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Regional Case Study

Delineation of Irrigation Network Performance in Subak in South Denpasar District, Bali Province

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Abstract

Massive conversion of agricultural land into built-up land occurred in South Denpasar District. These changes impacted the decline in rice production by 5.5% in 2023 and a decrease in the performance of the irrigation network. This study employs GIS to assess the efficacy of irrigation networks to enhance sustainable agriculture, community food security, and irrigation and subak network systems in South Denpasar. This study used spatial analysis to create an irrigation network performance map. Data analysis interprets primary data based on field observation to assess the irrigation network's physical condition. The irrigation network is divided into four levels: good, slightly damaged, medium damaged, and badly damaged. The study indicated that Subak Sesetan disintegrated since it was thought to have turned into a village. The land conversion reduced the 292.593 Ha of subak (Kerdung, Cuculan, Kepaon, and Sesetan) to 186.314 Ha, or 36.32%. The length of irrigation canals was 16.901 Km, with good conditions along 16.67 Km or 98.61%, slightly damaged conditions along 0.051 Km or 0.3%, and moderately damaged conditions along 0.1842 Km or 1.09%. This research should help South Denpasar District stakeholders decide on land-use change strategies and rehabilitation or irrigation network development priorities.

Keywords: Land conversion; spatial analysis; irrigation network performance; geographic information system; subak

1. Introduction

Irrigation is a water management activity that plays a significant role in the sustainability and success of the agricultural sector. Irrigation is essential in maintaining food supply while supporting economic development in various countries. Increased food demand impacts the development of irrigation networks (Tirtalistyani et al., 2022). The irrigation network consists of buildings and irrigation canals, and their complementary buildings are an irrigation infrastructure that distributes water evenly. A good irrigation network condition will significantly determine the quality of service to the irrigation area. The disruption or damage of one of the irrigation buildings will affect the performance of the existing irrigation system, resulting in a decrease in irrigation efficiency and effectiveness (Budimansyah, 2015). The strategic importance of irrigation requires a comprehensive approach built on a careful assessment of needs, potential, and performance. Mapping the needs and potentials of agricultural areas can be a guide for decision-makers in planning irrigation development investment as well as can be used as a common platform to map the needs of irrigation network development, its potential, and including

the evaluation of irrigation network performance so that it can become a specific decision support system for related parties (Akpoti et al., 2022).

The operation and maintenance of the irrigation network, which includes evaluation, monitoring and inventory, is needed so that the irrigation network's supporting infrastructure can function appropriately and its use can be adequately on target. Still, the inventory activity requires enormous costs, human resources, and a long time (Akbar et al., 2023). One of the things needed in the operation and maintenance of irrigation networks is the spatial data of irrigation networks, which can be gathered by utilizing advances in computer and information technology, which is Geographic Information System (GIS) technology. The GIS methodology utilizing terrestrial survey techniques successfully illustrates spatial data concerning irrigation networks (Abdurachman et al., 2019; Adil and Triwijoyo, 2021; Rivai et al., 2021; Tarate et al., 2024). Geographic Information Systems (GIS) are computer-based information systems for storing, managing, analyzing, and retrieving spatial data (Massei et al., 2014). GIS provides convenience for users or decision-makers in determining policies related to spatial aspects. With GIS technology, irrigation canal networks will be easier to map (Abdurachman et al., 2019). The mapping of GIS-based irrigation networks has been carried out by (Todorovic and Steduto, 2003) which uses GIS in irrigation management in the Apulia region, Southern Italy and the mapping of irrigation networks in Brebes Regency using GIS and satellite data (Abdurachman et al., 2019). In addition, the use of GIS has also been applied in irrigation management and flow distribution (Galoso and Principe, 2024). In addition to irrigation, GIS is utilized in various research domains, including the spatial monitoring and classification of urban degradation in Egyptian Cities (Osman et al., 2022), the integration of GIS and remote sensing for flood management in Alexandria City, Egypt (Afifi et al., 2023), and the application of GIS overlay in flood modelling due to dam failure in South Sulawesi Province, Indonesia (Karamma et al., 2022).

The city of Denpasar, as the centre of the government of Bali Province, is an area that continues to experience spatial and non-spatial development and has the potential to experience development dynamics. This results in agricultural land being increasingly eroded due to increasing changes in land use, which has an impact on reducing irrigation networks in terms of both quantity and performance levels. The spatial layout of Denpasar City is unique. There is still an active agricultural area where rice production 2023 is 26,763.23 tons. Still, there is a decrease of 5.5% in production in 2022, estimated to be due to a decrease in agricultural land due to changes in land use (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023) Another unique feature of the irrigation system in Denpasar City is the existence of the Subak system as a form of agricultural water user organization, with 35 subaks recorded in Denpasar City (Satu Data Indonesia Provinsi Bali, 2020). Based on Norken (2019) and Yekti et al. (2017), subak is a traditional irrigation system in Bali that has been inherited from generation to generation for a very long time. Subak still exists to maintain the sustainability of traditional irrigation management and operation. Subak is a social-agrarian-religious organization based on the philosophy of Tri Hita Karana, which is rooted in the philosophy of Hinduism, which are the creation of harmony between humans and God (called Parahyangan), humans and other humans (called Pawongan) and humans and the environment (called Palemahan)) (Arif, 1999; Luchman et al., 2009; M. I Yekti et al., 2017; M. I. Yekti et al., 2017).

South Denpasar District, one of the sub-districts in Denpasar City, has an agricultural area (paddy fields) with an irrigation network of 690 hectares. The irrigation area in South Denpasar District is spread across two Irrigation Areas (DI), which are DI Batannyuh and DI Tukad Badung with four subaks, which are Subak Kerdung, Subak Kepaon, Subak Cuculan, and Subak Sesetan. South Denpasar District also experienced a decrease in rice production, which is 8,602.58 tons in 2022 to 8,508.27 tons in 2023 (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023), and it is expected to continue to decline along with the increase in land conversion from agricultural land to residential land. The problem of land use change and the existence of subak in Denpasar City has become a crucial problem due to the very high level of urbanization and triggering the conversion of paddy fields for housing, commercial, tourism, and

so on. This problem must be solved to support sustainable agriculture to maintain community food security, maintain irrigation network systems and subak, and know the performance of irrigation networks, especially in the South Denpasar area. The spatial analysis methodology utilizing Geographic Information Systems is crucial as it seeks to define agricultural zones and assess the operational characteristics of irrigation networks while striving to preserve the presence of subak in urban environments. To the author's knowledge, GIS-based subak delineation especially in urban area, has never been researched and is expected to be a new thing in irrigation network mapping. The outcome, represented as a performance map of the subak-based irrigation network, is anticipated to significantly contribute to the preservation of subak and the assurance of food security in the metropolitan region of Denpasar City and beyond. This research is also expected to be a reference for related parties in determining land-use change policies and the priority scale of rehabilitation or irrigation network construction in the South Denpasar District area.

2. Methods

The method used in this study is qualitative descriptive based on spatial analysis. Spatial analysis is a set of techniques for obtaining new information and knowledge from spatial data or manipulating spatial information to extract new information and meanings from the original data. These techniques include all sampling, visualization, manipulation, and analysis methods that can be applied to spatial data. The critical thing in spatial analysis is location because spatial analysis results depend on the location of the object being analyzed (Longley et al., 2015).

Spatial analysis is usually carried out using Geographic Information Systems (GIS). GIS usually provides spatial analysis tools to calculate feature statistics and perform Geoprocessing as data interpolation. The ability to analyze systems such as statistical analysis and Overlay are the main characteristics of Geographic Information Systems. Analysis with such a system is often used with the term spatial analysis, which adds the dimension of 'space' or geography. In this spatial analysis, the attributes of various phenomena, such as land cover, soil type, and rock formation, are depicted in determining groundwater catchment areas, together with information on the location of an area. Due to the analysis, some maps will generate new maps using the overlay system (Ardana et al., 2023; McMaster and Manson, 2010).

This research procedure includes several stages, which are preparatory work (preparing tools and materials and applying for permission to collect data at related agencies), data collection (data needed in the research in the form of primary data and secondary data), survey and inventory (inventory and survey of irrigation networks are carried out to obtain data on the condition of the entire irrigation network/irrigation canal), as well as analysis methods used following the data that has been collected (using a spatial analysis approach, which is a research method that uses a map, as a model that represents the real world it represents, as an analysis medium to obtain analysis results that have spatial attributes).

2.1 Location and Time of Research

This research was carried out from May to July 2024 in the Irrigation Area (DI), included in the authority of Denpasar City, located in South Denpasar District (Figure 1). South Denpasar District geographically is between 08° 35' 31" to 08° 40' 36" South latitude and 115° 12' 29" to 115° 16' 27" East longitude and located on the South side of Denpasar City with an area of 2,231 Ha or 17.46% of the area of Denpasar City, which consists of rice fields (690 Ha), non-rice fields (164 Ha), and non-agricultural land such as roads, settlements, offices, hotels, shopping centers, rivers, and others (1,377 Ha) (Badan Pusat Statistik Kota Denpasar, 2023).

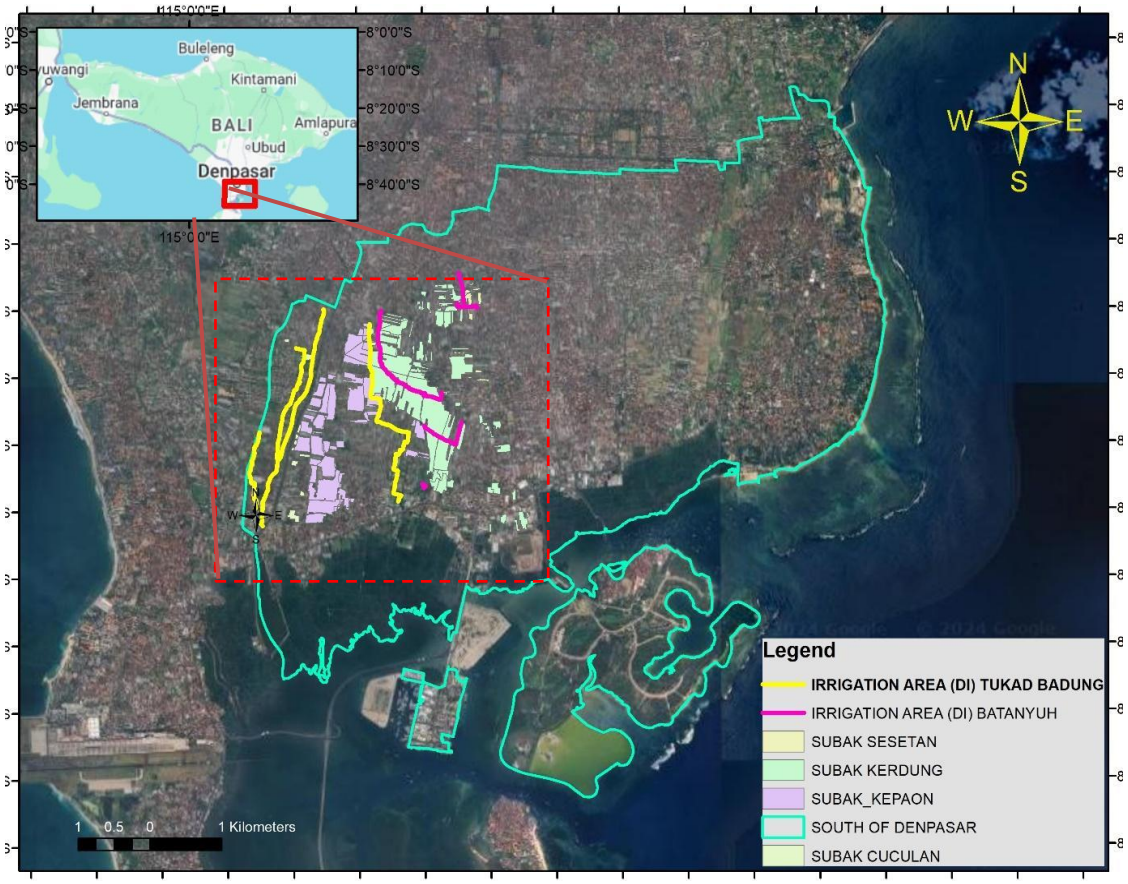

Figure 1. Location of study area

2.2 Data Collection

The data used in this study consists of primary data and secondary data. Primary data is collected directly in the field through surveys/observations/measurements of irrigation networks, irrigation canals and existing irrigation buildings, and the condition of irrigation canals at the research site. Secondary data was obtained from the results of previous research or studies, data from the Denpasar City Public Works and Spatial Planning Office, data from the Central Statistics Agency (BPS) of Denpasar City, administrative maps of Denpasar City, and maps of the irrigation network of Denpasar City related to the needs of analysis in this study. To meet the needs of these data, data collection activities are carried out using the following procedures: 1. Literature study: in the form of a literature study of all previous activities and investigations in the water resources related to irrigation. This literature study intends to establish theories and formulas based on the data available in the field; 2. Primary data collection method: this method is in the form of a field survey, which is a direct review in the field to obtain primary data at locations deemed necessary concerning incomplete data or in case a problem requires re-research. In addition, this method can also identify the characteristics of irrigation areas (type and length of irrigation channels), channel conditions, water supply systems, problems faced, and potential development and culture of subak farmers in the management of irrigation networks; 3. Primary data collection which will later be used in spatial data analysis by using data from the results of tracking tertiary channels in each subak in the irrigation area in the South Denpasar District area using GPS Test, Open Camera, GPS Photo Viewer, and Photo Map applications that are compatible with Android/IoS cellphones and input into Geographic Information System analysis; 4. Secondary data collection method: secondary data collection is collecting and evaluating all relevant, up-to-date data from related agencies. The type of data needed to compile the database and Geographic Information System (GIS) for mapping irrigation networks in South Denpasar District is a medium-scale base map (1:50,000 scale) covering the area of South Denpasar District. This base map includes the following information layers: administrative boundaries, irrigation canals, Subak

boundaries, irrigation area schemes, and rivers in shapefiles (.shp). These data are needed to identify irrigation area areas and irrigation network schemes in South Denpasar District.

2.3 Data Analysis

Data analysis is carried out by interpreting the physical condition of the irrigation network/canal in each segment (per 50 meters) based on primary and secondary data. The method of interpreting the physical condition of irrigation network buildings uses guidelines from the Directorate General of Water Resources (Pemerintah Republik Indonesia, 2015). In managing irrigation assets, the condition level is qualitatively stated into four levels: good, slighty damaged, moderate damaged, and badly damaged. In addition, the geographical analysis process uses Geographic Information System tools, which began by mapping the irrigation network of the authority of the City of Denpasar in all areas of South Denpasar District based on spatial data so that a thematic map of the irrigation network was produced. Then, this thematic map is integrated with the results of the physical assessment of the irrigation network, where this data is used as attribute data or additional information (length, condition and type of irrigation channel), in the thematic map of the irrigation network. The physical assessment of the irrigation network will appear according to the condition value of each network segment depicted in different symbols and legends in the thematic map. This thematic map can be helpful in monitoring and maintenance activities, becoming the primary consideration in policy-making for maintenance work. In detail, the process of geospatial analysis is as follows: 1. Processing the basic map, which are the administrative map of Denpasar City and the map of the irrigation network in Denpasar City; 2. Creating a new Shapefile layer on Geographic Information System tools, for the city of Denpasar has UTM: WGS 1984 UTM Zone 50S; 3. Check map updates; 4. Processing of maps and their attributes in Geographic Information System tools. This study's spatial analysis process was confined to representing shapefiles as points and lines, and data was supplied in the attribute table based on the survey findings; 5. Create a topology to check connectivity; 6. Edit the map by using the editing toolbar such as append, dissolve, merge and split tool, or add vertex to create an irrigation network in the map; 7. Create the irrigation network condition table data on the attribute table according to the irrigation network condition table; 8. Spatial analysis is the classification and symbology of the GIS map display with four categories into good, slighty damaged, moderate damaged, and badly damaged (can be seen in the Table 1) in each irrigation network or canal; 9. The database format of irrigation networks in the Geographic Information System (GIS) is created using the shapefile format in the form of layers; 10. The final analysis obtained results in the form of digital maps (.shp) showing irrigation network conditions and attribute tables.

Table 1. Irrigation channel damage criteria

No	Physical condition of infrastructure	Criteria
1	Damage level < 10 %	Good
2	Damage level 10 - 20 %	Slightly damaged
3	Damage level 21 - 40 %	Moderate damaged
4	Damage level > 40 %	Badly damaged

Source: (Pemerintah Republik Indonesia, 2015)

3. Results and Discussion

3.1 Subak Condition in Irrigation Areas in South Denpasar District

The agricultural area (rice fields) in South Denpasar District is part of the Batannyuh Irrigation Area (DI) and DI Tukad Badung. The main building (weir) of DI Batannyuh is located in Pemecutan Kelod Village, West Denpasar District and is located at the coordinates of 8° 40' 35.9" S and 115° 12' 05.1" E with an area of 412 Ha and a functional area of 107 Ha. Meanwhile, the main building of DI Tukad Badung is located at coordinates 8° 41' 04.0" S and 115° 11' 49.1" E. It is located in Pemecutan Kelod Village, West Denpasar District and has an area of 464 Ha with a functional area of 197 Ha. There are four subaks in the

irrigation area in the South Denpasar District area, namely Subak Kerdung, Subak Cuculan, Subak Kepaon, and Subak Sesetan (Dinas Pekerjaan Umum dan Penataan Ruang Kota Denpasar, 2019) which can be seen in Figure 2.

Based on the results of surveys, field observations, and GIS-based spatial analysis, it was found that one of the subaks in South Denpasar, Subak Sesetan, was not identified/disappeared because it is estimated that it has changed its function into a settlement (can be seen in Figure 3). The total area of Subak which was initially 292.593 Ha was reduced to 186.314 Ha or 36.32% due to land conversion (can be seen in Table 2).

Table 2. Comparison of the area of the initial and current subak

No	Subak	Initial area (Ha)	Current area (Ha)	Difference (Ha)
1	Kerdung	145.156	112.720	32.436
2	Kepaon	104.309	68.418	35.891
3	Cuculan	38.675	5.176	33.499
4	Sesetan	4.453	0	4.453

Based on Table 1, Subak Sesetan decreased by 4.453 Ha, Subak Cuculan decreased by 33.499 Ha, Subak Kerdung decreased by 32.436 Ha, and Subak Kepaon decreased by 35.891 Ha. This is in line with data on the area of rice fields and garden land in 2021 and 2023 by sub-district where the area of rice fields in 2021 was 536 hectares and decreased to 449 hectares in 2023 (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023). This statement is also corroborated by a decrease in rice production, which is 8,602.58 tons in 2022 to 8,508.27 tons in 2023 in South Denpasar District (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023) and it is expected to continue to decline along with the increase in land conversion, which is from agricultural land to residential land.

3.2 Performance Analysis of Irrigation System in Subak Kerdung

Based on the results of field observations in the Subak Kerdung Irrigation Area, as many as 188 survey points were obtained, which stated that the overall condition of the irrigation canal was still in good to slighty damaged condition and fourteen points were identified as moderate damaged, as seen in Table 3. Based on the analysis results, it was found that the irrigation canal length in Subak Kerdung is 7.598 Km.

Table 3. Data on channel damage in Subak Kerdung

Point	Length of damage (m)	Point	Length of damage (m)
Pd.K 2	2.2	Pd.K 96	2
Pd.K 5	1.5	Pd.K 103	5.7
Pd.K 10	12.2	Pd.K 104	26.6
Pd.K 15	5	Pd.K 110	4
Pd.K 33	7	Pd.K 131	4
Pd.K 49	4	Pd.K 133	3
Pd.K 73	5.3	Pd.K 134	2.7

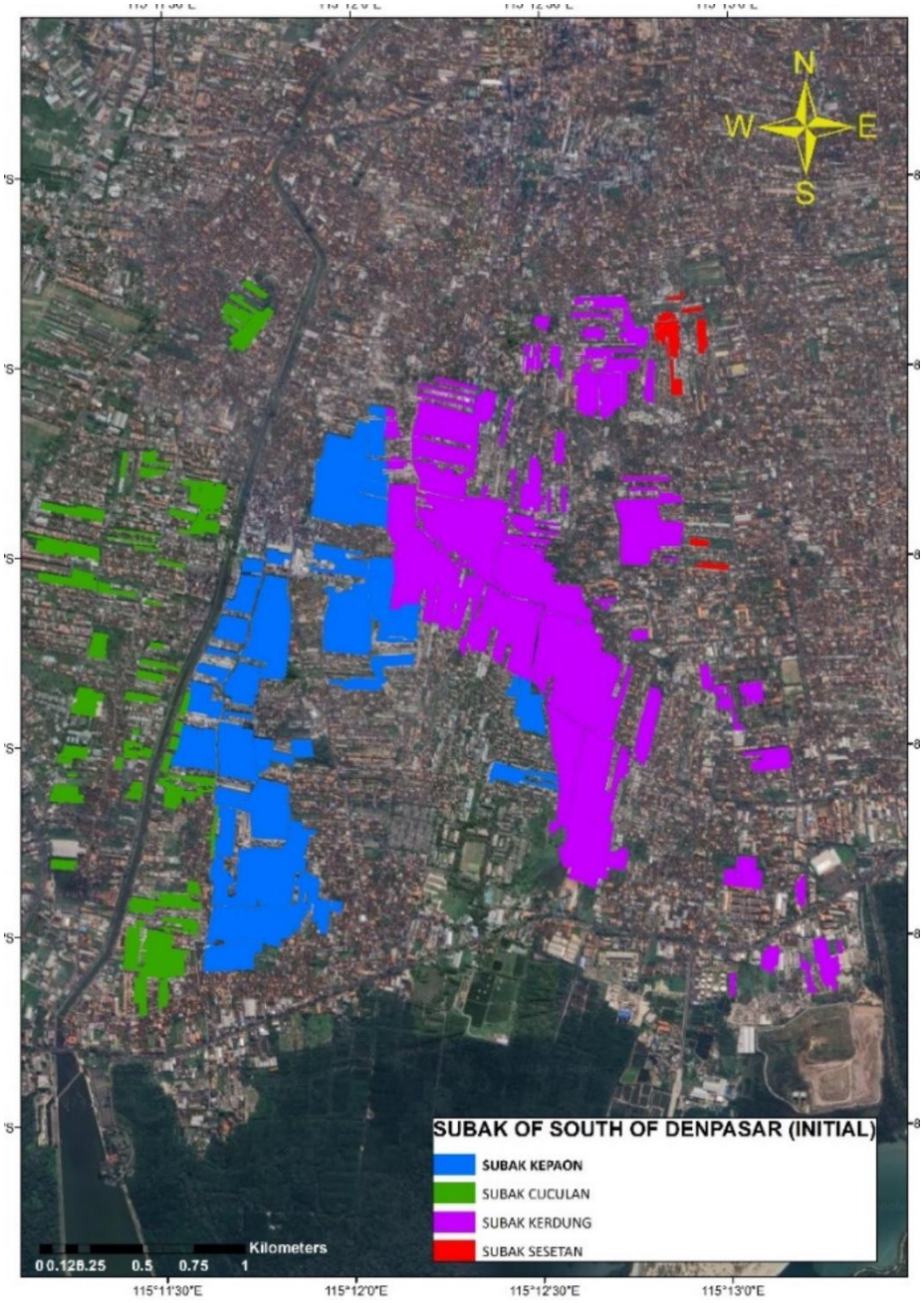

Figure 2. Map of subak in South Denpasar District in 2019
(Denpasar City Public Works and Spatial Planning Office, 2019)

The condition of Subak Kerdung irrigation network is still in good condition (along 7.4838 Km or 98.497% of the total length of the canal, the channel with slighty damaged conditions is 0.029 Km or 0.382%, and there is moderate damaged at several points with a total length of damage of 0.0852 Km or 1.12%. The delineation of the irrigation network as a result of spatial analysis based on the Geographic Information System in the Subak Kerdung area can be seen in Figure 4.

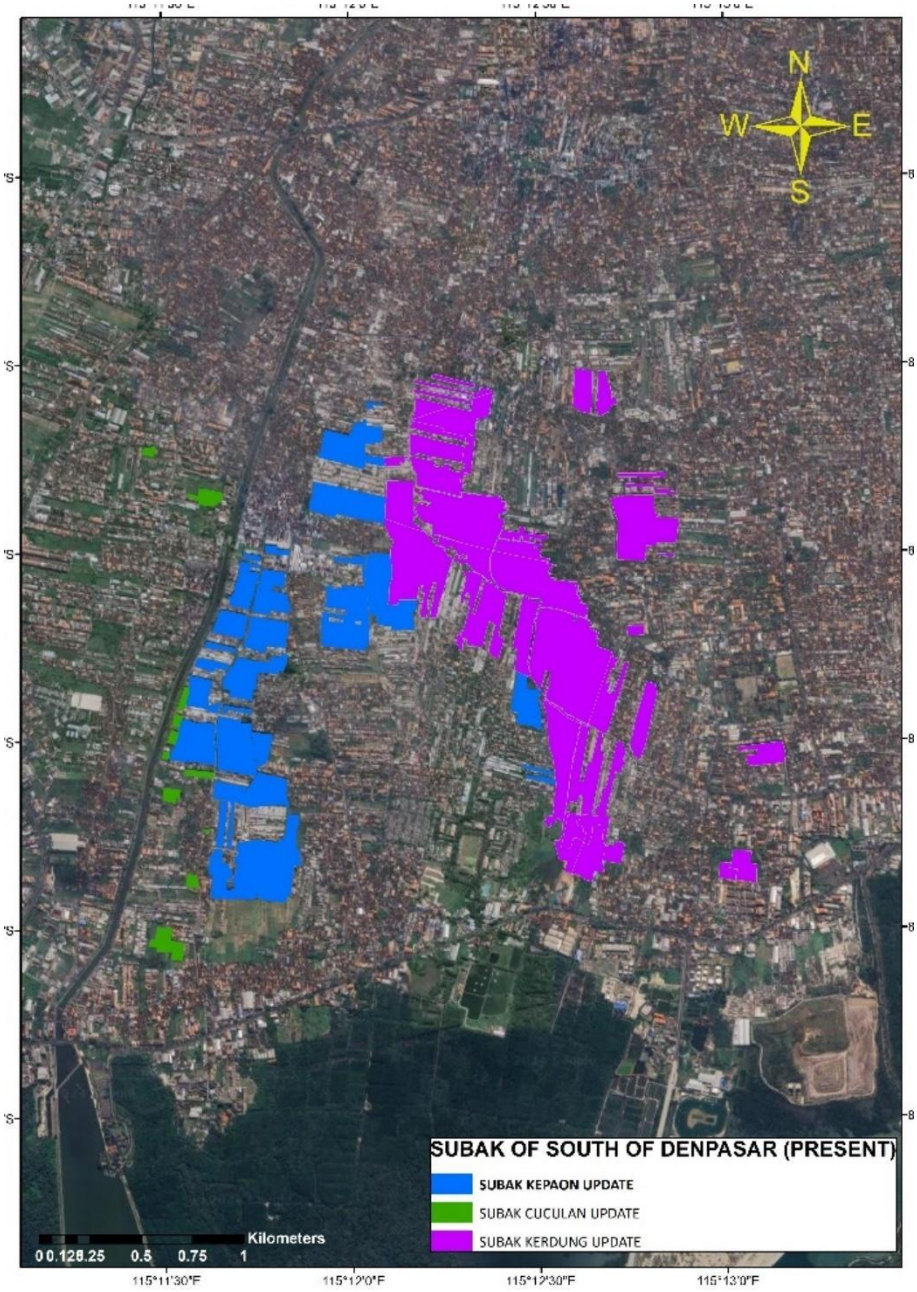

Figure 3. Map of subak in South Denpasar District in 2024 based on field observation and GIS analysis

3.3 Performance Analysis of Irrigation System in Subak Cuculan

Based on the results of field observations in the Irrigation Area in Subak Cuculan, as many as 40 survey points were obtained which stated that the condition of the irrigation channel as a whole was still in good to slighty damaged condition and one point was identified as moderate damaged, which is at the Pm.C 5 point in the form of an unpaved channel. Based on the results of the analysis, it was found that the length of the irrigation canal in Subak Cuculan is 1.677 Km and the condition of the Subak Cuculan irrigation network is still in good condition along 1.654 Km or 98.61% of the total length of the channel, the channel with slighty damaged conditions is 0.008 Km or 0.477% and there is moderate damaged to the Pm.C5 point with a total damage length of 0.01535 Km or 0.915%. The delineation of irrigation networks based on Geographic Information System-based spatial analysis in the Subak Cuculan area can be seen in Figure 5.

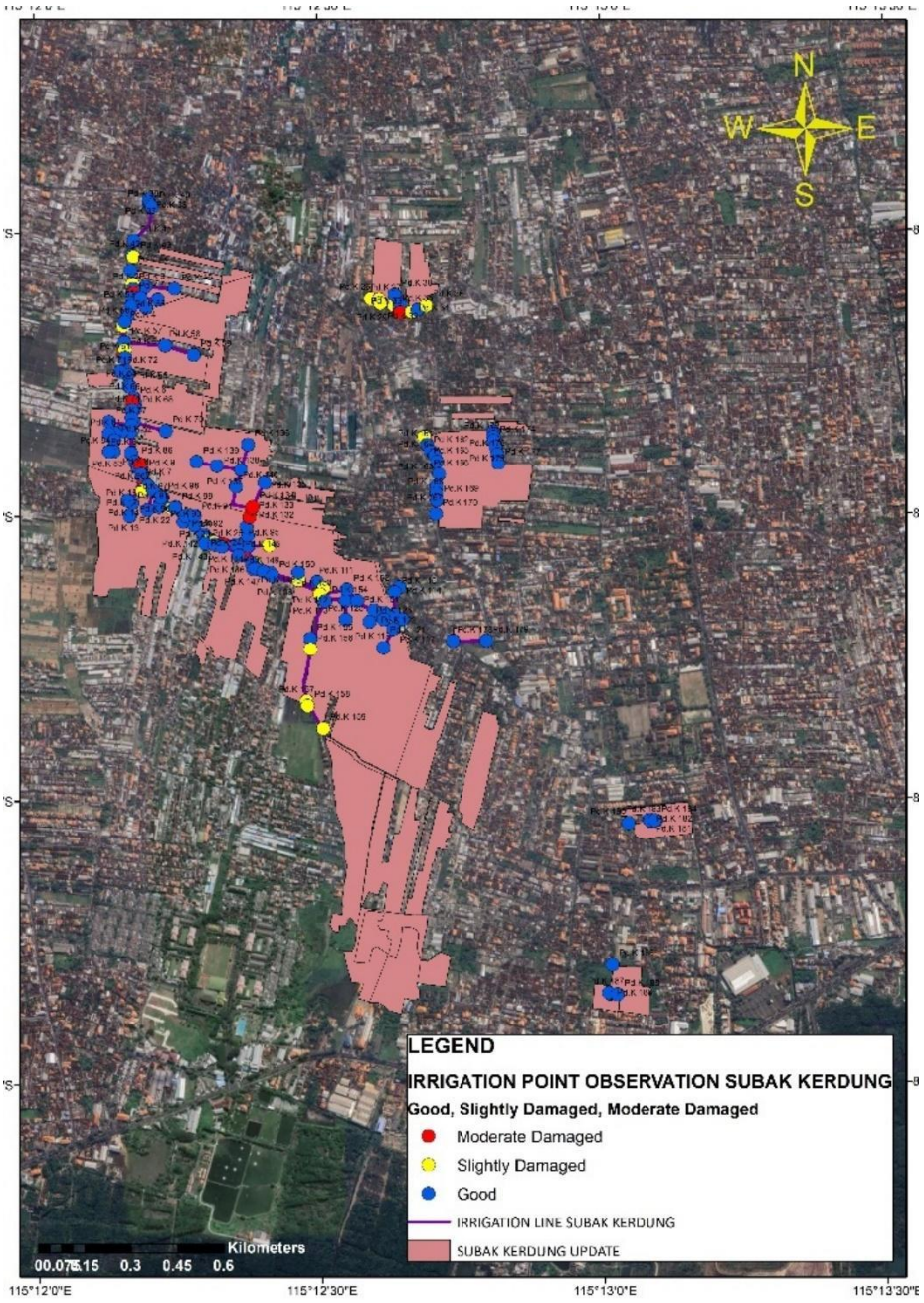

Figure 4. Map of the performance of the irrigation network in Subak Kerdung

3.4 Performance Analysis of Irrigation System in Subak Kepaon

Based on the results of field observations in the Irrigation Area in Subak Kepaon, as many as 140 survey points were obtained which stated that the overall condition of the irrigation canal was still in good to moderate condition and fourteen points were identified as damaged which can be seen in Table 4.

Figure 5. Map of the performance of the irrigation network in Subak Cuculan

Based on the results of the analysis, it was found that the length of the irrigation canal in Subak Kepaon is 7.626 Km and the condition of the Subak Kepaon irrigation network is still in good condition along 7.52835 Km or 98.72% of the total length of the channel, the channel with slighty damaged condition is 0.014 Km or 0.184% and the channel with moderate damaged condition with a total damage length of 0.08365 Km or 0.915%. The delineation of the irrigation network based on the Geographic Information System-based spatial analysis in the Subak Kepaon area can be seen in Figure 6.

Table 4. Data on channel damage in Subak Kepaon

Point	Length of damage (m)	Point	Length of damage (m)
Pm.K 66	3.8	Pm.K 89	9
Pm.K 67	9	Pm.K 119	2.6
Pm.K 75	2	Pm.K 120	3.2
Pm.K 76	6.4	Pm.K 122	5.55
Pm.K 78	4	Pm.K 123	4.8
Pm.K 79	3.7	Pm.K 124	8.7
Pm.K 88	18.3	Pm.K 139	2.6

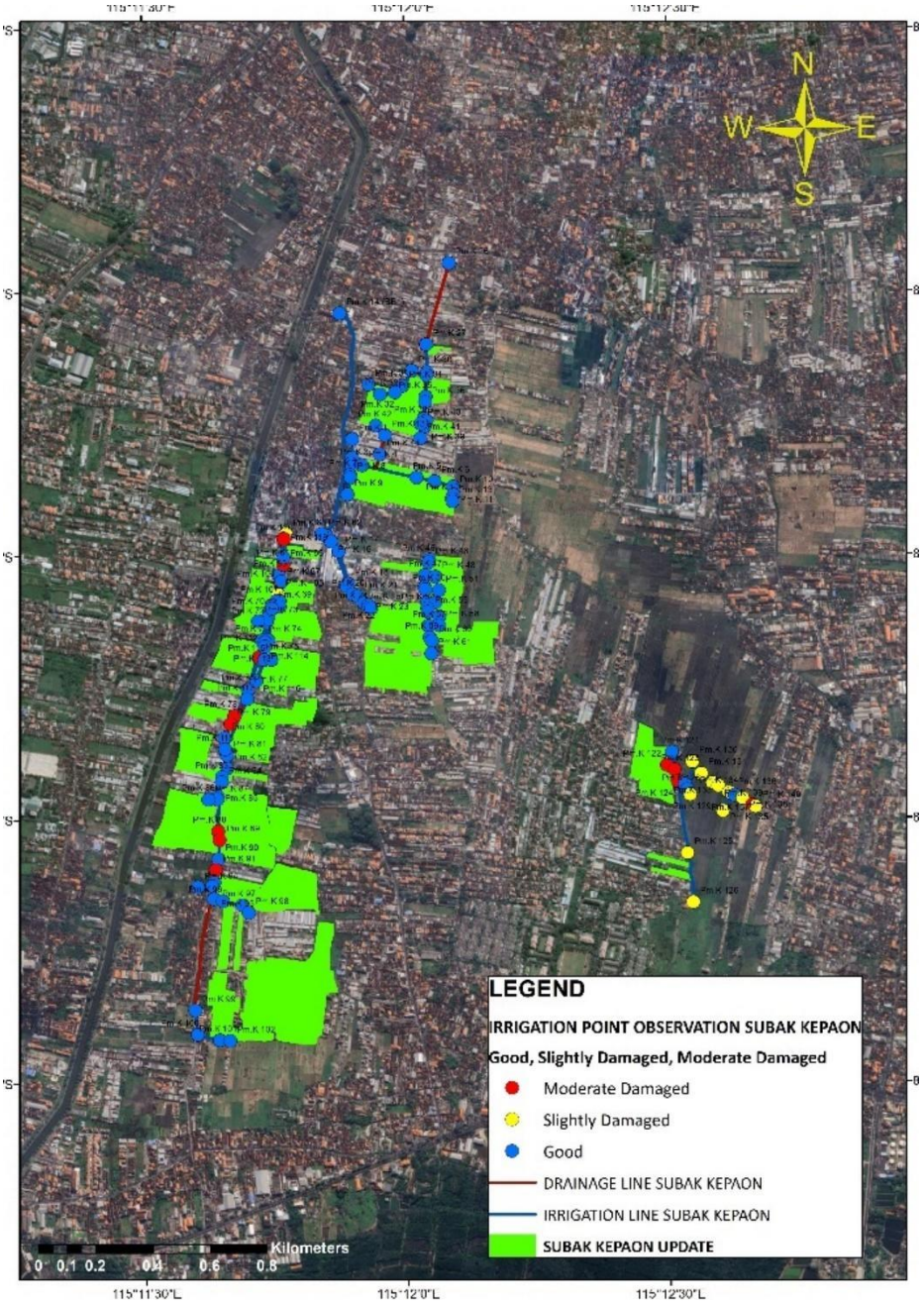

Figure 6. Map of the performance of the irrigation network in Subak Kepaon

The delineation of irrigation network conditions in this study uses Geographic Information System tools. From the analysis obtained, the total area of subak (Subak Kerdung, Subak Cuculan, Subak Kepaon, and Subak Sesetan) which was originally 292.593 Ha was reduced to 186.314 Ha or by 36.32% due to land conversion which inline with data on the area of paddy fields and garden land in 2021 and 2023 by sub-district, where the area of rice fields in 2021 was 536 hectares and decreased to 449 hectares in 2023 (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023). This statement is also corroborated by a decrease in rice production, which is 8,602.58 tons in 2022 to 8,508.27 tons in 2023 in South Denpasar District (Dinas Komunikasi Informasi dan Statistika Kota Denpasar, 2023) and it is expected to continue to decline along with the increase in land conversion, which is from agricultural land to residential land. The results of spatial analysis based on the Geographic Information System (GIS) show that the condition of the irrigation network in the subak area in South Denpasar District is dominated by good conditions with the value around 98.61% or along 16.67 Km form the 16.901 Km total length of irrigation channel. This statement should still be able to irrigate agricultural areas in South Denpasar District so that it can maintain the sustainability of food security in Denpasar City. With the acquisition of spatial data on the irrigation network, the Denpasar City Government is expected to be able to determine the priority scale in the management of irrigation network assets, especially in cost budget planning. Knowing the location of irrigation networks that are in good or damaged condition is very useful in the operation, maintenance, repair, and development of irrigation networks. In addition, spatial analysis is very useful in efforts to monitor the condition of irrigation networks in the field as well as efforts to monitor changes in agricultural land use into settlements. The delenition of irrigation networks based on the Geographic Information System (GIS) is expected to be a reference for other regions in an effort to realize spatial data in the form of irrigation network maps which aligns with the research findings from (Abdurachman et al., 2019). Furthermore, the availability of this performance map for the subak-based irrigation network may serve as a reference for preserving the subak system in the urban region of Denpasar City, ensuring the fundamental principles of Tri Hita Karana are upheld. This aligns with the expectations articulated in the research from Norken (2019), M. I Yekti et al., 2017 and Yekti et al., 2017.

4. Conclusions

ArcGIS applications can be used as a computer-based tool to evaluate the condition of irrigation networks. This is done by integrating or combining the results of observations of the condition of the irrigation network segment with the irrigation network map layer using the join and related functions in the application. This study also integrates the condition of the irrigation network from field observations with the irrigation network map of Denpasar City, the map of Subak in South Denpasar District and the administrative map of Denpasar City. Based on the analysis results, it was found that one of the subaks in South Denpasar District, which is Subak Sesetan, needed to be identified/disappeared because it is estimated that it has changed its function into a settlement. The total area of subak (Subak Kerdung, Subak Cuculan, Subak Kepaon, and Subak Sesetan), which was initially 292.593 Ha, was reduced to 186.314 Ha or 36.32% due to land conversion and only three subak were left (Subak Kerdung, Subak Cuculan and Subak Kepaon). Based on the results of the analysis, it was found that the irrigation canal length in Subak Kerdung is 7.598 km. The condition of Subak Kerdung irrigation network is still in good condition (along 7.4838 Km or 98.497% of the total length of the canal, the channel with moderate conditions is 0.029 Km or 0.382%, and there is damage at several points with a total length of damage of 0.0852 Km or 1.12%. In Subak Cuculan, the results were obtained in the form of an irrigation canal length of 1.677 Km. The condition of Subak Cuculan irrigation network is still in good condition along 1.654 Km or 98.61% of the total length of the canal, the channel with moderate conditions is 0.008 Km or 0.477%, and the total length of damage is 0.01535 Km or 0.915%. Meanwhile, the analysis results in Subak Kepaon identified the irrigation canal length as 7.626 Km. The condition of the Subak Kepaon irrigation network is still in good condition along 7.52835 Km or 98.72% of the total length of the canal, the channel with moderate condition is 0.014 Km or 0.184% and the channel with damaged condition with a total damage length of

0.08365 Km or 0.915%. The delineation of the irrigation network in South Denpasar District is anticipated to guide policy-making bodies in upholding the long-term viability of urban food security and preserving agricultural regions and subak in Denpasar City.

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