, and relationships, ensuring efficient data management, clustering, statistical analysis, and report generation.

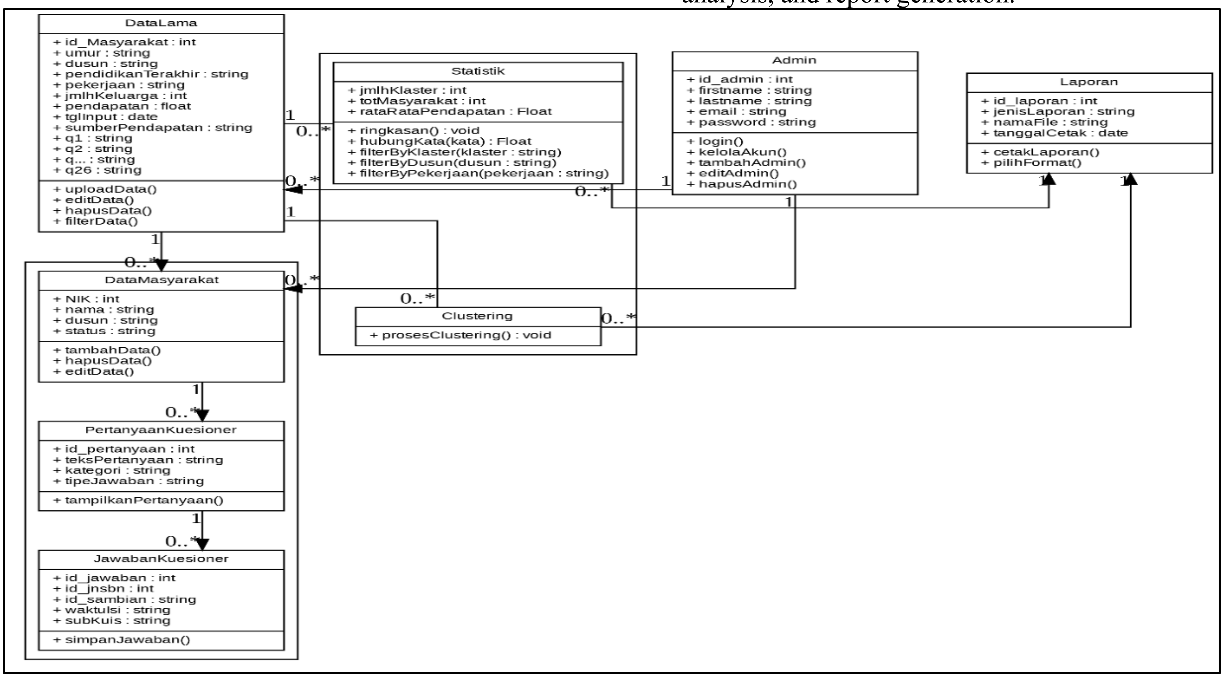

Figure 2. Class Diagram

3. DISCUSSION AND RESULT

3. 1 Respondent Data

1. Study location and data collection method

The study, conducted in Cikelat Village, Cisolok District, Sukabumi Regency (Ciletuh Geopark), involved 434 respondents from Bangbayang, Cikelat, Cikupa, and Nagrak hamlets. Data were collected between April and May 2025 through observations and structured questionnaires targeting household heads or adult members. The dataset, covering diverse socioeconomic backgrounds, formed the basis for hierarchical clustering and income mapping.

2. Respondent characteristics

The respondents' characteristics include demographic and socio-economic aspects such as gender, age, education level, occupation, and monthly income, serving as the basis for clustering analysis. The gender distribution shows that 78% of respondents are male and 22% female. Age is grouped into five categories, with the majority in the productive age range of 40–49 years. Most respondents completed secondary education 32% senior high school and 32% junior high school while 29% hold primary education, and higher education remains limited. Occupational data reveal that agriculture dominates (40%), followed by self-employed (26%) and laborers (16%), with small proportions in formal employment. Monthly income is largely concentrated below IDR 2.5 million (77%), with only 5% earning above IDR 3 million, indicating a predominance of low-income households. These patterns highlight the economic structure of Cikelat Village and provide a foundation for further clustering analysis.

3. 2 Data Processing Result

The final pre-processed dataset consisted of 434 valid respondent records and 27 clustering variables derived from the questionnaire. All variables were transformed into numerical form to ensure compatibility with the Hierarchical Clustering algorithm.

1. Categorical Variable Transformation

Several categorical variables from the questionnaire, including gender, education level, housing status, and occupation, were converted into numerical form to meet the requirements of the Hierarchical Clustering algorithm. Gender and education level were encoded ordinally, while occupation was transformed using one-hot encoding. All transformations were performed in Microsoft Excel and manually validated to ensure accuracy.

2. Data Normalization

All numerical variables, including those derived from categorical transformations, were normalized using the Min–Max Scaling method to a range of 0–1. This step ensures that differences in variable scales do not introduce bias into the Hierarchical Clustering process.

3. Final Pre-Processed Dataset

After undergoing transformation and normalization, all respondent data were converted into numerical format with a uniform scale. Categorical variables were encoded using label encoding and one-hot encoding, while Min–Max normalization was applied to all numerical variables. The final dataset includes features such as age, education level, gender, occupation type, and monthly income, all scaled between 0 and 1. This processed dataset was then used for the Hierarchical Clustering analysis to group respondents based on their socio-economic characteristics.

3. 3 Hierarchial Clustering Results

The data grouping was conducted using the Hierarchical Clustering method with the Ward Linkage approach. This method was selected for its ability to minimize the Sum of Squared Errors (SSE) at each cluster merging step, thereby producing a more optimal cluster division.

1. Desndogram and Cluster Determination

The Hierarchical Clustering method using Ward's Linkage and Euclidean Distance produced a dendrogram that revealed three natural clusters. The cut-off point was determined at the height where a significant increase in inter-cluster distance occurred, resulting in an optimal partition into three clusters.

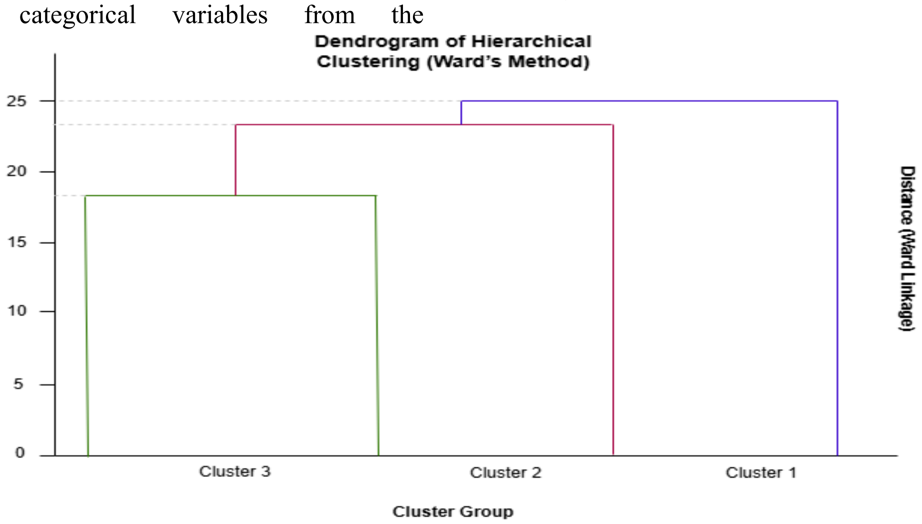

Figure 3. Dendogram of Hierarchial Clustering Results using Ward Linkage

Based on the dendrogram observation, three main branches (natural cluster separations) were identified. The dendrogram was cut at the height indicating a substantial distance change between clusters; therefore, the optimal number of clusters in this study was determined to be three.

2. Cluster Characteristic

Hierarchical Clustering with Ward Linkage produced three clusters reflecting socio-economic diversity in Cikelat Village. Cluster determination was based on normalized mean values of variables including demographics, occupation, income, perceptions of Geopark Ciletuh, and technology use.

1) Cluster 1 (n=212): Highest education level, dominated by self-employed individuals, with moderate income. High technology adoption (Q16–Q18) and strong support for Geopark-related policies (Q12, Q13, Q26). Represents a relatively well-educated, tech-savvy group with stable income.
2) Cluster 2 (n=131): Predominantly farmers, low education and lowest income, yet strong perceptions of Geopark's economic benefits and high policy support. Reflects an agrarian group with high reliance on agriculture but strong optimism toward Geopark development.
3) Cluster 3 (n=91): Low education, low income, and limited technology use, with weak perceptions and engagement in Geopark initiatives. Represents a vulnerable group with limited economic and technological resources.

3. Cluster Comparison

A One-Way ANOVA was conducted to examine differences across clusters. Most variables showed significant differences ($p < 0.05$), except for Household Size, Occupation: Honorary Teacher, and Support for Geopark Policy (Q26). Post-hoc tests revealed that:

1) Cluster 1 had significantly higher education, income, and technology use (Q16–Q18) compared to Clusters 2 and 3.
2) Cluster 2 was dominated by farmers, with medium technology engagement, and lower education and income than Cluster 1.
3) Cluster 3 had the highest proportion of housewives, the lowest education and technology use, and low Geopark-related engagement.

These differences highlight the need for tailored policy interventions: technology capacity building for Cluster 3, sustainable agriculture strengthening for Cluster 2, and Geopark optimization for Cluster 1.

4. Cluster Distribution by Hamlet

To examine the spatial distribution of the clustering results, an analysis was conducted based on the administrative hamlets in Cikelat Village. This analysis is important for identifying areas with specific socio-economic characteristics, which can serve as the basis for location-based policy planning. The distribution is summarized in Table I.

Table 1. Cluster Distribution by Hamlet

Hamlet	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Total**
Bangbayang	38 (41.8%)	35 (38.5%)	18 (19.8%)	91
Cikelat	54 (47.0%)	34 (29.6%)	27 (23.5%)	115
Cikupa	73 (52.9%)	31 (22.5%)	34 (24.6%)	138
Nagrak	47 (50.0%)	31 (33.0%)	16 (17.0%)	94
Total	**212**	**131**	**95**	**438**

The data reveal that:

1) Cluster 1, characterized by relatively higher education and technology adoption, is widespread across all hamlets and is most dominant in Cikupa (52.9%) and Cikelat (47.0%).
2) Cluster 2, consisting primarily of agricultural households with a high proportion of farmers, is most prevalent in Bangbayang (38.5%) and Nagrak (33.0%).
3) Cluster 3, dominated by housewives with low technology adoption, is more evenly distributed but slightly more concentrated in Cikelat and Cikupa.

These findings highlight socio-economic differences between hamlets, providing a valuable reference for the village government in formulating targeted development strategies. Cluster 1 consisted of 212 respondents (48.4%), Cluster 2 of 131 respondents (29.9%), and Cluster 3 of 95 respondents (21.7%).

5. Mockup of the Information System

The mockup was developed to visualize the user interface and workflow of the income mapping system for Desa Cikelat prior to implementation. The system serves two main roles: Admin (village officials) with full access to data management, clustering, and reporting features, and User (public/stakeholders) with access to view clustering results, filter information, and complete questionnaires.

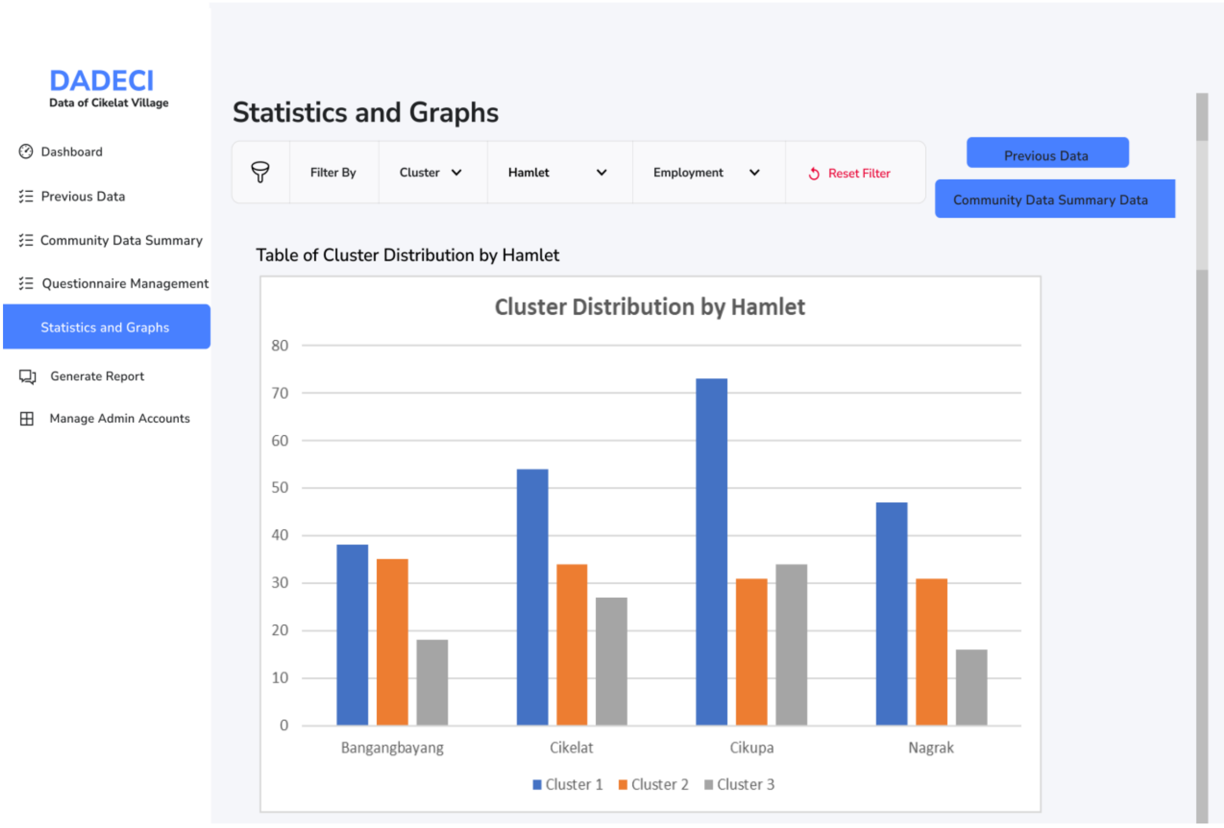

Figure 4. Admin Page of Statistics and Graphs

The figure above depicts an interface design that is kept simple and intuitive to ensure ease of use, including for non-technical users, while remaining fully functional to meet the intended requirements.

4. CONCLUSION

This study analyzed socio-economic conditions in Cikelat Village, which is part of the Ciletuh–Palabuhanratu UNESCO Global Geopark, using data from 434 respondents. The application of the Hierarchical Clustering method with Ward's linkage identified three distinct socio-economic clusters: (1) a relatively well-educated and technology-adaptive group with moderate income, (2) an agricultural low-income group with positive perceptions of Geopark benefits, and (3) a vulnerable low-income group with limited education and technology use. Statistical testing with ANOVA confirmed that most variables showed significant differences across the clusters.

The results emphasize that village development strategies should be tailored to the specific characteristics of each group rather than applying a uniform approach. For example, Cluster 1 can be empowered through Geopark optimization, Cluster 2 through sustainable agriculture programs, and Cluster 3 through technology and capacity-building initiatives.

In addition to the clustering analysis, this research contributes a design prototype of a web-based information system for income mapping in Cikelat Village. The system design, developed using the waterfall model and visualized with use case diagrams, class diagrams, and user interface mockups, provides a structured blueprint for future implementation.

The originality of this work lies in combining socio-economic clustering analysis with the design of a decision-support system at the village level, a dimension that has not been integrated in previous studies. Although the system has not yet been fully implemented, this blueprint offers strong potential to support data-driven policymaking, spatially adaptive planning, and sustainable rural development in Geopark contexts.

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