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Application of Geographic Information System (GIS) Technology to Formulate Unused Spring Water Optimization Strategy

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ABSTRACT

Background: This article presents the findings of a comprehensive community empowerment program that focused on the application of Geographic Information System (GIS) technology for the optimization strategy formulation of unused spring water.
Contribution: The contribution of this program address the challenge for better utilization of unused spring water and promote sustainable water management practices.
Method: The study employed GIS technology to identify and map unused springs, followed by hydrological analysis and water quality assessment to inform the development of optimization strategies.
Results: This program suggested infrastructure development, water conservation measures, and distribution network design to enhance water availability.
Conclusion: The findings show that GIS approach is suitable for further applications in other Indonesian mountainous villages with similarly shared community traits. However, further some locality aspects, including, but not limited to community leadership and economic power, need to be assessed further, as they play significant influences on the success of the program.

1. Introduction

Access to clean and reliable water sources is crucial for the well-being and development of communities worldwide [1]–[3]. Indonesia, as a tropical country with high precipitation rate, is a country blessed with abundance of water resources [4]. The global volcanic chain, especially the Pacific Ring of Fire, that goes through Indonesian territory [5] is also another factor of the abundance of high-quality water resources. Naturally in break of slope areas around volcanoes, there are many water springs, and is known as volcanic spring belt [6]. However, many of the springs are not or underutilized by local communities[7], [8], untapping the potential benefits that are possibly generated from the springs.

Volcanic springs are also found in Ngalian Hamlet, Widodomartani Village, Ngemplak Sub-regency, Sleman Regency, Yogyakarta Province (Figure 1). This hamlet is a natural place for the presence of volcanic springs, as it is located in the southern break of slope of Merapi Volcano. Despite high water resource potential of this hamlet from many springs present in this hamlet, many springs remain under or not utilized. This hamlet has long been dreaming of optimally utilizing their unused spring water, for the development of this hamlet. Maximizing the potential of these untapped water sources for community use requires effective management strategies. One of the primary goals in water management is to facilitate the provision of freshwater at the right time and location. This task is becoming increasingly challenging due to climate changes, coupled with the rise in both population and economic activities [9].

One solution for realizing the effective spring management strategies, many approaches could be employed. Among many approaches, one of the most effective ones is with the integration of Geographic Information System (GIS) technology. GIS technology provides a promising solution to identify, optimize, and sustainably utilize these springs, promoting community empowerment and equitable access to clean water [10], [11].

This journal article presents a community empowerment program report that focuses on the application of GIS technology for the optimization strategy of unused spring water for community use in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta conducted from February to August 2023. By harnessing the potential of GIS technology, this program aimed to enhance sustainable water management practices, empower the community, and ensure equitable access to this valuable resource.

GIS technology plays a vital role in the optimization of unused spring water for community use by enabling the collection, analysis, and visualization of geospatial data [11]–[13]. By mapping and monitoring the locations, characteristics, and flow patterns of these springs, GIS technology facilitates a comprehensive understanding of their potential as alternative water sources[12]. This knowledge allows for informed decision-making and the development of effective strategies to maximize the utilization of these resources, ultimately benefiting the community[14], [15].

One of the key advantages of GIS technology in optimizing unused spring water is its ability to generate spatial models and simulations [13], [15], [16]. By considering factors such as hydrological patterns, land use, and population growth, GIS technology can predict the availability and future demand for water resources in Ngalian [14], [17]. This predictive capacity empowers decision-makers to develop appropriate interventions, such as infrastructure development, water conservation measures, and distribution network designs, to optimize the use of unused spring water for the benefit of the community. GIS technology is also able to assists the quality and feasibility assessment of unused spring water for community use. By incorporating data on water quality parameters, hydrogeological characteristics, and potential sources of contamination, GIS technology enables the identification of viable springs that meet the necessary standards for drinking and domestic purposes [18], [19]. This ensures the provision of clean and safe water, promoting community health and overall well-being.

Figure 1. The main gate of Ngalian "Empon-empon" Hamlet

Active community involvement is crucial for the success of the optimization strategy for unused spring water [15], [20], [21]. GIS technology serves as an effective tool for communication and engagement, allowing community members to participate in decision-making processes [15], [22], [23]. Through interactive maps, public awareness campaigns, and participatory workshops, GIS technology promotes transparency, inclusivity, and a sense of ownership, thereby empowering the community to take an active role in sustainable water management [15], [24].

The adoption of GIS technology for the optimization strategy of unused spring water in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta, presents an opportunity to bridge the gap between scientific research and practical implementation[12], [15], [25]. This community empowerment program report aims to provide evidence-based recommendations and best practices for policymakers, water resource managers, and community leaders in the local context. By demonstrating the effectiveness of GIS technology in optimizing underutilized spring water, this report strives to inspire similar initiatives in other regions facing similar challenges.

This community empowerment program report highlights the application of GIS technology as an optimization strategy for unused spring water for community use in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta. By leveraging GIS technology, the program aimed to optimizing the unused and underutilized spring water in Ngalian while empowering the community, promoting sustainable water management practices, and ensuring equitable access to clean and sustainable water resources. The report contributes valuable insights and recommendations to foster community empowerment and inspire similar initiatives globally.

2. Method

2.1. Study Area Selection

Administration of Ngalian Hamlet in Widodomartani, Ngemplak, Sleman, Yogyakarta was selected as the study area based on the demand from thein Ngalian for the utilization of the underutilized spring water resources. Field surveys and consultations with local stakeholders were conducted to gather information on the existing water sources, community needs, and challenges.Admisitration of Ngalian Hamlet can see in Figure 2.

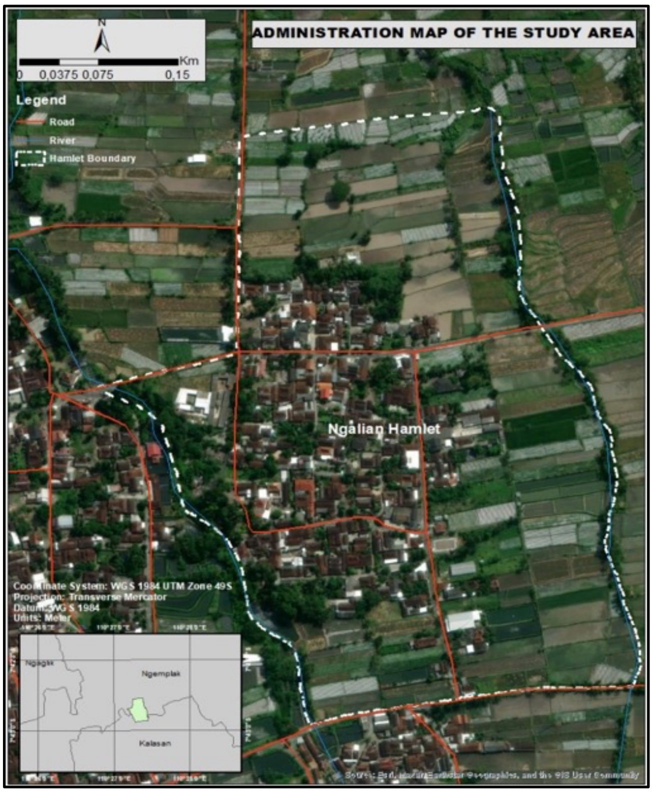

Figure 2. Administration map of the study area

2.2. Data Collection:

Based on Participatory Action Research (PAR) community service, geospatial data in this research, including satellite imagery, topographic maps, hydrological data, and land use information, were collected from reliable sources such as government agencies, research institutions, and community-based organizations. Field surveys, with the involvement of local community, were conducted to collect detailed information about the springs, including their locations, flow rates, water quality parameters, and potential sources of contamination.

a) GIS Data Preparation:

The collected data were compiled, processed, and organized using GIS technology software. Spatial layers, including topographic features, hydrological networks, land use patterns, and existing water infrastructure, were created to establish a comprehensive GIS technology database for the study area.

b) Spring Identification and Mapping:

GIS tools and analysis techniques were employed to identify and map potential unused springs in Ngalian. This stage was strongly involving local community as they are more aware and more knowing the research area in details. Criteria such as proximity to communities, hydrological characteristics, water quality, and sustainability were considered during the selection process. The identified springs were mapped and visualized using GIS software to provide a clear spatial representation of their locations and attributes.

c) Water Flow and Quantity Assessment:

Water flow and quantity assessments were carried out through field measurement from the selected springs with the involvement of local community. GIS technology was utilized to integrate the water flow and quantity data with the spatial information, allowing for the identification of spring water flow and quantity that met the need for community use.

d) Water Quality Assessment:

Water quality assessments were carried out through field observations from the selected springs, using three indicators: colour, taste and odour. This basic observation was chosen as the potential water resource will be used for non-potable uses. In this assessment, local people were involved, to give comparable assessment results. GIS technology was utilized to integrate the water quality data with the spatial information, allowing for the identification of springs that met the necessary standards for community use.

During the data collection processes, the authors involved local communities a form of active community participation.

2.3. Hydrological Analysis

Hydrological analysis was conducted using GIS technology to understand the flow patterns. This analysis helped in determining the hydrological dynamics of the springs and identifying optimal strategies for their utilization.

2.4. Optimization Strategy Development

Community engagement activities and meetings were conducted to involve the local community in the decision-making process. GIS-based tools and interactive maps were utilized to facilitate discussions, gather community input, and incorporate local knowledge into the optimization strategies.

Based on the analysis of data, community input, and water demand projections, optimization strategies were developed to maximize the utilization of the identified unused springs. The strategies included infrastructure development plans, distribution network designs, and community-based management approaches to ensure sustainable water use and equitable access.

The methodology described above outlines the key steps taken in the community empowerment program research based on active community participation, utilizing GIS technology for the optimization strategy of unused spring water for community use in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta. The steps can be simplified using a flow diagram can see in Figure 3.

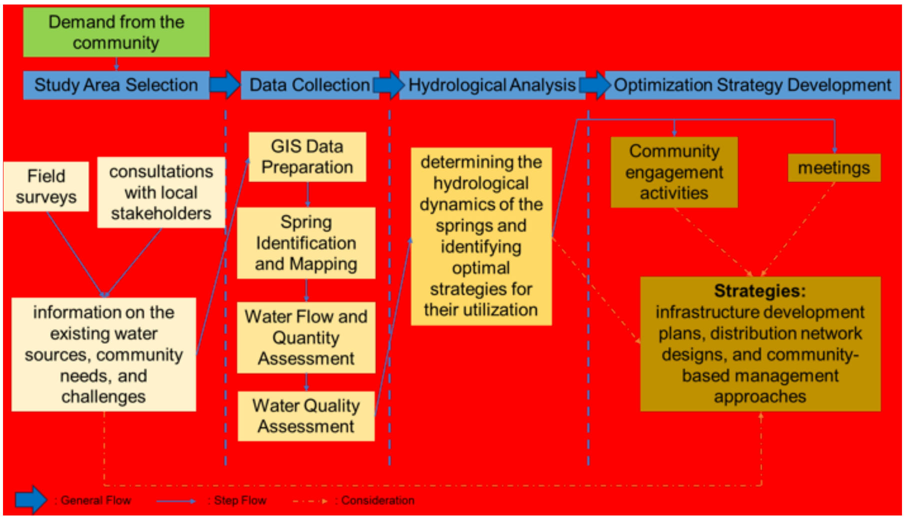

Figure 3. Flow diagram of the research method

3. Results and Discussion

3.1. Spring Identification and Mapping

This stage successfully identified and mapped 3 unused springs in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta (Figure 4). The GIS mapping provided a visual representation of the springs' locations and their proximity to communities and existing water infrastructure. This information serves as a valuable resource for decision-makers to optimize the utilization of these springs for community water needs.

(a) (b) (c)

Figure 4. The springs found in Ngalian Hamlet; (a) Spring 1, (b) Spring 2, and (c) Spring 3

3.2. Water Flow and Quantity Assessment

This stage revealed essential insights into the flow patterns of the identified springs. All of the spring water are flowing to the south, following the direction of the slope; and this is in accordance with the study by [26]. Some local community members also informed that some springs exhibited consistent flow rates throughout the year, suggesting their reliability as potential water sources. For further information about the spring water flow and quantity, see Table 1. Understanding the hydrological dynamics of the springs is crucial for implementing effective strategies to optimize their use and ensure sustainable water availability.

Table 1. Spring identification and mapping results

No	*X Coordinate*	*Y Coordinate*	*Altitude*	*Above MSL*	*Flow Rate and Types*
1	440066.64	9147879.95	271.90	247.07	Low-flow artesian
2	440036.63	9147806.95	271.40	246.58	Non-artesian
3	439923.21	9147851.47	279.5	254.68	Moderate-flow artesian

3.3. Water Quality Assessment

The water quality assessment conducted for the identified springs (see Figure 5 and Table 2) demonstrated that the majority of them have good water quality suitable for community use. This can be indicated by the quick water quality assessment results, based on their color, tastes and odor[27]. [28] The results show that there was no objection or issue on these three parameters. The program did not examine other parameters as the water would not be used for human consumption. Rather, it will go for watering plants or fish ponds.

(a) (b) (c)

Figure 5 Spring water quality assessment in (a) Spring 1, (b) Spring 2, and (c) Spring 3

Table 2. Spring water quick quality assessment results

No	*Spring*	*Note*	*Colour*	*Taste*	*Odour*
1	Spring 1	Low-flow artesian	Clear	Neutral	Neutral
2	Spring 2	Non-artesian	Clear	Neutral	Neutral
3	Spring 3	Moderate-flow artesian	Clear	Neutral	Neutral

The integration of water quality data with GIS technology provided a comprehensive understanding of the springs' suitability for community needs. These findings indicate that the optimized use of these springs can contribute to improving the community's access to clean water.

Based on the spatial analysis of hydrological data, water quality assessment, and community input assisted by GIS technology, optimization strategies were developed to maximize the utilization of the identified unused springs. These strategies encompass infrastructure and distribution network designs, and water resource management organization. By implementing these strategies, the community can ensure equitable access to water resources while promoting sustainable water management practices.

The use of GIS technology in this project has significantly help the processes. GIS technology analysis aided in identifying suitable locations for infrastructure development, such as storage tanks, pipelines, and distribution networks. The integration of GIS data, including topographic features and existing infrastructure, enabled the selection of optimal routes and placement of infrastructure, minimizing cost and maximizing water accessibility. Besides, GIS analysis played a crucial role in designing an efficient distribution network for the optimized use of unused spring water. By considering factors such as population density, topography, and proximity to water sources, GIS-based tools helped in determining the optimal placement of distribution points and pipelines, ensuring equitable water access across the community. Figure 6 shows the placement of the supporting infrastructures for the optimization of spring water in Ngalian Hamlet.

Figure 6. Spring water use optimization design (a) Scenario 1, (b) Scenario 2

3.4. Community Engagement

The community engagement activities conducted through meetings, field activities and the use of GIS-based tools fostered active community involvement and empowerment (see Figure 7). Through these activities, community members were able to contribute their knowledge, preferences, and concerns regarding the optimization strategies. This participatory approach ensures that the community's needs and aspirations are considered in the decision-making process, enhancing their sense of ownership and empowerment.

(a) (b) (c)

Figure 7. Activities involving local communities in (a) designing program, (b) finding and surveying springs, (c) assessing the quantity and quality of the springs

The integration of local knowledge and community input is also a crucial aspect of the program. Participatory workshops will provide a platform for community members to share their traditional knowledge, observations, and preferences regarding water resources. Integrating this local knowledge with scientific data and GIS analysis enhanced the overall effectiveness and relevance of the optimization strategies.

In comparison to existing studies focused on the application of GIS technology in water resource optimization, our research presents distinctive contributions and aligns with broader trends in the field. Several studies have explored GIS applications in water resource management, yet our emphasis on the formulation of an unused spring water optimization strategy within the unique context of Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta differentiates our work.

Several studies, such as [29], [30], have employed GIS to assess water quality. Meanwhile, several studies, such as [31], [32], have employed GIS to assess water quantity. These studies emphasize the importance of spatial analysis in identifying optimal water sources. While these studies contribute valuable insights, our research extends beyond assessment to formulate a comprehensive optimization strategy for underutilized spring water resources, considering hydrological characteristics, water quality, and community engagement.

Moreover, [33], [34] focused on GIS applications for water infrastructure planning, highlighting the significance of spatial data in designing distribution networks. Our study complements this perspective by not only incorporating infrastructure development into the optimization strategy but also emphasizing the socio-economic and empowerment aspects of community engagement.

In terms of challenges, our study resonates with findings by [35], revealing common obstacles related to data availability and accuracy. However, our research addresses these challenges by detailing the rigorous methodologies employed for data collection and ensuring reliability through field surveys and stakeholder consultations.

While existing studies lay the groundwork for understanding GIS applications in water management, our research uniquely contributes by providing a specific, replicable model for optimizing unused spring water resources. The context-specific nature of our optimization strategy, along with its emphasis on community empowerment, offers a nuanced perspective within the broader GIS literature on water resource management.

The implementation of the optimization strategies will have a significant impact on water availability in the community. By utilizing the unused springs and implementing efficient distribution networks, the community will experience improved access to water resources. The optimized utilization of these springs will help maximize the use of spring water in Ngalian Hamlet. Besides, there are numerous benefits that can be gained by the communities, including environmental and economic aspects. The optimization of unused spring water resources not only benefits the community but also has positive environmental implications. By utilizing local water sources, the community reduces the extraction of groundwater or surface water from distant locations. This minimizes the environmental impact associated with long-distance water transportation, reduces energy consumption, and preserves natural water resources.The optimization of unused spring water resources through GIS-based strategies will have positive economic implications for the community. By utilizing local water sources, the community can reduce their reliance on expensive water supply systems or costly water treatment processes. This can result in cost savings for the community and potentially stimulate local economic development.

The integration of GIS technology in the optimization strategies aims to ensure the long-term sustainability of water resources in Ngalian. By considering factors such as hydrological characteristics, water quality, and community needs, the optimization strategies are designed to adapt to future changes and challenges. This emphasis on long-term sustainability reinforces the resilience of the community's water supply system. This, indeed, needs for community collaboration and strong social cohesion. Decision-making processes should actively involve community members to come together to collectively address water-related challenges. This collaboration not only enhanced the effectiveness of the optimization strategies but also built stronger social bonds within the community.

The success of the community empowerment program is also influenced by policy and institutional support. Collaboration with local government agencies, water management organizations, and community-based institutions played a crucial role in ensuring the alignment of the program with existing policies and regulations. These partnerships also will facilitate the implementation of the optimization strategies and provided access to necessary resources. Therefore, this aspect should become an inseparable part of this program.

The community empowerment program employing GIS technology in Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta demonstrates notable strengths in replicability and scalability. The methodologies and strategies deployed serve as a robust model for communities confronting analogous water challenges. This GIS-based approach, adaptable to specific circumstances, offers a template for optimizing unused spring water resources and fostering community empowerment. The program's success establishes a foundation for its replication in diverse geographic contexts, affirming the potential for scalable and transferable applications of GIS technology in similar community-based water management initiatives.

In tandem with its strengths, the community empowerment program utilizing GIS technology faced noteworthy challenges and limitations during implementation. Chief among these challenges was the availability and accuracy of data, particularly concerning the hydrological characteristics and water quality of the springs. The constraints imposed by limited resources and expertise in data collection and analysis added complexity to the program's execution. Despite these challenges, conscientious efforts were undertaken to enhance data reliability through rigorous field surveys and consultations with relevant stakeholders. Acknowledging these limitations provides valuable insights for refining future iterations of GIS-based community empowerment programs, emphasizing the iterative nature of such initiatives and the importance of adapting strategies to local constraints.

5. Conclusion

In conclusion, this research represents a significant advancement in the domain of water resource management by introducing a meticulously formulated Unused Spring Water Optimization Strategy leveraging Geographic Information System (GIS) technology. The theoretical contributions of this study extend beyond the prevailing literature by not only utilizing GIS for assessment but by innovatively integrating spatial analysis to craft a comprehensive optimization strategy tailored to the unique context of Ngalian, Widodomartani, Ngemplak, Sleman, Yogyakarta. The study advances our understanding of GIS applications by incorporating social dimensions, community empowerment, and infrastructure development into the optimization framework. This integration responds to the specific water challenges faced by the community and underscores the adaptability of GIS technology in formulating context-specific strategies for sustainable water management. However, acknowledging the limitations of our study is paramount. Challenges related to data availability and accuracy were encountered, and while efforts were made to mitigate these issues through rigorous field surveys and stakeholder consultations, the study's outcomes are subject to the constraints of available data. Furthermore, future research endeavors should explore more granular aspects of GIS applications in water management, considering advancements in remote sensing technologies and improved data acquisition methods.

In summary, our findings demonstrate a marked improvement in water resource uses and management through the optimized use of underutilized springs. The GIS-based strategy, considering hydrological characteristics, water quality, and community engagement, serves as a replicable model for similar communities facing analogous water challenges. This research contributes significantly to the growing body of knowledge in GIS applications by providing a holistic framework for formulating optimization strategies, thereby fostering sustainable water management and community empowerment. The innovative approach and context-specific nature of our strategy underscore its relevance as a model for fostering resilience in water-scarce regions globally.

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