Journal of Infrastructure Planning and Engineering

Journal homepage: ejournal.warmadewa.ac.id

e-ISSN: 2829-5153

Spatial mapping approach and irrigation water quality assessment for dryland management strategy in Abang district, Karangasem regency, Bali province

Luthfi Inayah[1], I Putu Gustave Suryantara Pariartha[1]*, Silvia Gabrina Tonyes[1]

[1] *Department of Civil Engineering Udayana University, Bukit Jimbaran, Badung, 80361, Indonesia*
*gustave_sp@unud.ac.id

Received 13 August 2025; accepted 1 April 2026; published 30 April 2026

ABSTRACT

This study analyzes irrigation water quality and evaluates dryland suitability in Abang District, Karangasem Regency, Bali Province, using two assessment models: the National Sanitation Foundation Water Quality Index (NSF-WQI) and the Index of Surface Water Vulnerability to Pollution (IKAPP). Water samples from six irrigation points along Tukad Nyuling were analyzed for physical and chemical parameters, while rainfall, land use, and population density were integrated through spatial analysis. The results show that NSF-WQI values ranged between 69.96–79.78, indicating moderate to good irrigation quality, while the IKAPP average value of 23.69 represented a low vulnerability level. Spatial variation was influenced by topography, soil permeability, and land cover distribution. The integration of NSF-WQI and IKAPP provides a reliable framework for site-specific irrigation management, supporting sustainable dryland agriculture in tropical environments.

Keywords: dryland irrigation, irrigation water quality, spatial mapping, water quality index

1 Introduction

Improvements in agricultural production play an important role in achieving national food sovereignty. This is inseparable from the successful performance of irrigation systems, which are highly dependent on their management [1], including water resources. Water quality is a crucial element in effective irrigation management, agricultural yield improvement, and environmental protection, especially in drylands. Pollution of surface water sources, often resulting from urban sewage, agricultural practices, and inadequate waste management [2], is a significant problem in Abang District, Karangasem. The integrity of the Tukad Nyuling ecosystem, which is the main source for irrigation, is threatened by natural challenges and human activities [3].

To thoroughly evaluate the potential for pollution, this study applied the NSF-WQI method to assess the suitability of water quality based on physic-chemical parameters [4], The application of this method is also due to the fact that it tends to be underutilized because of the complexity involved in its application, which involves numerous parameters and underlying calculations [5], [6]. In addition, the IKAPP method for determining the vulnerability of surface water. Vulnerability itself is the value or tendency of an entity to experience damage [7]. Both approaches were used in three villages: Abang, Ababi, and Tiyingtali. In Abang village, water quality ranged from moderate to low with salinity and soil permeability issues present.

Ababi Village shows water quality at low limits that can still be used for horticulture, while Tiyingtali Village has water quality at low limits in steep topographic areas that require attention in conservation and efficient irrigation systems. These different situations highlight the importance of planning that considers water quality, soil characteristics, and land use to support sustainable agriculture [8].

This research concept is able to answer and explain the technical aspects of the issues described,

https://doi.org/10.22225/jipe.5.1.2026.15-22
2829-5153 ©2026 The Author(s). Published by Master Program of Infrastructure and Environmental Engineering, Postgraduate Program, Warmadewa University. This is an open access article CC BY-SA license (https://creativecommons.org/licenses/by-sa/4.0/)
How to Cite: L. Inayah, I. P. G. S. Pariartha, and S. G. Tonyes, "Spatial mapping approach and irrigation water quality assessment for dryland management strategy in Abang District, Karangasem Regency, Bali Province," *Journal of Infrastructure Planning and Engineering*, vol. 5, no. 1, pp. 15 - 22, April, 2026.

namely the optimization of sub-optimal land, including the management of dry acidic land, which must be based on the achievement of four objectives, namely productivity, production efficiency, resource and environmental sustainability, and farmer welfare [9].

Previous studies on irrigation water quality in Indonesia have primarily focused on physical or chemical approaches without integrating spatial and environmental pressures. However, the combination of water quality indices and spatial vulnerability models has rarely been applied to dryland irrigation systems, particularly in areas with limited water resources such as Karangasem.

Therefore, this research aims to: (1) assess the irrigation water quality using the NSF-WQI method; (2) evaluate the spatial vulnerability of surface water through the IKAPP model; and (3) propose a sustainable irrigation management strategy based on the integration of both indices.

Most previous studies have analyzed irrigation water quality or spatial vulnerability separately. However, few have combined both in one integrated model, especially in dryland irrigation areas like Karangasem. This study fills that gap by integrating water quality (NSF-WQI) and vulnerability (IKAPP) analyses within a GIS-based approach.

2 Data and Methods

2.1 Location

The study was conducted during the dry season to obtain sample parameters under normal water quality conditions taken based on 3 main villages namely Tiyingtali, Abang, and Ababi Villages. In each village, two areas of land were selected to represent the topography, land cover, and intensity of water use, which would later be evaluated according to Figure 1 regarding existing land use.. The land area of DI Pajegan is located in Tiyingtali Village with an area of 42.34 Ha, DI Andong is located in Abang Village with an area of 16.84 Ha and DI Ababi VII is located in Ababi Village with an area of 15.37 Ha, all of which are sourced from Tukad Nyuling [10].

The irrigation area was chosen because it has a variety of subak sawah and abian types. Subak abian is an area where most of the land tends to be dry and is used for growing dry crops [11]

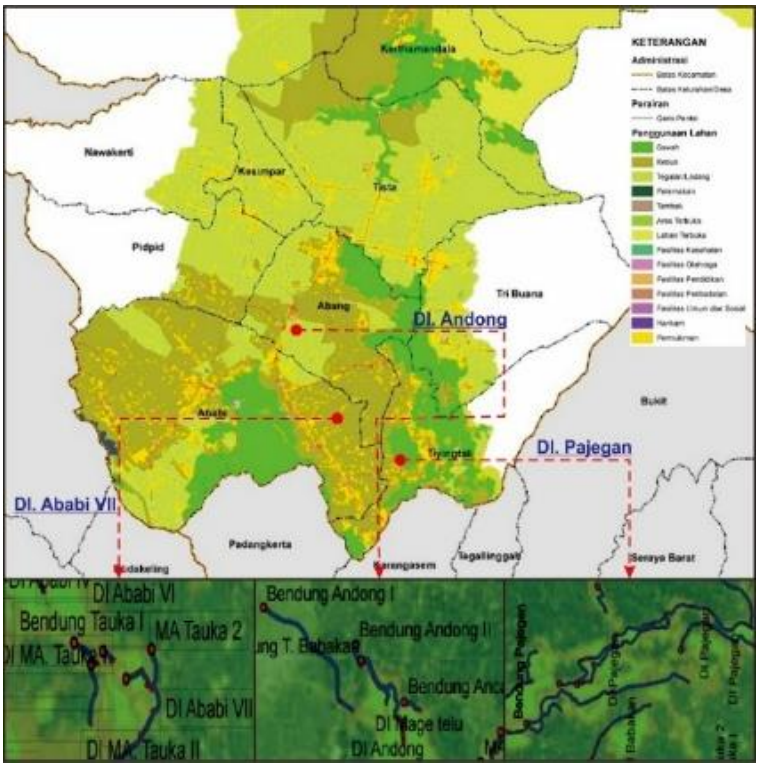


Figure 1. Irrigation Area of the Research Location

2.2 Data Collection

Water samples were taken from the inlet of each irrigation canal. Physical parameters such as temperature, pH, DHL, and TDS were measured directly on site, while chemical parameters such as Na^+, HCO_3-, Cl-, SAR, BOD, COD, nitrate, phosphate, Pb, and other indicators were analyzed in the laboratory.

Rainfall data were obtained from the Bali–Penida River Basin Authority (BWS Bali–Penida), while population and land-use data were collected from the Central Bureau of Statistics (BPS) of Karangasem Regency. Field verification was conducted to ensure consistency between satellite imagery and observed land cover classifications. Soil samples at the same location were taken for permeability testing to assess infiltration and water retention potential.

Soil samples were taken from the same location to test their permeability and texture in order to assess their potential for water infiltration and retention. Soil texture itself is a basic property determined by the relative distribution of components such as sand, silt, and clay fractions that make up the soil structure [12].

2.3 Methods

The integration of NSF-WQI and IKAPP provides a more complete assessment because NSF-WQI measures actual water quality, while IKAPP considers environmental pressures such as rainfall, population, and land use. Combining both helps identify not only the current water condition but also potential risks in each area.

Samples were taken from six irrigated areas, with physical (temperature, pH, DHL, TDS) and chemical (Na^+, HCO_3-, Cl-, BOD, COD, NO_3-, PO_4^{3}-, Pb) parameters measured in the laboratory.

The water quality assessment applied methods: NSF-WQI, which estimates quality values based on the weights and sub-indice of physic-chemical parameter [13] and IKAPP which relate water quality to indicator of rainfall (ICH), population density (IKP), land use and vegetation cover (IPLV), and river physical characteristics (IHS) [7].

The NSF-WQI was computed using:

$$\text{NSF-WQI} = \sum_{i=1}^{n} \text{qi} \times \text{wi} \quad (1)$$

where $w_i$is the assigned weight of parameter *i*, and q_i is its corresponding sub-index value derived from laboratory results.

The composite index (IKAPP) was calculated as:

$$\text{IKAPP} = 0.29\text{I}_{\text{KA}}+0.23\text{I}_{\text{KP}}+0.14\text{I}_{\text{CH}}+0.20\text{I}_{\text{PLV}}+0.14\text{I}_{\text{HS}} \quad (2)$$

where IKA (water quality index), ICH (rainfall index), IKP (population index), IPLV (land use/vegetation index), and IHS (hydro-geomorphological index).

Each index was normalized and integrated spatially using the Inverse Distance Weighting (IDW) method to visualize spatial variation of vulnerability. All parameters were then integrated in ArcGIS 10.4.1 to produce a distribution map of water quality and vulnerability. Interpolation was performed using the *Inverse Distance Weighting* (IDW) method to describe the gradient of values between observation points.

The use of spatial distribution can be a tool for conducting land evaluation, where land evaluation is carried out as an effort to maximize the use of potential land, thereby increasing productivity and maximizing its potential [14].

3 Results and Discussion

The results of measurements taken directly based on physical parameters can be seen in **Table 1**, while the results of measurements based on chemical parameters taken through laboratory testing are shown in the data tables in **Table 2** and **Table 3**. The measurements and tests were then analyzed within the framework of the IWQI model, water suitability for certain soil types and crops, and spatial distribution mapping, to generate suggestions and solutions that are suitable for the problems that have been recognized [15]. The following are the measurement results that have been carried out in the following table:

Table 1. Physical Parameter Measurement Results

Sample	Parameter				
	Temp	TDS	TSS	DHL	pH
T.01	27.00	181.0	5.00	251	6.1
T.02	28.00	214.5	4.80	264	6.8
T.03	27.60	253.2	26.60	698	7.2
T.04	28.60	212.0	31.90	234	7.1
T.05	27.60	265.6	24.10	362	6.6
T.06	26.50	257.2	21.60	256	6.7

Table 2. Chemical Parameter Measurement Results

Samp	Parameter					
	Ca^{+2} mg/l	Mg^{+2} mg/l	SO_4^{-2} mg/l	Na^{+} mg/l	Cl^{-} mg/l	HCO^{-}_3 (mg/l)
T.01	9.25	6.66	27.27	16.25	17.89	94.06
T.02	9.15	6.56	35.85	15.60	17.35	95.73
T.03	17.49	25.80	76.18	17.90	40.78	324.50
T.04	12.88	7.33	43.22	14.30	44.74	309.80
T.05	14.99	14.67	46.70	16.20	24.44	320.20
T.06	9.14	6.59	35.89	15.20	20.37	101.90

In addition to testing water quality parameters, soil parameters were also tested to obtain soil permeability values in accordance with **Table 2**, in order to refine the analysis of plant suitability at the study site, as shown in **Table 3** below:

Table 3. Soil Permeability Value

Sample	Permeability cm/jam	Permeability Classification	Soil Texture
TS.01	1.99	Very slow	Sandy clay
TS.02	125.92	Very rapid	Clay
TS.03	129.90	Very rapid	Sandy clay

3.1 NSF-WQI Method Calculation Result

The results of water quality evaluation for irrigation in Abang Subdistrict revealed differences in conditions across various locations, reflecting the combined impact of physical, chemical, and environmental characteristics. The classification thresholds for irrigation water quality were defined according to the NSF-WQI standardwhere a score of 71-90 indicates good quality, 51-70 indicates moderate, and below 51 indicates poor quality, the

parameters that most influence low scores are high electrical conductivity (EC/DHL), sodium adsorption ratio (SAR), and anion concentrations (particularly Cl^- and SO_4^{2-}), as these factors directly affect soil permeability and plant water uptake efficiency.

These results indicate that the water is still suitable for irrigation purposes, although management is required to control parameters that could pose obstacles, such as DHL, SAR, and certain anion levels in a number of locations. The SAR value is one of the factors in determining the suitability of irrigation water, whereby the higher the SAR, the less suitable the water is for irrigation purposes [16]. **Table 4 and 5** show the results for each indicator and the overall calculation results for each study location from the quality analysis based on the NSF-WQI method, which can be seen in the following table:

Table 4. Results of NSF-WQI Water Quality Index

Loc	pH	DHL	Ca^{+2}	Mg^{+2}	SO_4^{-2}
T.01	6.1	251	0.46	0.55	0.57
T.02	6.8	264	0.46	0.54	0.75
T.03	7.2	698	0.87	2.12	1.59
T.04	7.1	234	0.64	0.60	0.90
T.05	6.6	362	0.75	1.21	0.97
T.06	6.7	256	0.46	0.54	0.75

Table 5. Results Of NSF-WQI Water Quality Index

Loc	SAR	Na^+	Cl^-	HCO^-_3	Result
T.01	0.69	0.71	0.50	1.54	79.78
T.02	0.83	0.68	0.49	1.57	79.62
T.03	0.99	0.78	1.15	5.32	69.96
T.04	0.85	0.62	0.98	5.08	73.74
T.05	0.76	070	0.16	5.25	72.86
T.06	0.81	0.66	0.58	1.67	79.04

The NSF-WQI results indicate that water quality ranged from moderate to good, with higher conductivity, salinity, and result observed in midstream points (T.03 – T.05). These conditions suggest moderate limitation for irrigation use in the Abang and Ababi areas.

3.2 Calculation Results of the IKAPP Method

Modeling through the calculation of IKAPP is done with a polynomial regression model of each constituent indicator in each parameter, and later the IKAPP land value is tabulated based on the area studied. The following Tables 6 to 11 show the results of the calculation of index parameters for each village:

Table 6. Tiyingtali Village Water Quality Calculation

Indicator	Weight	Formula	Actual Data X (Mean)	Sub-Indicator Index	Index
Temp	0.120	y = -10x + 360	27.50	85.24	10.23
TDS	0.150	y = 0.5022x	197.73	99.30	14.89
BOD	0.190	y = 12.022x	4.95	59.51	11.31
COD	0.130	y = -3.6166x + 134.97	17.97	70.00	9.10
Phosphate	0.070	y = -142.86x + 120	0.21	90.00	6.30
NO_2 sbg N	0.069	y = 6027.7x	0.015	87.40	6.03
pH	0,117	y = 12,5x + 8,75	6.550	90.63	10.60
TSS	0.075	y = 20.4x	4.90	99.96	7.50
Lead (Pb)	0.074	y = -600.6x + 110.15	0.034	90.00	6.66
	1.00	Water Quality Index			82.62

Table 7. Tiyingtali Village IKAPP Composite Calculation

Component	Sub-index	Weight	Index
Water Quality	82.62	0.29	23.96
Rainfall	65.04	0.14	9.11
Population	70.93	0.23	16.31
Land Use and Vegetation Cover	54.03	0.20	10.81
River Hydrogeometry	67.51	0.14	9.45
IKAPP		1.00	69.84

Table 8. Abang Village Water Quality Calculation

Indicator	Weight	Formula	Actual Data X (Mean)	Sub-Indicator Index	Index
Temp	0.120	y = -10x + 360	28.10	79.00	9.48
TDS	0.150	y = -0.2426x + 151.43	232.61	95.00	14.25
BOD	0.190	y = -16.667x + 145	4.50	70.00	13.30
COD	0.130	y = 5.168x	15.48	80.00	10.40
Phosphate	0.070	y = -142.86x + 120	0.23	80.00	5.60
NO_2 sbg N	0.069	y = 7E-11x + 80	0.029	80.00	5.52
pH	0.117	y = 12.5x + 1.25	7.150	90.63	10.60
TSS	0.075	y = -0.9015x + 97.757	29.25	71.40	5.36
Lead (Pb)	0.074	y = -600.6x + 110.15	0.024	90.00	7.40
	1,00	Water Quality Index			81.91

Table 9. Abang Village IKAPP Composite Calculation

Component	Sub-index	Weight	Index
Water Quality	81.91	0.29	23.75
Rainfall	65.04	0.14	9.11
Population	67.63	0.23	15.55
Land Use and Vegetation Cover	75.12	0.20	15.02
River Hydrogeometry	67.51	0.14	9.45

IKAPP	1.00	72.89

Table 10. Ababi Village Water Quality Calculation

Indicator	Weight	Formula	Actual Data X (Mean)	Sub-Indicator Index	Index
Temp	0.120	y = -10x + 360	27.05	89.50	10.74
TDS	0.150	y = 2E-13x + 90	261.42	90.00	13.50
BOD	0.190	y = 12.022x	1.00	90.00	17.10
COD	0.130	y = -3.6166x + 134.97	1.00	90.00	11.70
Phosphate	0.070	y = -142.86x + 120	1.00	90.00	6.30
NO_2 sbg N	0.069	y = 6027.7x	1.00	90.00	6.21
pH	0.117	y = 12.5x + 8.75	6.650	91.88	10.75
TSS	0.075	y = -1.1111x + 103.33	22.85	77.94	5.85
Lead (Pb)	0.074	y = -600.6x + 110.15	0.030	90.00	6.66
	1.00	Water Quality Index			88.80

Table 11. IKAPP Composite Calculation of Ababi Village

Component	Sub-index	Weight	Index
Water Quality	88.80	0.29	25.75
Rainfall	65.04	0.14	9.11
Population	60.16	0.23	13.84
Land Use and Vegetation Cover	70.19	0.20	14.04
River Hydrogeometry	67.51	0.14	9.45
IKAPP		1.00	72.19

The IKAPP method identifies that the level of surface water vulnerability falls into the moderate to moderately vulnerable category, with values ranging from 69.84 to 72.89.

The most dominant factor influencing the vulnerability score was water quality, followed by population density, land use and vegetation cover. This suggests that the impacts of population growth and land use change play an important role in determining the likelihood of pollution.

However, in research related to water use for irrigated land systems, only the water quality index parameter is prioritized, which has a vulnerability index level of 23.75 to 25.75, which is still in the low limit category or suitable for agricultural land.

3.3 Spatial Mapping of Irrigation Water Quality Index

The mapping that has been done shows variations in the distribution of water quality and vulnerability in each village using both the NSF-WQI and IKAPP methods. The resulting mapping will be a classification based on the color gradient of the distribution area in the study area.

Mapping was first conducted using data from the IWQI with the NSF-WQI method as shown in **Figure 2**, where the first category is shown in blue to light green, indicating areas of low water quality, with index values ranging from 70 to 85. The second category, shown in beige to light green, indicates areas of moderate water quality, with index values ranging from 55 to 70.

Then, **Figure 3** shows the spatial mapping resulting from water quality analysis using the IKAPP method for the classification results of all villages in Abang Subdistrict, where the distribution mapping is divided into several color gradations, ranging from pink to light green, which describes the lowest water quality index value ranging from 70-75. while the light green to purple gradation represents values above 75.

Meanwhile, **Figure 4** uses the same method but tabulates the results based on the classification of each village, with the lowest value of 69-70 colored red (somewhat vulnerable) to values above 72 colored green (moderate). As in the NSF-WQI method, these results were obtained through interpolation using the *Inverse Distance Weighting* (IDW) method in ArcMap software version 10.4.1 [17].

This mapping not only focuses on determining the water quality index for irrigation, but also enriches the visualization with soil permeability zones and land use distribution [18]. As shown in **Figure 5**, soil with low or slow permeability is marked in cream color, while soil with very fast or high permeability is marked in dark brown. However, soil texture is not always directly proportional to its structure. For example, some types of clay soil are plastic and easily compacted, but there are groups whose properties do not appear, or conversely, not all sandy soils have a loose and dry structure [19].

Through this detailed mapping, it is hoped that it can provide a comprehensive insight into the potential and challenges related to irrigation water in Abang District, so that the results can later be used as technical recommendations in evaluating or improving land in Abang District.

This comparison shows that sites with lower NSF-WQI scores generally correlate with higher IKAPP vulnerability levels based on the influence of other indicators. However, in water quality observations that are interrelated with the NSF-WQI method, when viewed from water quality values alone, which have low values when pollution is low, this confirms the complementary relationship between the two indices.

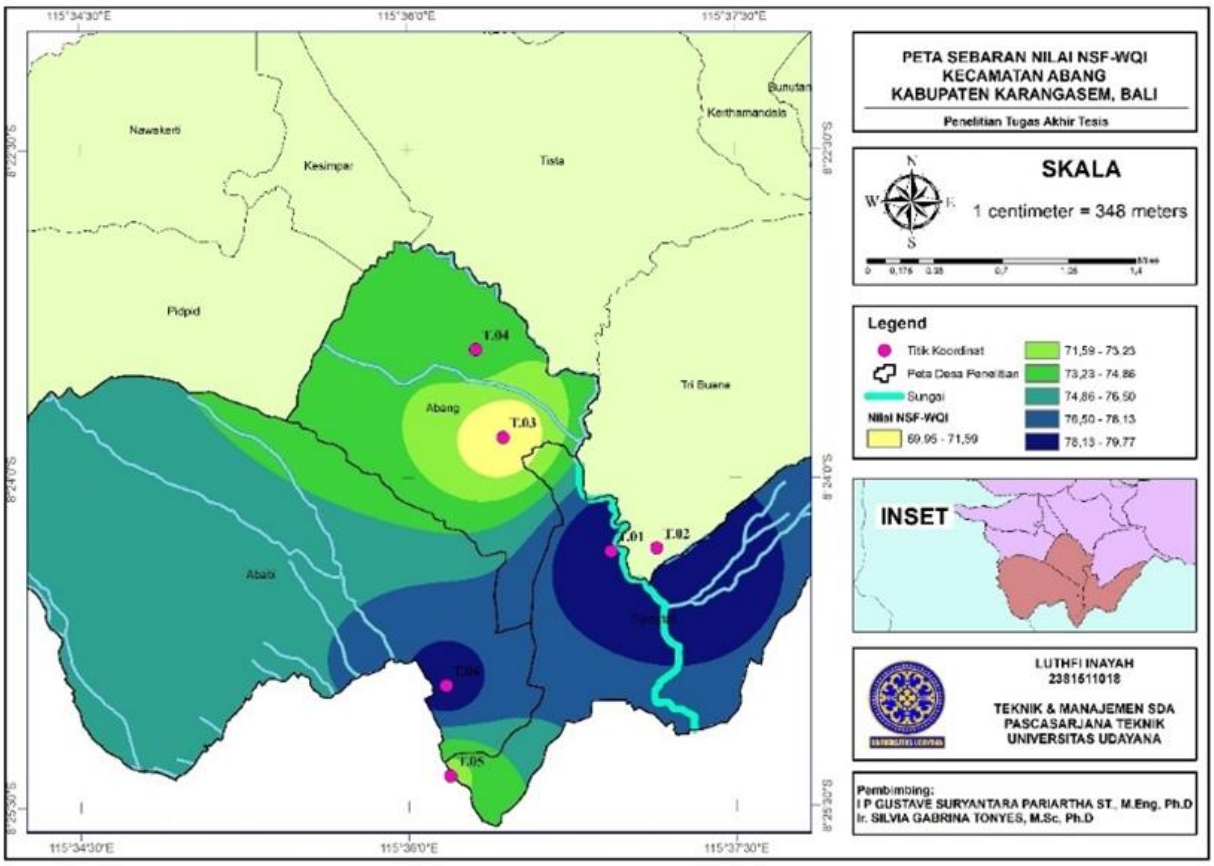


Figure 2. IWQI Value Distribution Map (NSF_WQI Method

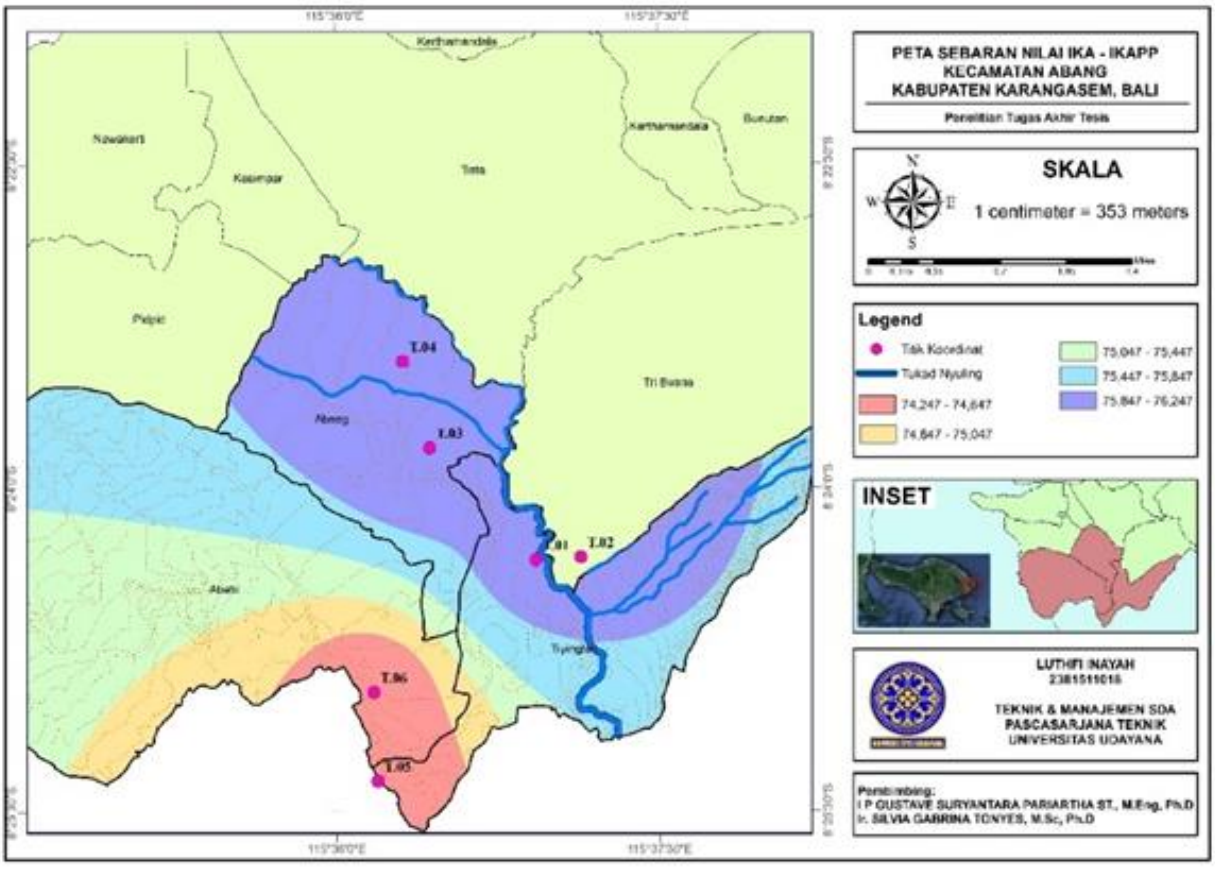


Figure 3. IWQI Value Distribution Map (IKAPP Method)

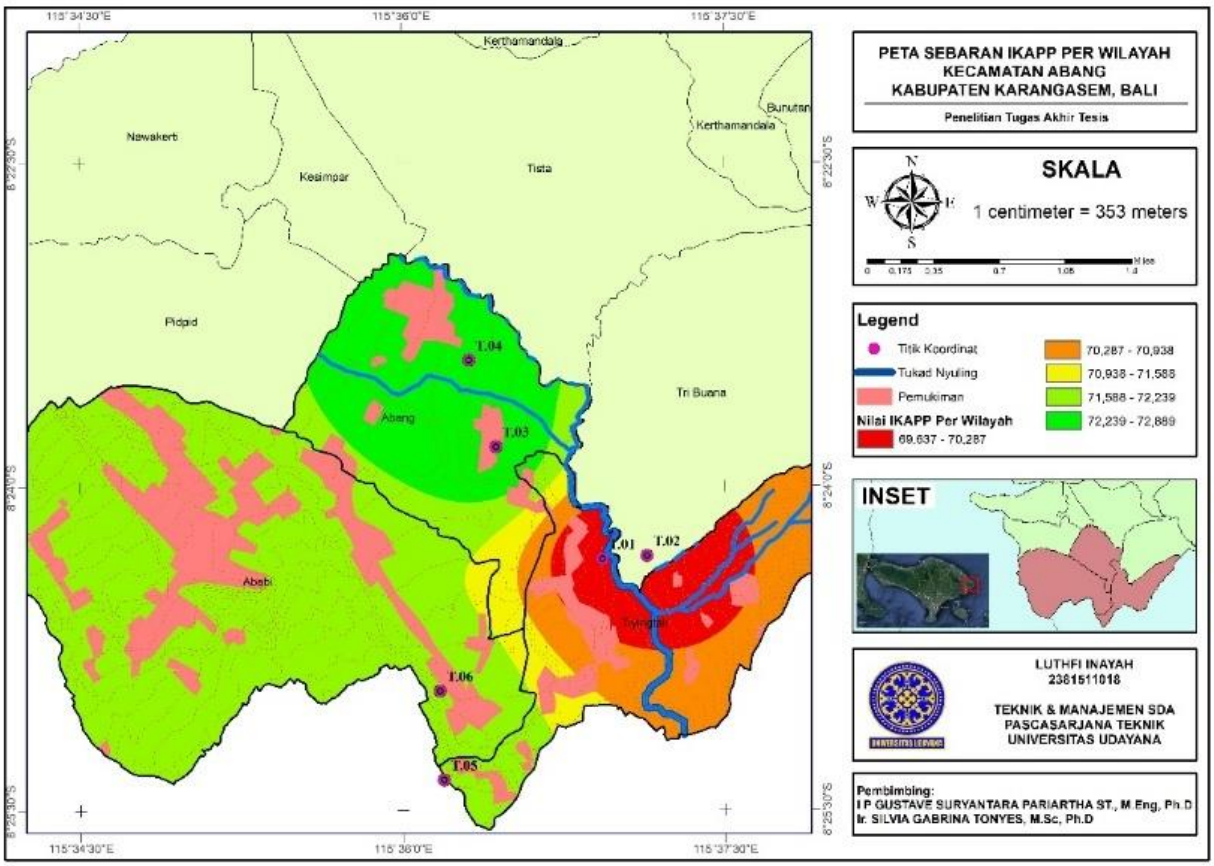


Figure 4. Distribution map of IKAPP composite value for each village

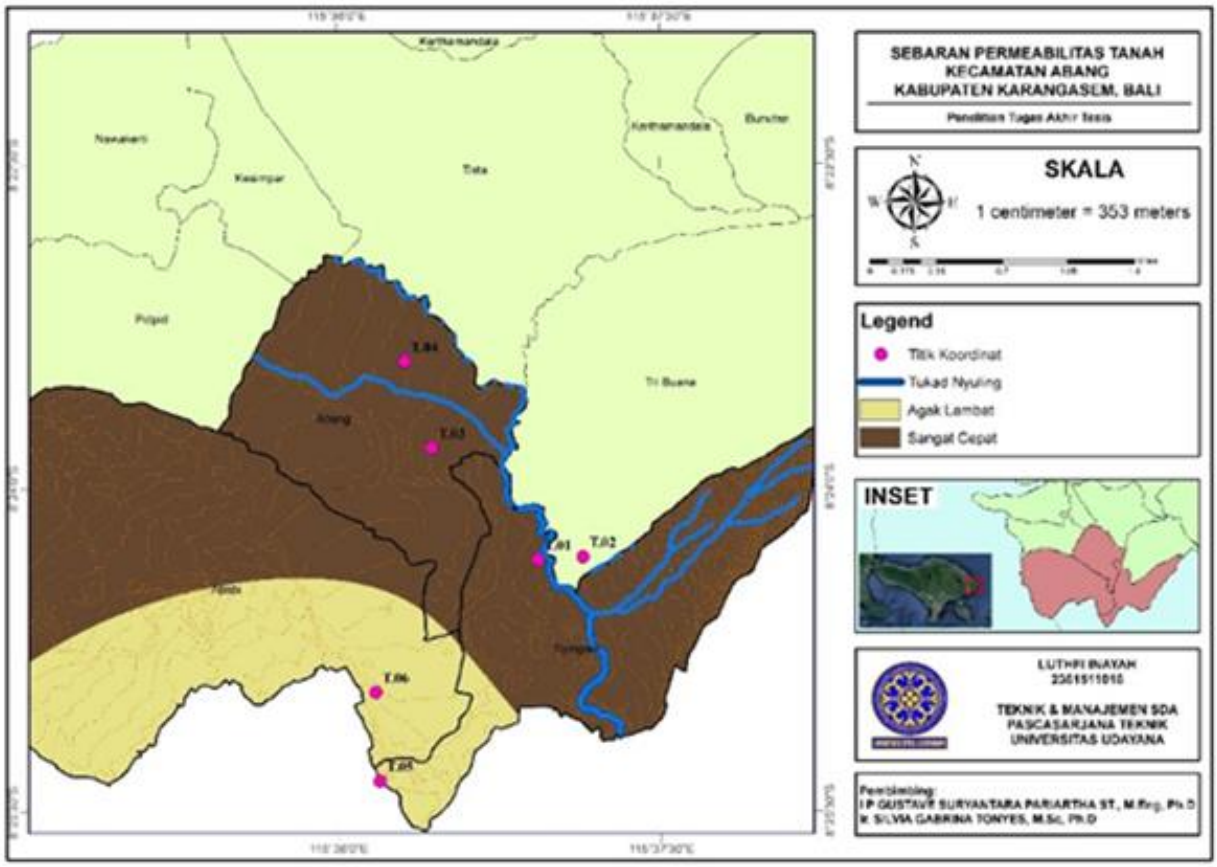


Figure 5. Distribution map of soil permeability values

4. Conclusion

The results of the study show that combining spatial mapping with irrigation water quality evaluation using the NSF-WQI and IKAPP methods can provide a comprehensive picture of the state of water resources in Abang District. In general, the NSF-WQI values fall into the feasible category with low to moderate limits, while the water quality values from the IKAPP method indicate a low level of vulnerability while for the overall IKAPP composite value per area it is categorized as moderate to moderately vulnerable with variations between areas.

This discrepancy reflects the sensitivity of each approach, where NSF-WQI is more efficient in measuring water quality in *real time*, while IKAPP is more effective in spatially mapping pollution risk over the entire watershed and over the long term.

Combining these two results, along with soil permeability data, allows for more precise land suitability zoning. Thus, the application of such spatially integrated analysis can be implemented in other semi-arid or arid areas to improve water resource management efficiency, maintain land productivity, and minimize the risk of overall environmental degradation.

5. Acknowledgment

This research is the final project of a thesis that focuses on water resources development that has previously been made related to "Mapping Groundwater Quality Index Values for Irrigation". Of course, thank you to the supervisors, examiners, academic lecturers, and all those who have provided support and valuable input in the process of research work and the preparation of this paper.

References

[1] Putu Indah Dianti Putri, Putu Ardi Suputra, Dan I Ketut Nuraga, "Study Of Irrigation Performance Index In Saba Irrigation Area," *Jipe*, Vol. 1, No. 1, Hlm. 15–26, Apr 2022, doi: 10.22225/jipe.1.1.2022.15-26.

[2] E. Ngoye Dan J. F. Machiwa, "The Influence Of Land-Use Patterns In The Ruvu River Watershed On Water Quality In The River System," *Physics And Chemistry Of The Earth, Parts A/B/C*, Vol. 29, No. 15–18, Hlm. 1161–1166, Jan 2004, doi: 10.1016/j.pce.2004.09.002.

[3] Kementerian Lingkungan Hidup Dan Kehutanan, "Laporan Pendahuluan Buku Indeks Kualitas Lingkungan Hidup (Iklh) Kabupaten Karangasem Tahun 2020." Andi Putra, 2020. [Daring]. Tersedia Pada: https://www.scribd.com/document/704250470/lapdal-iklh-karangasem-2020?utm_source=chatgpt.com

[4] M. Dimas Permata Gupta, "Studi Penentuan Status Mutu Air Menggunakan Metode Indeks Pencemaran Dan Wqi Di Tukad Badung, Denpasar," *Pengairan*, Vol. 11, No. 2, Hlm. 83–93, Nov 2020, doi: 10.21776/ub.pengairan.2020.011.02.02.

[5] Md. H. R. B. Khan, A. Ahsan, M. Imteaz, Md. Shafiquzzaman, Dan N. Al-Ansari, "Evaluation Of The Surface Water Quality Using Global Water Quality Index (Wqi) Models: Perspective Of River Water Pollution," *Scientific Reports*, Vol. 13, No. 1, Hlm. 20454, Nov 2023, doi: 10.1038/s41598-023-47137-1.

[6] W. Zhang, Y. Liu, Dan H. Yu, "Adaptation Of Water Quality Index (Wqi) For Local Watersheds: A Case Study Of The Yellow River Basin, China," Hlm. 8, 2021, doi: 10.1002/wat2.1502.

[7] U. Kaly, *Environmental Vulnerability Index (Evi) To Summarise National Environmental Vulnerability Profiles*. Suva, Fiji: Sopac, 1999.

[8] A. C. M. Meireles, E. M. D. Andrade, L. C. G. Chaves, H. Frischkorn, Dan L. A. Crisostomo, "A New Proposal Of The Classification Of Irrigation Water," *Rev. Ciênc. Agron.*, Vol. 41, No. 3, Hlm. 349–357, Sep 2010, doi: 10.1590/s1806-66902010000300005.

[9] A. Dariah, "Pengembangan Dan Diseminasi Inovasi Teknologi Pertanian Mendukung Optimalisasi Pengelolaan Lahan Kering Masam," Vol. 9, No. 1, 2015.

[10] Badan Pusat Statistik, "Badan Pusat Statistik Karangasem," 2023.

[11] I. A. Janiawati, "Sistem Subak Dan Subak Abian Pada Tatanan Lanskap Di Bali (Subak And Subak Abian System In Landscape Level Of Bali)," *Landscape Ecology Subject, Ipb University*, 2014, [Daring]. Tersedia Pada: https://www.academia.edu/9766440/sistem_subak_dan_subak_abian_pada_tatanan_lanskap_di_bali_subak_and_subak_abian_system_in_landscape_level_of_bali_

[12] C. Fanning, K. R. Brye, M. B. Daniels, T. L. Roberts, S. Fernandes, Dan L. S. Wood, "Near-Surface Soil Chemical Properties As Affected By Cover Crops Over Time In The Lower Mississippi River Valley," *As*, Vol. 15, No. 09, Hlm. 1035–1056, 2024, doi: 10.4236/as.2024.159056.

[13] J. L. Eimers, J. C. Weaver, S. Terziotti, Dan R. W. Midgette, "Methods Of Rating Unsaturated Zone And Watershed Characteristics Of Public Water Supplies In North Carolina," Report 99–4283, 2000. doi: 10.3133/wri994283.

[14] S. Hardjowigeno Dan Widiatmika, *Evaluasi Lahan Dan Perencanaan Tataguna Lahan*, Vol. Ketujuh, Juni 2023. 2007. [Daring]. Tersedia Pada: https://ugmpress.ugm.ac.id/id/product/pertanian/evaluasi-kesesuaian-lahan-dan-perencanaan-tataguna-lahan

[15] H. Poedjiastoeti, S. Sudarmadji, S. Sunarto, Dan S. Suprayogi, "Penilaian Kerentanan Air Permukaan Terhadap Pencemaran Di Sub Das Garang Hilir Berbasis Multi-Indeks," *Jwl*, Vol. 5, No. 3, Hlm. 168, Des 2017, doi: 10.14710/jwl.5.3.168-180.

[16] A. Aprila Permatasari Dan S. Vienastra, "Kelayakan Air Tanah Untuk Irigasi Pertanian Menggunakan Sodium Arbsoption Ratio (Sar)," *Comserva*, Vol. 2, No. 5, Hlm. 497–505, Sep 2022, doi: 10.59141/comserva.v2i5.605.

[17] A. Q. Munir, "Implementasi Sistem Informasi Geografis Penentuan Jalur Jalan Optimum Kodya Yogyakarta Menggunakan Algoritma Dijkstra," *Jtir*, Vol. 7, No. 20, Jun 2017, doi: 10.35842/jtir.v7i20.29.

[18] A. W. Nurrohman, M. Widyastuti, Dan S. Suprayogi, "Penilaian Kerentanan Air Permukaan Terhadap Pencemaran Menggunakan Data Penginderaan Jauh Dan Teknik Gis," *Majalah Ilmiah Globe*, Vol. 23, Hlm. 73–80, 2021.

[19] Bureau Of Plant Industry, Soils, And Dan Agricultural Engineering, "Soil Survey Manual," *2013*, Vol. 18, Hlm. 206, 2013.