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RESEARCH ARTICLE

The Impact of Land Use Change on Groundwater Depth in The Groundwater Transition Zone of Merapi Volcano, Yogyakarta, Indonesia

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Abstract Studies of the impact of land use change on groundwater on the southern slopes of Merapi Volcano tend to be carried out on a macro basis. Micro studies, especially in groundwater transition zones, have not been previously conducted. In-depth studies need to be undertaken in the groundwater transition zone on the southern slope of Merapi Volcano to identify the impact of land use change on the dynamics of groundwater depth in 2012-2021. Data was collected through field surveys and remote sensing. Groundwater depth data were collected through field surveys in 2012 and 2021. Groundwater depth data were measured in dug wells. The location of the excavated well was determined by using the systematic random sampling method. Groundwater depth data were analyzed using the kriging spatial interpolation method. The results of groundwater depth interpolation in 2012 and 2021 were then compared to determine the changes. Rainfall data were also used in the study. Rainfall data were collected using remote sensing data through cloud computing. Literature studies related to the condition of monitoring wells were also used to determine groundwater dynamics based on rainfall conditions. Data on land use change for 2012-2021 were collected using remote sensing data. Land use change was analyzed using pansharpening, supervised classification, and overlay methods. Cross-tabulation analysis was performed to determine the impact of land use change on groundwater depth. The groundwater depths in the study area were classified into <6 m, 6-11 m, and >11 m. Changes in land use from irrigated rice fields to settlements and open land to scrub occurred predominantly in the study area. Changes in land use did not have a significant impact on changes in groundwater depth in the study area. Based on cross-tabulation analysis, it is known that 11.46% of the study area experienced groundwater deepening, 7.73% experienced groundwater siltation, and 80.81% experienced no change in groundwater depth in the period of 2012-2021. Groundwater deepening generally occurs in areas dominated by scrub and settlements far from river channels. Groundwater that grows shallower and does not change in depth occurs around irrigated rice fields close to river channels. Land use change that does not significantly impact groundwater depth is likely to occur because rainfall in the study area is high. The aquifer material in the study area also had an excellent ability to drain groundwater coming from the upper slopes of Merapi Volcano.

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1. Introduction

The southern slope of Merapi Volcano in Java, Indonesia, makes an essential contribution to the groundwater supply. Groundwater on the south slope of Merapi Volcano is contained in an aquifer system called the Yogyakarta-Sleman groundwater basin (Hendrayana &; Vicente, 2013). The Yogyakarta-Sleman groundwater basin is spatially distributed from the volcano's upper slopes at 630 masl (meters above sea level) to the coastal areas of the Indian Ocean (Hendrayana & Vicente, 2013; True, 2020). The Yogyakarta-Sleman groundwater basin is classified into three zones: the groundwater recharge zone, the groundwater transition zone, and the groundwater discharge zone (Hendrayana & Vicente, 2013). These three zones arranged in a hierarchical pattern from the north side to the south slopes of Merapi Volcano.

The dynamics of social, economic, and population conditions in the Special Region of Yogyakarta Province resulted in a physical development pattern leading to a groundwater transition zone on the southern slope of Merapi Volcano. Neritarani and Sejati, in their research, stated that there had been a conversion of non-developed land into developed land, covering an area of 235.58 hectares in a span of ten years (2006-2015) (Neritarani & Sejati, 2021).

The results of Neritarani and Sejati's study also show that massive physical development, without being based on the principle of sustainable development, can increase the vulnerability index of groundwater pollution. Several researchers from various countries also revealed that changes in land use from non-developed to developed one cause multiple negative impacts on groundwater (Sajjad et al., 2022). The effect is a decrease in groundwater recharge volume, a decrease in infiltration capacity (Mishra et al., 2014; Siddik et al., 2022), changes in water balance (Ghazavi & Ebrahimi, 2016), changes in groundwater accessibility (Singh & Katpatal, 2018), lowering groundwater table (Hendrayana et al., 2023), groundwater scarcity, and quality (Karimian et al., 2019; Wilopo, 2021). Land use change is positioned as a variable that harms groundwater sustainability. However, the performance of these variables goes hand in hand with the ongoing climate change phenomena. The formulation of groundwater management recommendations is needed amid massive physical development and climate change phenomena. Hendrayana et al. (2023), in their study suggested that land use change is an important variable to consider in groundwater protection (Hendrayana et al., 2023).

Previous studies of the impact of land use change on groundwater on the southern slopes of Mount Merapi tend to be carried out on a macro basis. Studies tend to be carried out in the groundwater discharge zone. Macro studies have been conducted in the Yogyakarta-Sleman groundwater basin system to determine changes in groundwater depth using groundwater depth data in 2011 and 2015 (Hendrayana et al., 2021), groundwater depth changes studies have also been carried out in the groundwater discharge zone section of the Yogyakarta-Sleman groundwater basin system using groundwater depth data in 1985 and 2015 (Manny et al., 2016), there have been macro studies conducted on the changes in groundwater depth in the Yogyakarta-Sleman groundwater basin system using data from 2011-2017 (Wilopo et al., 2021). The results of macro studies cause information on changes in groundwater depth in each zone, especially in groundwater transition zones, to be explained in less detail. The results of studies and discussions delivered by predecessor researchers also focused more on the groundwater discharge zone. Meanwhile, microstudies have never been conducted, especially in the groundwater transition zones.

Based on the background description, research was conducted to determine the impact of land use change on groundwater, especially the pattern of groundwater depth in some groundwater transition zones. Some areas in the groundwater transition zone on the southern slope of Merapi Volcano were chosen as study area because there has never been an in-depth study of the impact of land use change on groundwater depth. An integrated approach, namely remote sensing (RS) and geographic information systems (GIS), was chosen as research methods. RS and GIS are used as research approaches because of their excellent capabilities to manage, analyze, and present spatial and temporal data or information visualizations (Butt et al., 2015; Fayaz et al., 2020; Gebeyehu et al., 2019; Ochuko & Lecturer, 2015) to achieve research objectives. The expected results of this study are spatial information on land use change patterns, spatial information on groundwater depth change patterns, and land use change impact studies on groundwater depth changes in the groundwater transition zone on the southern slope of Merapi Volcano.

The study was conducted in part of the groundwater transition zone on the southern slope of Merapi Volcano. The groundwater transition zone was chosen as the study area because the impact of land use change on groundwater tends to be carried out in the groundwater discharge zone. The study area is located in Cangkringan District, Sleman Regency, Yogyakarta. Cangkringan District was chosen as the research administration area because it is part of the groundwater transition zone, which is indicated to experience land use changes due to tourism activities. In addition to tourism, the activities of residents in the study area are agriculture, animal husbandry, and sand mining (Nofrita & Krol, 2014).

Based on initial surveys and literature studies, it is known that not all Cangkringan sub-districts have groundwater. Groundwater is only found in locations whose altitude is below 630 masl (Riasasi & Sejati, 2019; Sejati & Adji, 2013), thus the

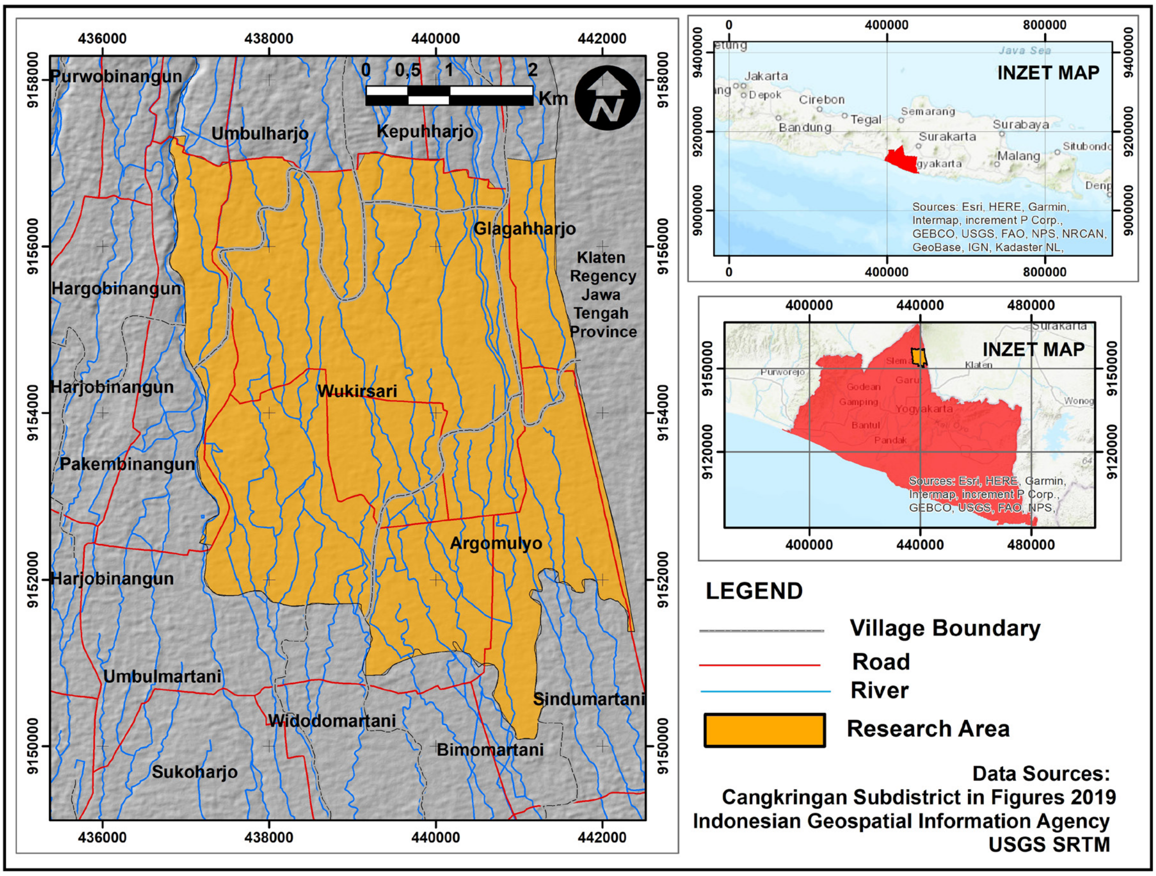


Figure 1. Research Area

area used as a study area is delineated by the *coordinates of the universal transverse Mercator* (UTM) as follows 9150000-9158000 *North* and 436000-442000 *East*. A map of the study area can be seen in Figure 1.

2. Methods

The data used in the study included land use data, groundwater depth data, and rainfall data, as well as data collected from literature studies on groundwater levels in monitoring wells around the study area. The *spatiotemporal approach* was used as the basis for data collection, processing, and analysis. It was due to its ability todetect patterns of changes in terrestrial objects at specified times (Longley et al., 2011). The research flow diagram is visualized in Figure 2.

The land use change was carried out using spatial analysis in a multitemporal manner, which used two land use data in different years, namely in 2012 and 2021. The mapping of the distribution of land use change in this study utilized remote sensing data, namely Landsat 8 Pansharpening 10 m, for visual interpretation of land use. The visual interpretation method was used to define the land use in the study area in multiple years, namely in 2012 and 2021, to identify the differences between two land use conditions, resulting in land use changes in distribution. The 2012 land use data started using the Indonesian topography map (*Peta Rupabumi Indonesia*) of the Cangkringan District in 2009. Updating data processes to require the 2012 land use data was conducted by visual interpretation of Landsat 2012, acquired in USGS. The 2021 land use data were obtained from visual interpretation results from Landsat 8, which were then validated with fact and analysis document, which are part of the Detailed Spatial Planning (*Rencana Detail Tata Ruang* (RDTR)) document of Cangkringan District covered in the study area. Detailed Spatial Planning (RDTR) document consists of a fact and analysis document and a planning document. The fact and analysis document consists of the existing planning area data, such as land use data, infrastructure data, spatial pattern data, etc. The land use data of the Cangkringan District in the Detailed Spatial Planning (RDTR) document, used for validating land use data in 2021, is the existing land use data in the Fact and Analysis Document.

The analysis of land use change in the study area was carried out by conducting a cross-tabulation analysis based on the site for each type of land use in the study area; the results of this cross-tabulation are expected to show the percentage of changes that occur in every kind of land use in the study area. Data on the distribution of land use change for each land use type will be used as a unit of observation in conducting an impact analysis on groundwater conditions in the study area.

Groundwater depth data were collected through field surveys in 2012 and 2021. The sampling technique used was a random system with a grid method. A grid measuring 250 m^2 was formed on the map of the study area map as a reference or sample frame. Each developed grid was then used to determine the location of groundwater depth measurements. The object used to measure the depth of groundwater was a dug well. The groundwater depth data in 2012 were collected during the rainy season in November 2012. Data on groundwater depth in 2021 were also collected during the rainy season in December 2021. Equipment used to collect groundwater depth data included Garmin 64s GPS receivers, Byson 50-tape measure, checklists, and stationery. GPS receiver was used to determine the position of the coordinates of the location of the sample. Groundwater depth data using meters. A tape measure was used to determine the depth of groundwater. The groundwater depth was known by inserting a tape measure into the dug well. The groundwater depth figure was known directly after the tape measure's tip reached the groundwater table for wells of which lips are parallel to the ground surface (using a good case parallel to the ground surface). There were repeated measurements to wells of which lips are above ground level (using a well case up to above ground level),. The first measurement was made to determine the depth of groundwater from the well lip case, and the second was made

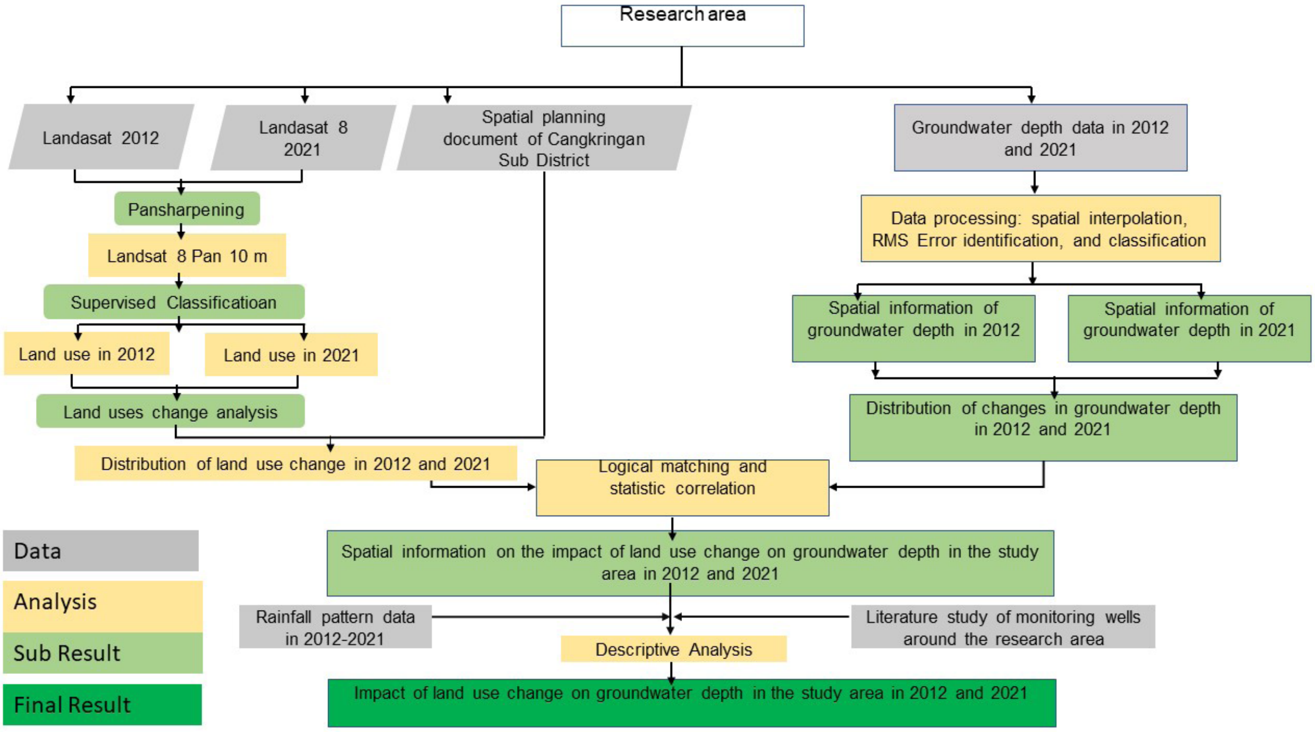


Figure 2. Research Flow Chart

to assess the thickness of the case above ground level. The groundwater depth figure was known by subtracting the value of groundwater depth from the well lip with the thickness of the well case (Sejati &; Adji, 2013). In 2012, 53 groundwater depth data points were collected, while in 2021, there were 39. There were less data collected in 2021 than which in 2012 due to some residential locations imposing lockdowns related to the COVID-19 pandemic.

Groundwater depth data were then processed and analyzed using geostatistical methods and classification with Arc GIS Pro 2.5 software to determine changes in groundwater depth patterns in predetermined years, namely 2012 and 2021. Geostatistical methods were used to perform spatial interpolation of groundwater depth data. The spatial interpolation technique used in the data analysis was Ordinary Kriging (OK). OK was chosen as the spatial interpolation technique due to its ability to produce reasonable predictions of field data collected using the systematic grid random sampling method (Sejati, 2019). Geostatistical indicators used to determine interpolation results included Root Mean Square Error (RMSE), mean standardized error, and Root Mean Square Standardized Error (RMSSE) (Sejati, 2019; Seyedmohammadi et al., 2016; Wang et al., 2017). The indicator number can be known automatically through the geostatistical analysis feature provided by the data processing software. The results of groundwater depth interpolation were then classified into three classes, namely less than 6 meters (<6 m), 6 to 11 meters (6-11 m), and more than 11 meters (>11 m). Changes in the depth of the interpolated groundwater are then compared with the condition of the groundwater table in the monitoring well. The monitoring well of Pakem District, located in the west of the study area, was used to compare information because there were no monitoring wells in the study area. Information on groundwater conditions in the monitoring well of Pakem District was obtained from a study by Razi et al. (2023).

Rainfall data were used to deepen the discussion of changes in groundwater depth in the study area. Temporal rainfall data in the study area were collected using remote sensing-based data. Remote sensing-based data is used due to the limitations of institutional data. Temporal rainfall data were obtained by CHRIPS satellite data. The CHIRPS satellite provides rainfall data with a daily temporal resolution with a spatial resolution of 0.05 degrees (Funk et al., 2015; Jain et al., 2022). The data was analyzed using cloud computing methods based on Google Earth Engine (GEE) to determine the variation in total rainfall per year from 2012 to 2021. The following is an example of modified Java script text from Funk et al. (2015) and Jain et al. (2022) to analyze rainfall data using GEE.

```
var aoi               = researcharea
var startDate         = ’2012-01-01’
var endDate           = ’2021-12-31’
var image Collection  = ’UCSB-CHG/CHIRPS/DAILY’
var bandName          = ’precipitation’
var resolution        = 5000 //in meters
var rainfall          =e.ImageCollection(imageCollection).
                      filter(ee.Filter.date(startDate,
                      endDate)).select(bandName);
var chart             =ui.Chart.image.series({image
                      Collection: rainfall, region: aoi,
                      reducer: ee.Reducer.mean(), scale:
                      resolution,});print(chart);Map.
                      addLayer (aoi)Map.centerObject(aoi)
```

3. Result and Discussion

Land Use Change in 2012 and 2021

Land use change was analyzed using the 2012 and 2021 multi-temporal remote sensing data. According to the 2012 remote sensing imagery interpretation, it can be seen that land use in the study area consists of shrubs, buildings, grassland, open land, settlements, plantations, irrigated rice fields, and moors/ leas. The 2012 land use analysis shows that the dominant land use is irrigated rice fields, reaching 42.65% of the total study area or 1123.86 hectares. Following the irrigated rice fields, the second dominating land use is settlements, reaching 609.10 hectares or 23.14% of the study area. The third dominating land use is plantations, reaching 458.82 hectares or 17.41% of the study area. The percentage of land use in the study area in 2012 can be seen in Figure 3, and the spatial distribution of land use in the study area in 2012 can be seen in Figure 4.

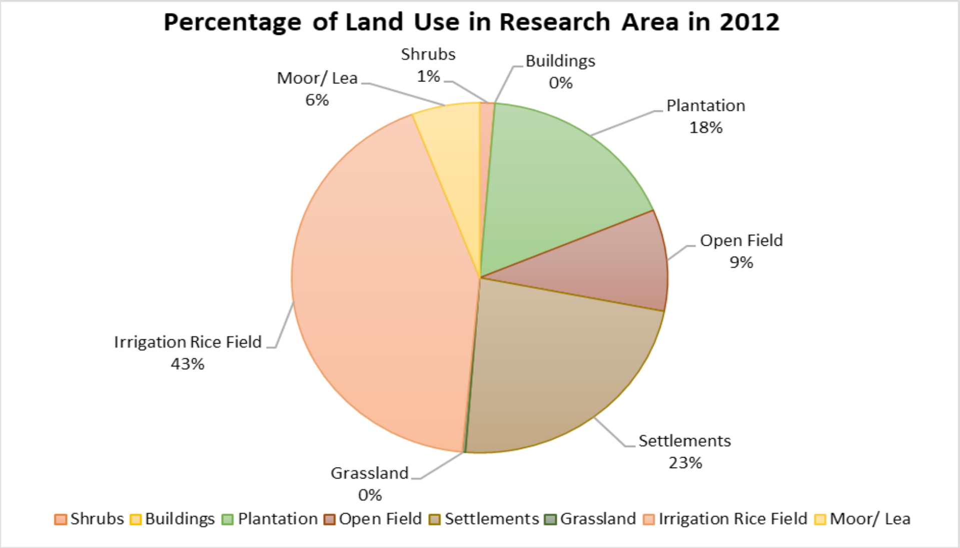


Figure 3. Distribution of Land Use in Research Area in 2012
Source: Image Interpretation (2012)

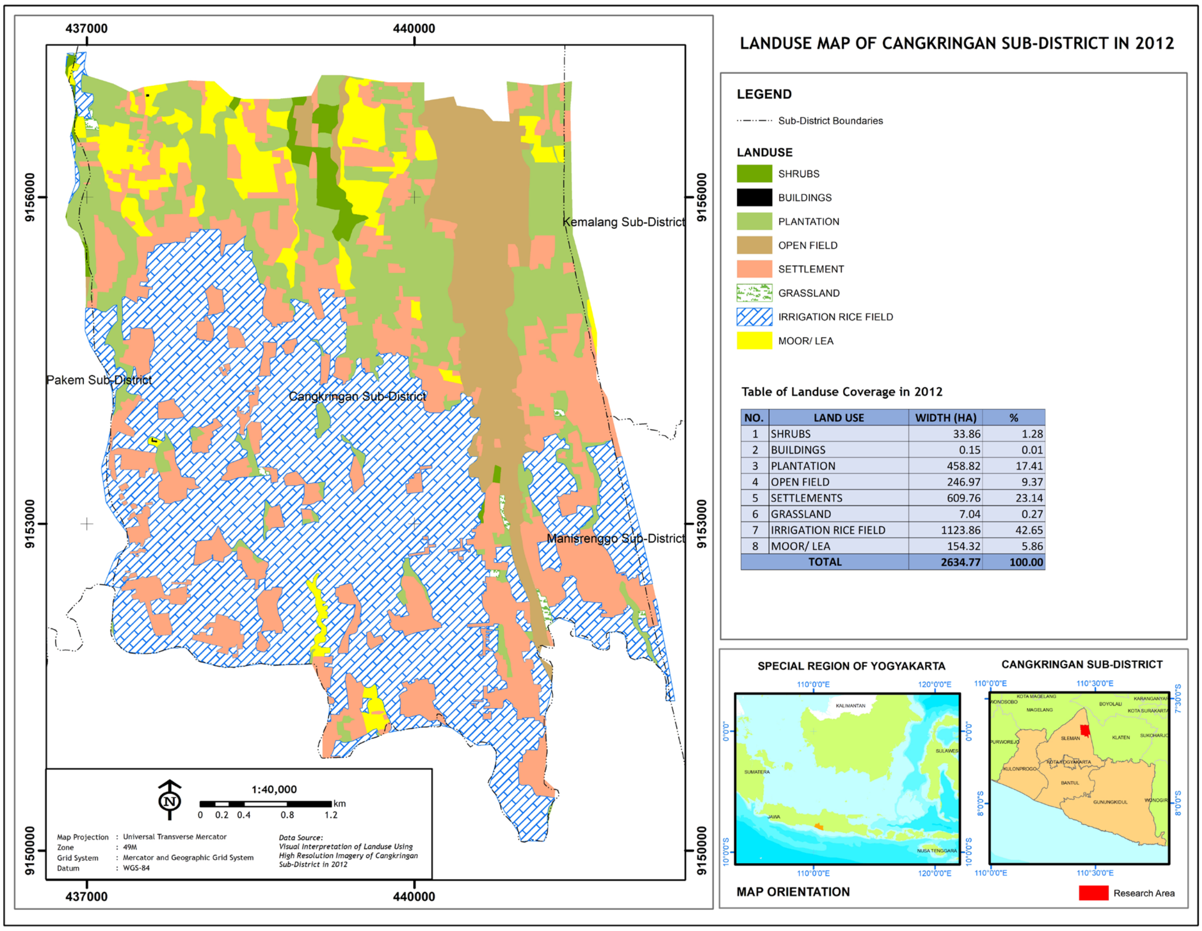


Table of Landuse Coverage in 2012

NO.	LAND USE	WIDTH (HA)	%
1	SHRUBS	33.86	1.28
2	BUILDINGS	0.15	0.01
3	PLANTATION	458.82	17.41
4	OPEN FIELD	246.97	9.37
5	SETTLEMENTS	609.76	23.14
6	GRASSLAND	7.04	0.27
7	IRRIGATION RICE FIELD	1123.86	42.65
8	MOOR/ LEA	154.32	5.86
TOTAL		2634.77	100.00

Map Projection : Universal Transverse Mercator
Zone : 49M
Grid System : Mercator and Geographic Grid System
Datum : WGS-84

Data Source:
Visual Interpretation of Landuse Using High Resolution Imagery of Cangkringan Sub-District in 2012

Figure 4. Land Use Map of Research Area in 2012
Source: Image Interpretation (2012)

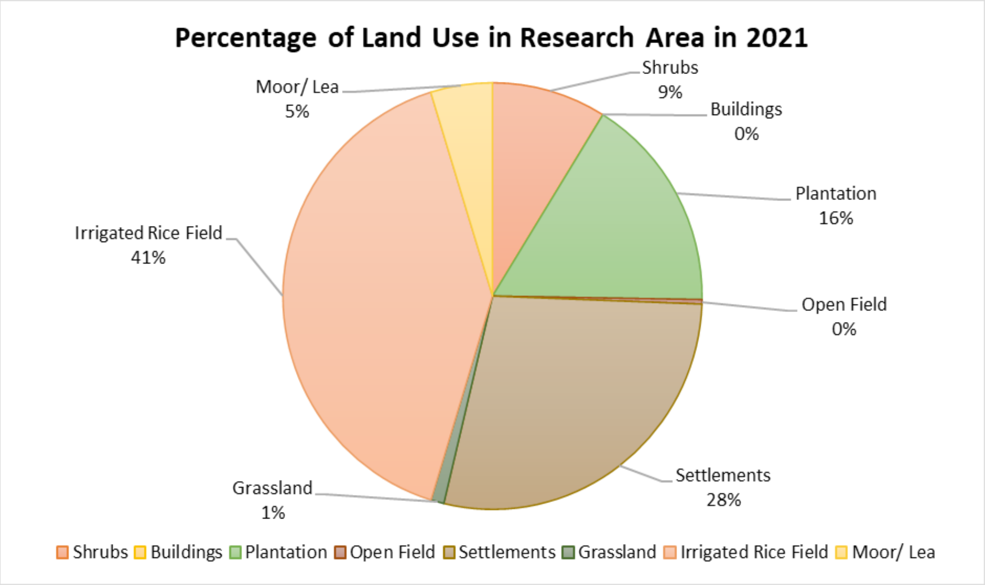


Figure 5. Distribution of Land Use in Research Area in 2021
Source: Image Interpretation (2021)

Similar to land use in 2012, the irrigated rice fields were still dominant in land use in 2021. According to the results of the land use analysis 2021, the types of land use in the study area are shrubs, buildings, grassland, open land, settlements, plantations, irrigated rice fields, and moors. The results of land use analysis 2021 show that irrigated rice fields still dominate the land use in the study area, reaching 40.34% or 1062.96 hectares. Following the irrigated rice fields, the second most dominant land use in 2021 is settlements, reaching 738.59 hectares or 28.03% of the total study area. The third dominating land use is plantations, reaching 440.82 hectares or 16.73% of the study area. The percentage of land use in the study area in 2021 can be seen in Figure 5, and the spatial distribution of land use in the study area in 2021 can be seen in Figure 6.

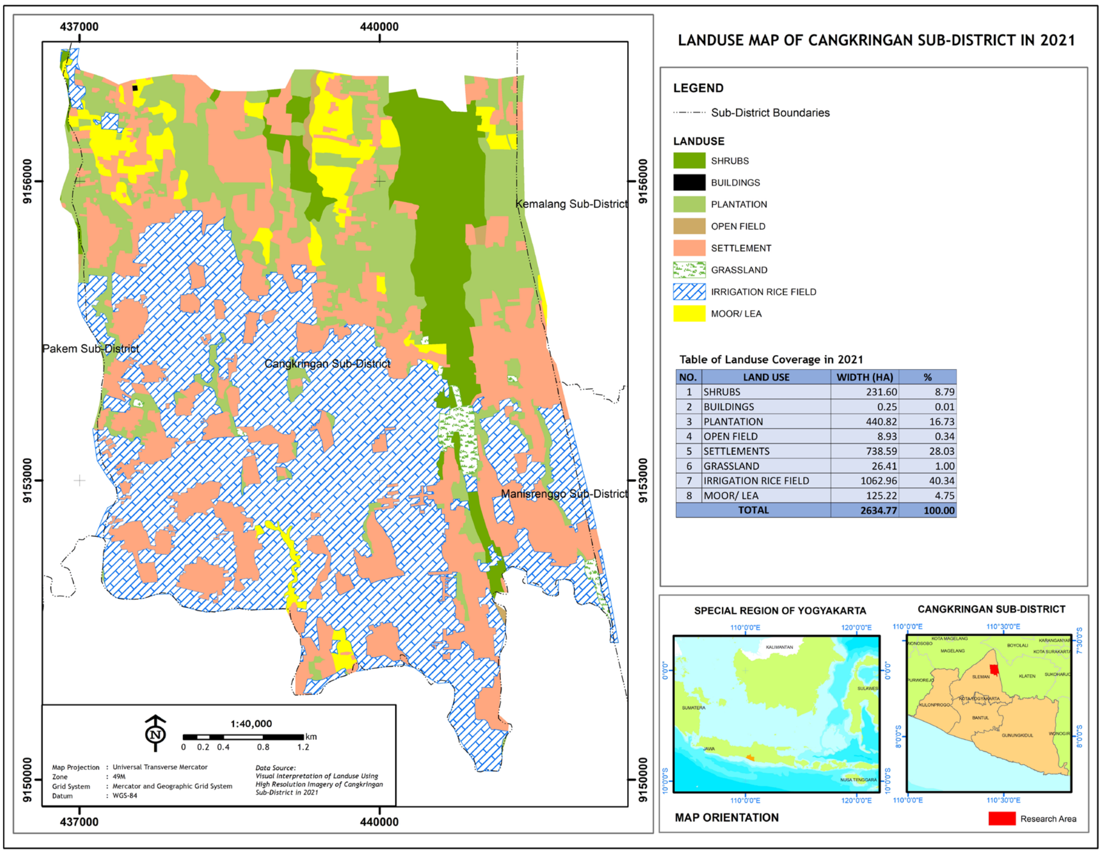


Figure 6. Land Use Map of Research Area in 2021
Source: Image Interpretation (2021)

Table 1. Land Use Change of Research Area in 2012 – 2021

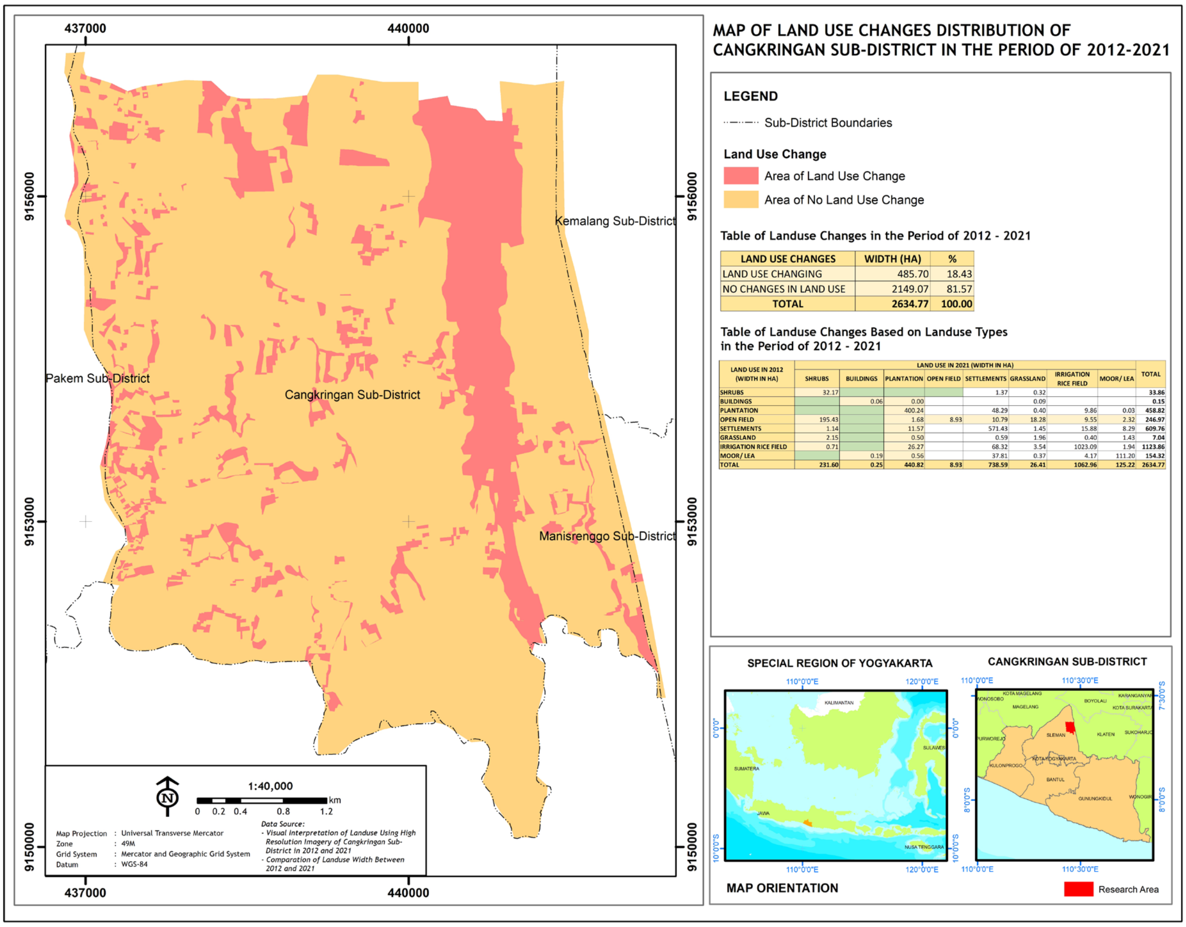
Land Use	Land Use in 2012 (hectare)	Land Use in 2021 (hectare)	Land Use Change (hectare)	Classification
Shrubs	33.86	231.60	197.75	Increase
Buildings	0.15	0.25	0.10	Increase
Plantation	458.82	440.82	-18.01	Decrease
Open Field	246.97	8.93	-238.04	Decrease
Settlements	609.76	738.59	128.83	Increase
Grassland	7.04	26.41	19.37	Increase
Irrigation Rice Field	1123.86	1026.96	-60.90	Decrease
Moor/ Lea	154.32	125.22	-29.10	Decrease
Total	2634.77	2634.77		

Source: Data Analysis (2023)

According to the results of a comparison of land use area between the 2012 and 2021 data, there was an increase in shrub area in 2021, which increased by 197.75 hectares. An increase in land use area also occurred in settlements. In 2021, there was an increase in land use in the form of settlements, covering an area of 128.83 hectares. However, based on the results of a comparison of land use area in the last decade, it can be seen that there are land uses that have decreased in area, namely open land, irrigated rice fields, moors/ leas, and grassland. In 2021, there was a decrease in open land area of 238.04 hectares, irrigated rice fields of 60.90 hectares, moor of 29.10 hectares, and gardens of 18.01 hectares. The distribution of increases and decreases in land use area from 2012 to 2021 can be seen in Table 1.

Based on the table, it can be seen that in the span of 10 years, there was some decrease in land use area. Land use that has decreased significantly is open land. In 2012, the size of open land reached 246.97 hectares or 9.37% of the total study area. Meanwhile, in 2021, it was only 8.93 hectares, or 0.34% of the total study area. In addition to open land, the land usefor irrigated rice fields decreased in the last 10 years. In 2012, the land use for irrigated rice fields covered a total area of 1123.86 hectares, while in 2021, it decreased to 1026.96 hectares.

Land use changes in some study areas are marked by both increases and decreases in land use area. The increases in land use area that occurred in part of the study area from 2012 to 2021 were in the form of shrubs, settlements, pastures, and buildings. Shrubs and settlements had significant incrase. In 2012, the area of land use in the form of shrubs only reached 33.86 hectares. Meanwhile, in 2021, it increased to 231.60 hectares. In addition to shrubs, land use that has grown significantly was settlements. In 2012, the area of settlements reached 609.74 hectares or 23.14% of the total area. Meanwhile, in 2021, land use in settlements increased to 738.59 hectares or 28.03% of the area. The spatial distribution of land use changes can be seen in Figure 7.



Map Projection : Universal Transverse Mercator
Zone : 49M
Grid System : Mercator and Geographic Grid System
Datum : WGS-84

Data Source:
- Visual Interpretation of Landuse Using High Resolution Imagery of Cangkringan Sub-District in 2012 and 2021
- Comparation of Landuse Width Between 2012 and 2021

Table of Landuse Changes in the Period of 2012 - 2021

LAND USE CHANGES	WIDTH (HA)	%
LAND USE CHANGING	485.70	18.43
NO CHANGES IN LAND USE	2149.07	81.57
TOTAL	2634.77	100.00

Table of Landuse Changes Based on Landuse Types in the Period of 2012 - 2021

LAND USE IN 2012 (WIDTH IN HA)	LAND USE IN 2021 (WIDTH IN HA)								TOTAL
	SHRUBS	BUILDINGS	PLANTATION	OPEN FIELD	SETTLEMENTS	GRASSLAND	IRRIGATION RICE FIELD	MOOR/ LEA	
SHRUBS	32.17				1.37	0.32			33.86
BUILDINGS		0.06	0.00			0.09			0.15
PLANTATION			400.24		48.29	0.40	9.86	0.03	458.82
OPEN FIELD	195.43		1.68	8.93	10.79	18.28	9.55	2.32	246.97
SETTLEMENTS	1.14		11.57		571.43	1.45	15.88	8.29	609.76
GRASSLAND	2.15		0.50		0.59	1.96	0.40	1.43	7.04
IRRIGATION RICE FIELD	0.71		26.27		68.32	3.54	1023.09	1.94	1123.86
MOOR/ LEA		0.19	0.56		37.81	0.37	4.17	111.20	154.32
TOTAL	231.60	0.25	440.82	8.93	738.59	26.41	1062.96	125.22	2634.77

Figure 7. Spatial Distribution of Land Use Change for the Period 2012 – 2021
Source: Data Analysis (2023)

Table 2. Cross-Tabulation Analysis of Land Use in Research Area in 2012 – 2021

Land Use in 2012	Land Use in 2021							
	Shrubs	Buildings	Plantation	Open Field	Settlements	Grassland	Irrigation Rice Field	Moor/ Lea
Shrubs	32.17				1.37	0.32		
Buildings		0.06	0.00			0.09		
Plantation			400.24		48.29	0.40	9.86	0.03
Open Field	195.43		1.68	8.93	10.79	18.28	9.55	2.32
Settlements	1.14		11.57		571.43	1.45	15.88	8.29
Grassland	2.15		0.50		0.59	1.96	0.40	1.43
Irrigation Rice Field	0.71		26.27		68.32	3.54	1023.09	1.94
Moor/ Lea		0.19	0.56		37.81	0.37	4.17	111.20
TOTAL	231.60	0.25	440.82	8.93	738.59	26.41	1062.96	125.22

Source: Data Analysis (2023)

According to the results of a comparison of the increases and decreases in land use area in a period of 10 years, namely from 2012 to 2021, it can be seen that there has been a significant land use change, which is indicated by a decrease in the area of irrigated rice fields,offset by an increase in settlements area. The study area's analysis of land use change in 2012 and 2021 shows that 485.70 hectares of land have changed their functions. This indicates that in the study area, there has been a change in land use by 18.43% between 2012 and 2021. The study area, which is located in the Cangkringan District, is in the upper slopes of Merapi Volcano. This causes this area to be categorized as a protected area because it is most frequently affected by the eruption of the Merapi Volcano. One of the impacts of the eruption is changes in land use. From 1999 to 2010, the Cangkringan District experienced a change in residential land use to non-residential due to the eruption of the Merapi volcano. (Widodo, 2015). According to this study, in 2015, land use changes occurred after a volcano eruption.

According to the results of cross-tabulation analysis for two land use data in different years, namely in 2012 and 2021, in Cangkringan District, In 2012, the irrigated rice fields, covering 1,123.86 hectares, underwent various transformations. They were converted into shrubs, covering 0.71 hectares, into plantations covering an area of 26.27 hectares, into settlements covering 68.32 hectares, into grasslands covering 3.54 hectares, and into moors/leas covering 1.94 hectares. However, by 2021, a portion remained unchanged, still serving as irrigated rice fields, covering 1,023.09 hectares. The results of cross-tabulation analysis can be seen in Table 2.

Groundwater Change in 2012 and 2021

Primary groundwater depth data in 2012 and 2021 were used to map patterns of groundwater depth change in the study area. The data can be seen in Table 3 and Table 4. The results of geostatistical analysis using Ordinary Kringing (OK) techniques on groundwater depth data can be seen in Table 5.

Table 3. Groundwater Depth Data in 2012

X	Y	Hamlet	Depth to Groundwater (m)
441376	9156495	Jetissumur	12.6
441253	9156760	Jetissumur	5.6
440909	9155043	Ngancar	18.3
441125	9154914	Banjarsari	17.8
440995	9154763	Banjarsari	20.4
441135	9154686	Banjarsari	17.7
441125	9154465	Banjarsari	17.0
441386	9154593	Banjarsari	16.5
441561	9154589	Banjarsari	12.8
441525	9154691	Banjarsari	6.0
441515	9154462	Banjarsari	15.0
441668	9154333	Banjarsari	12.5
441486	9154242	Mudal	8.5
441088	9154168	Besalen	8.2
441153	9153845	Gadingan	2.7
441431	9154029	Mudal	4.9
441470	9153839	Mudal	3.4
441580	9153561	Gayam	3.9
441220	9152873	Gadingan	0.9
441129	9152631	Wonokerso	1.0
441182	9152409	Wonokerso	1.5
441653	9152318	Jiwan	2.2
441340	9152663	Cawisan	1.9
440855	9152473	Jetis	2.8
440768	9152111	Karanglo	2.5
442086	9152409	Dliring	2.6
438302	9153516	Kiyaran	0.2
438598	9153781	Dongkelsari	1.4
439079	9153052	Karangnongko	0.2
437671	9153989	Tanjung	5.9
438490	9152743	Sabrang Wetan	4.5
438405	9152066	Pusmalang	4.4
439325	9151835	Rejosari	0.2
439330	9151020	Randusari	3.0
439778	9151087	Punthuk	1.7
440972	9151136	Brongkol	0.7
438107	9154742	Keten	1.0
437949	9155658	Cancangan	0.5
438847	9155769	Polorejo	9.7

438663	9155157	Plupuh	0.2
439208	9154403	Bulaksalak	1.9
439025	9155501	Bulaksalak	11.5
439904	9155973	Gondang	16.5
439959	9154683	Kesongo	2.6
440409	9154600	Gungan	11.0
440573	9152777	Bronggang	0.1
440663	9153306	Suruh	0.5
440223	9151154	Kebur Kidul	0.9
438639	9153382	Dawung	2.2
440058	9151509	Kebur Lor	0.6
439856	9152087	Kwangen	0.5
439120	9156364	Tegalbarep	12.7
439054	9156632	Tegalbarep	15.3

Source: Field Survey (2012)

Table 4. Groundwater Depth Data in 2021

X	Y	Hamlet	Groundwater Depth (m)
439909	9155965	Gondang	16.1
439239	9155144	Bulak Salak	3.9
438657	9155109	Plupuh	2.5
438692	9155515	Sambisari	4.9
437842	9155656	Cancangan	1.5
437236	9155340	Pentingsari	12.4
437516	9154576	Bedoyo	6.8
437748	9154066	Tanjung	7.2
437248	9153593	Kedung	4.0
437978	9152637	Jambu Bangkong	6.2
438084	9153320	Sembungan	0.5
438646	9153487	Kiyaran	2.7
438609	9154510	Watuadeg	2.5
438112	9154353	Keten	1.5
438132	9154754	Keten	2.6
439347	9154336	Kregan	1.7
439398	9153501	Ngemplak	0.5
439961	9154684	Duwet	4.1
440129	9154416	Cakran	4.0
440164	9154175	Pandan	2.3
439723	9154748	Salam	5.9
438397	9152787	Sabrang Wetan	1.9
438088	9151973	Pusmalang	1.0
438661	9152122	Seruni	3.1
439338	9152398	Kuwang	1.0
439446	9152135	Tegalsari	1.3
439425	9151448	Losari	3.5
440125	9151290	Kebur Kidul	1.4
440098	9152124	Ngliwang	1.2
440740	9151316	Cangkringan	3.0
440984	9150626	Sewon	0.6

440737	9152340	Jetis	2.5
440752	9153033	Bronggang Suruh	2.3
441395	9152669	Cawisan	2.1
441556	9153344	Gayam	3.0
441027	9154043	Besalen	6.3
441126	9155386	Ngancar	12.3
441566	9154424	Banjarsari	14.8
441598	9154137	Mudal	10.5

Source: Field Survey (2021)

Table 5. Result of Geostatistical Analysis of Groundwater Depth Data

Indicator	Groundwater Depth Data (2012)	Groundwater Depth Data (2021)
Root Mean Square Error (RMSE)	2.8	2.9
Mean Standardized Error (MSE)	0.008	0.03
Root Mean Square Standardized Error (RMSSE)	0.72	1.22

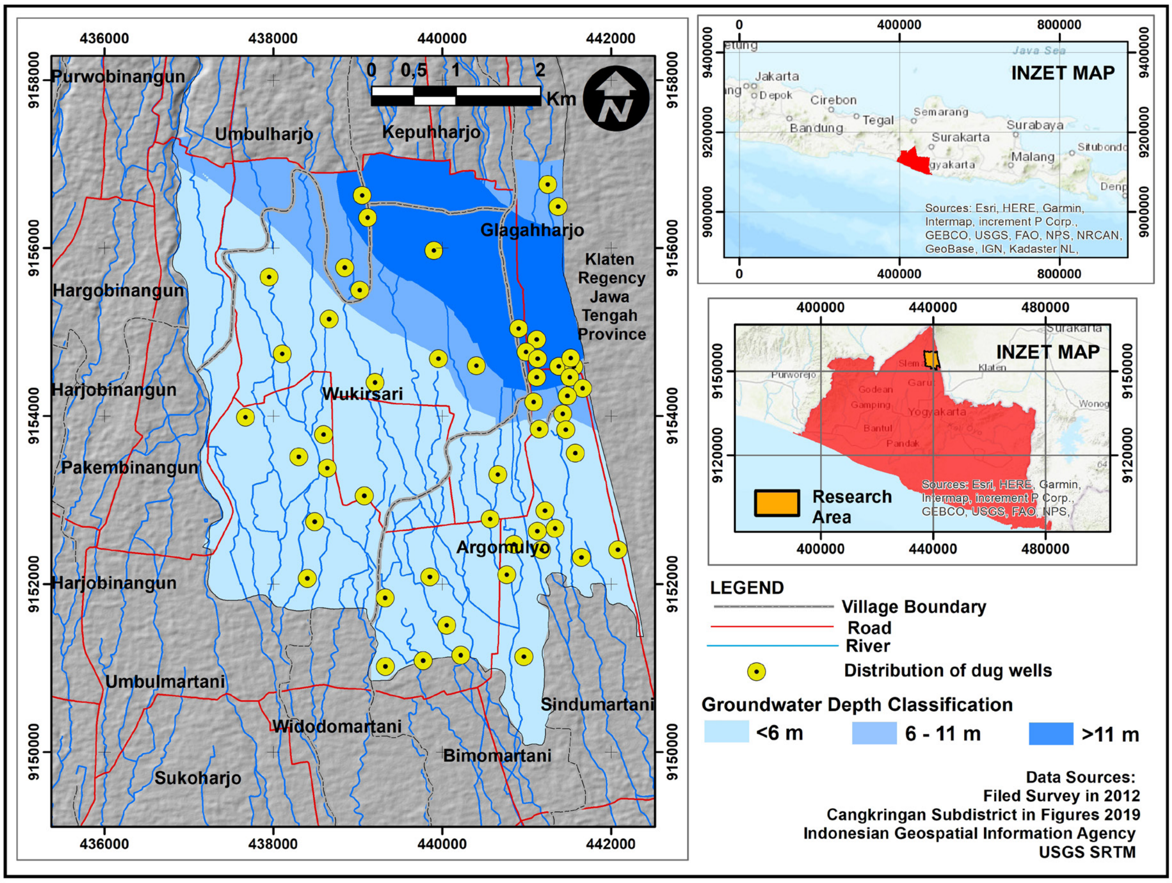


Figure 8. Spatial Pattern of Groundwater Depth in 2012

Based on Table 6, it is known that the indicator number is not greater than three and is almost close to 0. Based on previous studies, the number of error indicators that do not exceed three and get closer to 0 indicates that the results of spatial interpolation predictions are valid and can be used as a basis for decision-making (Hussin et al., 2020; True, 2019).

Based on the results of groundwater depth data analysis, it is known that there are differences in spatial patterns of groundwater depth in the study area in 2012 and 2021. The difference in spatial patterns of groundwater depth can be seen in Figure 8 and Figure 9.

The groundwater depth in classes less than 6 meters (< 6 m) has decreased in area. In 2012, the area of less than 6 meters depth was 1,807 ha, while in 2021, it was 1,669 ha. The groundwater depth in classes 6 to 11 (6-11 m) meters increases in width. In 2012, the area with a groundwater depth of class 6 to 11 meters was 378 ha; in 2021, the depth increased to 541 ha. The groundwater depth class of more than 11 meters

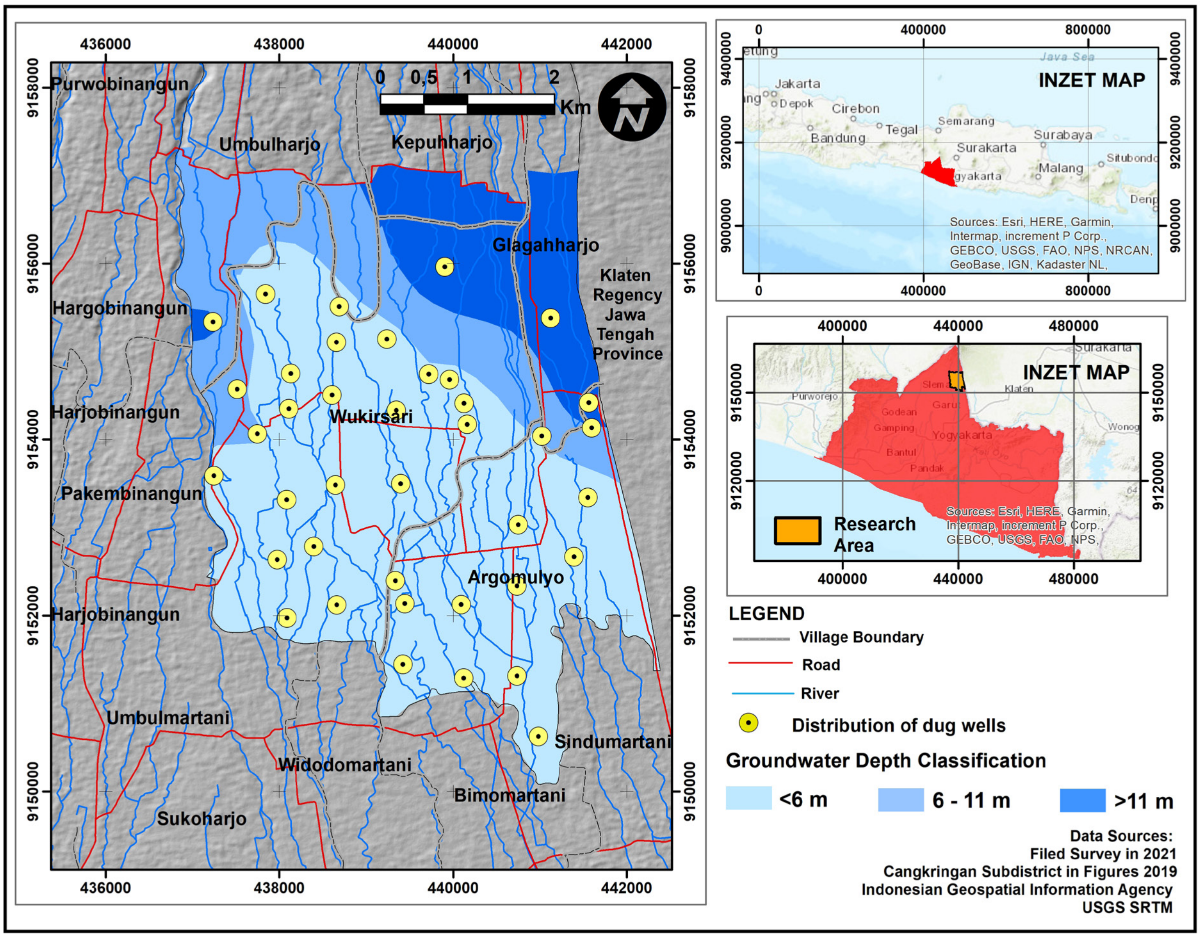


Figure 9. Spatial Pattern of Groundwater Depth in 2021

(>11 m) has decreased in the area; in 2012, the groundwater depth in the more than 11-meter class was 451 ha, while in 2021, it was 425 ha. Based on previous studies, changes in groundwater depth can be caused by changes in land use (S. Kumar et al., 2021; Oiro et al., 2020; Steward & Allen, 2016). The depth of groundwater increases with changes in land use from non-developed to developedland (Masoud et al., 2016; Purwantara et al., 2019).

The Impact of Land Use Change on Groundwater Depth

Analysis of the impact of land use change is carried out by comparing areas that experience land use change and those that experience changes in the groundwater level. Each land use change has a different impact on groundwater levels in part of the study area from 2012 to 2021. According to the results of the analysis of land use change, in 10 years, there have been changes in land use into pastures, gardens, irrigated rice fields, moors, settlements, shrubs, and buildings.

From 2012 to 2021, there was a change in land use to grasslands, covering an area of 24.45 hectares. Based on the results of the comparative analysis between changes in land use and changes in the level of the groundwater table, there is an increase in groundwater level to be shallower as much as 5.45% of the total changes in land use to pastures in a part of the study areas. Meanwhile, 94.55% of areas that experienced land use change to grasslands did not experience changes in the level of their groundwater table. This change in groundwater level occurs in open land areas that experience changes in land use to grasslands, with changes in groundwater level, from 6-11 meters to <6 meters. It shows an insignificant impact of changing land use to grasslands on changes in groundwater level. The effect of changes in land use to grasslands on groundwater level in the study area can be seen in Table 6.

In addition to the changes in land use to grasslands, from 2012 to 2021, there was also a change in land use to plantations, covering an area of 40.58 hectares. The results of the comparative analysis between changes in land use and changes in the level of the groundwater table, there was a decrease in groundwater level by 30.49% of the area, from <6 meters to 6-11 meters deep. It occurred in irrigated rice fields, moors, and settlement areas that experienced land use changes to plantations in 2021. The more profound decline in groundwater levels occurred as much as 0.48% of the area, that turned into plantations in 2021. The groundwater table becomes deeper, from <6 to >11 meters deep. It occurred in settlement areas that experience changes in land use to gardens. It shows a significant impact of changing settlements into gardens on changes in groundwater levels.

However, the changes in land use from settlements to plantations also have an impact on significant increase in groundwater levels, which is shallower, from >11 meters to <6 meters deep, as much as 1.71%. It occurred in settlement areas that experienced land use changes to plantations in 2021. In addition, an increase in groundwater level from 6-11 meters to <6 meters also occurred in the study area, reaching 1.39%. Based on this result, a part of the study areas that experiences changes in land use to plantations, the impact on the decrease of groundwater levels is more profound. The impact of changes in land use to plantations on groundwater level in the study area can be seen in Table 7.

Table 6. The Impact of Land Use Change into Grassland on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Building to Grassland	-	-	-	-	-	-	-	-	-	-	0.09	100.00	0.09
Irrigated Rice Field to Grassland	-	-	-	-	-	-	-	-	-	-	3.54	100.00	3.54
Moor/ Lea to Grassland	-	-	-	-	-	-	-	-	-	-	0.37	100.00	0.37
Open Field to Grassland	-	-	-	-	-	-	-	-	1.33	7.28	16.95	92.72	18.28
Plantation to Grassland	-	-	-	-	-	-	-	-	-	-	0.40	100.00	0.40
Settlements to Grassland	-	-	-	-	-	-	-	-	-	-	1.45	100.00	1.45
Shrubs to Grassland	-	-	-	-	-	-	-	-	-	-	0.32	100.00	0.32
Total	-	-	-	-	-	-	-	-	1.33	5.45	23.12	94.55	24.45

Source: Data Analysis (2023)

Table 7. The Impact of Land Use Change into Plantations on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Building to Plantation	-	-	-	-	-	-	-	-	-	-	0.00	100.00	0.00
Grassland to Plantation	-	-	-	-	-	-	-	-	-	-	0.50	100.00	0.50
Irrigated Rice Field to Plantation	-	-	3.92	14.93	-	-	-	-	-	-	22.34	85.07	26.27
Moor/ Lea to Plantation	-	-	0.23	40.47	-	-	-	-	-	-	0.33	59.53	0.56
Open Field to Plantation	-	-	-	-	-	-	-	-	-	-	1.68	100.00	1.68
Settlements to Plantation	0.12	1.01	3.31	28.58	-	-	0.42	3.62	0.34	2.93	7.39	63.85	11.57
TOTAL	0.12	0.48	7.45	30.49	-	-	0.42	1.71	0.34	1.39	32.25	131.91	40.58

Source: Data Analysis (2023)

In addition to changes in land use to plantations, from 2012 to 2021, there was also a change in land use to irrigated rice fields, covering an area of 39.87 hectares. The results of the comparative analysis between changes in land use and changes in the groundwater table level show a decrease in groundwater level by 15.3%, from <6 meters to 6-11 meters deep. It occurred to moors, plantations, and settlement areas that experienced land use changes to irrigated rice fields in 2021. In addition, there was also a significant increase in groundwater levels, which became shallower, from 6-11 meters to <6 meters deep, as much as 5.39%. It happened to areas of open land, gardens, and settlements that experienced land use changes to irrigated rice fields in 2021. This case shows that in the study area that changes land use to irrigated rice fields, the impact of the decrease in groundwater levels becomes significantly more profound than the impact of increasing groundwater levels. The effect of changing land use to irrigated rice fields on groundwater depth in the study area can be seen in Table 8.

Table 8. The Impact of Land Use Change into Irrigated Rice Field on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Grassland to Irrigated Rice Field	-	-	-	-	-	-	-	-	-	-	0.40	100.00	0.40
Moor/ Lea to Irrigated Rice Field	-	-	3.02	72.30	-	-	-	-	-	-	1.16	27.70	4.17
Open Field to Irrigated Rice Field	-	-	-	-	-	-	-	-	1.39	14.54	8.16	85.46	9.55
Plantation to Irrigated Rice Field	-	-	2.71	27.45	-	-	-	-	0.36	3.60	6.80	68.95	9.86
Settlements to Irrigated Rice Field	-	-	0.38	2.37	-	-	-	-	0.41	2.56	15.10	95.06	15.88
TOTAL	-	-	6.10	15.30	-	-	-	-	2.15	5.39	31.61	79.30	39.87

Source: Data Analysis (2023)

Table 9. The Impact of Land Use Change into Moor/ Lea on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Grassland to Moor/ Lea	-	-	1.43	100.00	-	-	-	-	-	-	-	-	1.43
Irrigated Rice Field to Moor/ Lea	-	-	-	-	-	-	-	-	-	-	1.94	100.00	1.94
Open Field to Moor/ Lea	-	-	-	-	-	-	-	-	2.10	90.63	0.22	9.37	2.32
Plantation to Moor/ Lea	-	-	0.03	100.00	-	-	-	-	-	-	-	-	0.03
Settlements to Moor/ Lea	-	-	0.08	0.91	-	-	0.59	7.11	0.68	8.18	6.95	83.81	8.29
TOTAL	-	-	1.54	10.97	-	-	0.59	4.21	2.78	19.84	9.11	64.98	14.02

Source: Data Analysis (2023)

In addition to changes in land use to irrigated rice fields, from 2012 to 2021, there was also a change in land use to moors/ leas, covering an area of 14.02 hectares. The results of the comparative analysis between changes in land use and changes in the level of the groundwater table show that there is a decrease in the level of groundwater by 10.97% of the area, from <6 meters to 6-11 meters deep. It occurred to grasslands, plantations, and settlements that experienced land use change to moors/leas in 2021. However, changes in land use to moors/ leas also have an impact on changing the level of groundwater to be shallower, as much as 19.84%, with an increase in groundwater level from 6-11 meters to <6 meters deep and 4.21% experienced an increasein groundwater level, from >11 meters to 6-11 meters deep. Areas that experience an increase in groundwater level from 6-11 meters to <6 meters deep are open lands and settlements, that have changed their land use to moors/leas. Meanwhile, areas that experience an increase in groundwater level from >11 meters to 6-11 meters deep are settlement areas that have changed their land use to moors/ leas. According to this result, study areas that experienced changes in land use to moors/leashave an impact on significant increase in groundwater level, shallower than the impact on decreasing groundwater level. The effect of changes in land use into moors/leas on groundwater level in the study area can be seen in Table 9.

In addition to changes in land use to moors/leas, from 2012 to 2021, there was also a change in land use to settlements, covering an area of 167.16 hectares. According to the results of the comparative analysis between changes in land use and changes in the level of the groundwater table, In the areas experiencing changes in land use to settlements, the groundwater level tends to increase, becoming shallower, while in other areas, it decreases, becoming deeper. The proportion of areas where the groundwater level increased from 6-11 meters to less than 6 meters is 3.68%. This was observed in the areas previously classified as moors/leas, open lands, and plantations that transitioned into settlements by 2021. Additionally, there was a 4.05% increase in areas where the groundwater level increased from >11 meters to 6-11 meters. This change occurred in areas previously categorized as moors/leas, open lands, plantations, and shrubs that transformed into settlements by 2021.

The changes of land use to settlements also causes to a more profound decrease in groundwater levels. Only 0.05% of areas experienced a significant decrease in groundwater levels from >6 meters to <11 meters. This change occurred mainly in plantation areas that experienced land use changes to settlements by 2021. Additionally, there was an 11.41% decrease in groundwater levels from <6 meters to >6-11 meters in irrigated rice fields, moors/leas, and plantations that changed into settlements by 2021.

According to these findings in the study area, due to the land use changes to settlements, the decrease in groundwater level is more significant than the increase in groundwater level. The impact of land use changes into settlements on groundwater level in the study area can be seen in Table 10.

In addition to changes in land use to settlements, from 2012 to 2021, there was also a change in land use to shrubs, covering an area of 199.43 hectares. According to the results of the comparative analysis between changes in land use and changes in the level of the groundwater table, in the areas that experienced changes in land use to shrubs, the groundwater level increased, becoming shallower, and shared a more profound decrease in groundwater levels. Only 4.10% of the

Table 10. The Impact of Land Use Change into Settlements on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Grassland to Settlements	-	-	-	-	-	-	-	-	-	-	0.59	100.00	0.59
Irrigated Rice Field to Settlements	-	-	6.37	9.33	-	-	-	-	-	-	61.95	90.67	68.32
Moor/ Lea to Settlements	-	-	2.57	6.80	-	-	0.09	0.25	1.68	4.45	33.46	88.50	37.81
Open Field to Settlements	-	-	-	-	-	-	5.37	49.79	2.01	18.63	3.41	31.59	10.79
Plantation to Settlements	0.08	0.17	10.13	20.97	-	-	0.04	0.08	2.46	5.10	35.58	73.67	48.29
Shrubs to Settlements	-	-	-	-	-	-	1.27	92.62	-	-	0.10	7.38	1.37
TOTAL	0.08	0.05	19.07	11.41	-	-	6.77	4.05	6.16	3.68	135.08	80.81	167.16

Source: Data Analysis (2023)

Table 11. The Impact of Land Use Change into Shrubs on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Grassland to Shrubs	-	-	-	-	-	-	-	-	-	-	2.15	100.00	2.15
Irrigated Rice Field to Shrubs	-	-	-	-	-	-	-	-	-	-	0.71	100.00	0.71
Open Field to Shrubs	-	-	-	-	12.19	6.24	37.62	19.25	8.18	4.19	137.44	70.33	195.42
Settlements to Shrubs	-	-	-	-	-	-	-	-	-	-	1.14	100.00	1.14
TOTAL	-	-	-	-	12.19	6.11	37.62	18.86	8.18	4.10	141.44	70.92	199.43

Source: Data Analysis (2023)

area where groundwater levels increased from 6-11 meters to <6 meters. This change occurred predominantly in open land areas that were changed into shrubs in 2021. Moreover, 18.86% of the area has an increase in groundwater level, from >11 meters to 6-11 meters. This change occurred to open land areas that changed into into shrubs in 2021.

The changes of land use to settlements also resulted in a more profound decrease in groundwater levels. About 6.11% of the areas experienced a significant decline in groundwater levels, from 6-11 meters to >11 meters. This change primarily has an impact on open land areas that changed into shrubs in 2021. This indicates that in the study area undergoing land use changes into shrubs, the impact on increasing groundwater levels is more significant than the impact on deeper groundwater levels. The effect of land use change to shrubs on groundwater levels in the study area can be seen in Table 11.

In addition to changes in land use to shrubs, from 2012 to 2021, there was also a change in land use to buildings covering an area of 0.19 hectares. Based on the results of the comparative analysis between changes in land use and changes in the level of the groundwater table, in the areas that experienced changes in land use to buildings, there were no changes in groundwater level. It shows no significant impact of land use change to buildings on changes in groundwater level in the study area. The effect of land use changes in buildings on groundwater levels in the study area can be seen in Table 12.

According to the analysis of land use change compared to changes in the depth of the groundwater table in the study area, there is an insignificant impact of land use change on changes in the level of the groundwater table. Changes in land use to grasslands have an impact on the increasing groundwater levels. The changes in land use to plantations involves reducing

Table 12. The Impact of Land Use Change into Buildings on Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Moor/ Lea to Buildings	-	-	-	-	-	-	-	-	-	-	0.19	100.00	0.19
TOTAL	-	-	-	-	-	-	-	-	-	-	0.19	100.00	0.19

Source: Data Analysis (2023)

Table 13. The Impact of Changes in Land Use Types on Groundwater Level Changes

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Land Use Change to Buildings	-	-	-	-	-	-	-	-	-	-	0.19	100.00	0.19
Land Use Change to Grassland	-	-	-	-	-	-	-	-	1.33	5.45	23.12	94.55	24.45
Land Use Change to Irrigated Rice Field	-	-	6.10	15.30	-	-	-	-	2.15	5.39	31.61	79.30	39.87
Land Use Change to Moor/ Lea	-	-	1.54	10.97	-	-	0.59	4.21	2.78	19.84	9.11	64.98	14.02
Land Use Change to Plantation	0.12	0.29	7.45	18.37	-	-	0.42	1.03	0.34	0.84	32.25	79.47	40.58
Land Use Change to Settlements	0.08	0.05	19.07	11.41	-	-	6.77	4.05	6.16	3.68	135.08	80.81	167.16
Land Use Change to Shrubs	-	-	-	-	12.19	6.11	37.62	18.86	8.18	4.10	141.44	70.92	199.43
No Land Use Change	8.61	0.40	170.48	7.93	46.31	2.15	47.60	2.21	54.92	2.56	1821.15	84.74	2149.07
Total	8.81	0.33	204.65	7.77	58.50	2.22	93.00	3.53	75.86	2.88	2193.96	83.27	2634.77

Source: Data Analysis (2023)

groundwater levels to be significantly deeper than increasing groundwater levels to be shallower. Changes in land use to irrigated rice fields substantially lowers groundwater levels compared to the effect on increasing groundwater levels..

Changes in land use to moors have an impact on increasing groundwater levels to be significantly shallower than affecting reducing groundwater levels to be more profound. Changes in land use to settlements have an impact on reducing groundwater levels to be considerably deeper than on increasing groundwater levels to be shallower. Changes in land use to shrubs have an impact on increasing groundwater levels to be significantly shallower than on decreasing the groundwater levels to be deeper. The effect of changes in land use types on the level of groundwater levels in the study area can be seen in Table 13.

According to the analysis of land use change, it shows that in part of the Cangkringan District, areas that experienced land use change have an impact on increasing and decreasing the groundwater levels. Ther were 9.58% of areas experiencing land use change have deeper groundwater levels. Meanwhile, 13.66% of areas experiencing land use changes also experienced increased groundwater levels. It shows that in the study area, changes in land use in the period 2012 to 2021 have a relatively greater impact on increasing groundwater levels compared to decreasing them. The effects are detailed in Table 14.

The groundwater depth zone affected by land use change in part of the Cangkringan District are areas with different land use types between 2012 and 2021, leading to increased or decreased groundwater levels. The study area has 112.89 hectares of affected zones. The analysis shows that the affected zone that experienced the most significant change in groundwater table levels was the area that experienced land use change to shrubs, reaching 51.37%. In addition, the second largest affected zone is an area that has experienced land use change to settlements, reaching 28.42%. The distribution of groundwater level affected zones detailed in Table 15.

Based on the overlay analysis of groundwater depth spatial information in 2012 and 2021, groundwater depth conditions in the study area were classified into three: the groundwater decrease, groundwater increase, and no change in groundwater depth. The spatial pattern of changes in groundwater depth in 2012 and 2021 can be seen in Figure 11. Based on the results of data analysis, shallower groundwater is found in in-depth classes of less than 6 meters and at depths of 6-11 meters.

Deepens groundwater occurs in the 6-11 m depth class and extends beyond 11 meters. At the same time, the depth of groundwater remains unchanged (fixed) across all groundwater depth classes. Based on the results of logical matching analysis, it is known that changes in land use do not significantly impact changes in groundwater depth in the study area. Changes in land use from the non-developed to developed areas do not result in a homogeneous impact on changes in groundwater depth. Groundwater in some locations does deepen due to changes in land use, but groundwater tends to remain stable and become shallower in others.

Table 14. The Impact of Land Use Change on Changes in Groundwater Level

Land Use Change from 2012 - 2021	Changes in the Groundwater Level												Total
	Groundwater decrease, from < 6 m to >11 m		Groundwater decrease, from <6 m to 6-11 m		Groundwater decrease, from 6-11 m to >11 m		Groundwater increase, from >11 m to 6-11 m		Groundwater increase, from 6-11 m to <6 m		No changes in groundwater level		
	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	Ha	%	
Area of Land Use Change	0.20	0.04	34.17	7.03	12.19	2.51	45.40	9.35	20.94	4.31	372.81	76.76	485.70
Area of No Land Use Change	8.61	0.40	170.48	7.93	46.31	2.15	47.60	2.21	54.92	2.56	1821.15	84.74	2149.07
Total	8.81	0.33	204.65	7.77	58.50	2.22	93.00	3.53	75.86	2.88	2193.96	83.27	2634.77

Source: Data Analysis (2023)

Table 15. The Distribution of Groundwater Level Affected Zones by Land Use Change

Land Use Change from 2012 - 2021	Groundwater Impacted Zone				Total
	Impacted Zone	% Impacted Zone	Unimpacted Zone	% Unimpacted Zone	
Land Use Change to Buildings	-	-	0.19	0.01	0.19
Land Use Change to Grassland	1.33	1.18	23.12	0.92	24.45
Land Use Change to Irrigated Rice Field	8.25	7.31	31.61	1.25	39.87
Land Use Change to Moor/ Lea	4.91	4.35	9.11	0.36	14.02
Land Use Change to Plantation	8.33	7.38	32.25	1.28	40.58
Land Use Change to Settlements	32.08	28.42	135.08	5.36	167.16
Land Use Change to Shrubs	57.99	51.37	141.44	5.61	199.43
No Land Use Change	-	-	2149.07	85.22	2149.07
Total	112.89	100.00	2521.88	100.00	2634.77

Source: Data Analysis (2023)

Researchers have previously stated that the effects of land-use change, especially from non-developed areas to developed areas, lead to deeper groundwater due to reduced infiltration and percolation (S. Kumar et al., 2021; Purawantara et al., 2019; Sajjad et al., 2022; Steward & Allen, 2016). However, in this study, land-use change did not negatively impact groundwater. This is due to several factors. The first study area has good rainfall with thick aquifer conditions consisting of pyroclastic material that can distribute water abundantly (Riasasi & Sejati, 2019; Sejati & Prayoga, 2023).

The distribution of groundwater depth zones affected by land use change in the study area can be seen in the following Figure 10. The changes in groundwater Depth in 2012 and 2021 can be seen in Figure 11.

Changes in land use are not the main factor causing the dynamics of groundwater depth. Based on literature studies, several factors have an impact on the dynamics of groundwater depth. These factors are grouped into factors that impact groundwater deepening and groundwater siltation (El Garouani et al., 2023; P. J. S. Kumar, 2022; Manny et al., 2016). Based on studies conducted on the Saiss Plain, Morocco, from 2005 to 2020, groundwater deepening occurred in residential areas far from rivers or irrigation canals. Massive utilization of groundwater in residential areas also causes deepening of groundwater. Siltation of groundwater occurs in people's wells around irrigated rice fields. Siltation happens because groundwater gets input from surface water flowing through irrigation canals. Rainfall factors also result in the dynamics of groundwater depth. Studies conducted in Tamil Nadu, India, show groundwater dynamics occur during the rainy and dry seasons (2016-2017). Groundwater levels in Tamil Nadu, India, mainly residential areas, tend to deepen when rainfall decreases. Still, wells located in agricultural regions experience siltation due to inputs from surface water used in irrigation systems (P. J. S. Kumar, 2022). Similar conditions also occur in parts of Yogyakarta, Indonesia. Yogyakarta City is included in the Yogyakarta-Sleman groundwater basin. Based on a study by Manny et al. (2016), decreasing rainfall and increasing residential areas only sometimes results in deeper groundwater. Groundwater in some locations in Yogyakarta City is shallow. Siltation of groundwater occurs in residential areas where there are sewage channels.

Impact of Rainfall Patterns and River Channels on Groundwater Depth

Groundwater dynamics in the study area are complex for periodic identification due to the absence of monitoring wells. Based on literature studies, the closest monitoring wells to the study area are located in the Pakem District, which is west of the study area (Razi et al., 2023). The groundwater level in the Pakem monitoring wells remained relatively high from 2018 to 2022. The difference between the shallowest and most profound groundwater depth is 3 meters (Razi et al., 2023). The dynamics of groundwater that did not change significantly due to monthly rainfall in 2018-2022 also did not change significantly, varying from 0 to 900 mm/month (Razi et al., 2023).

Based on the results of CHIRPS data analysis, annual rainfall in the study area varies (Figure 12).

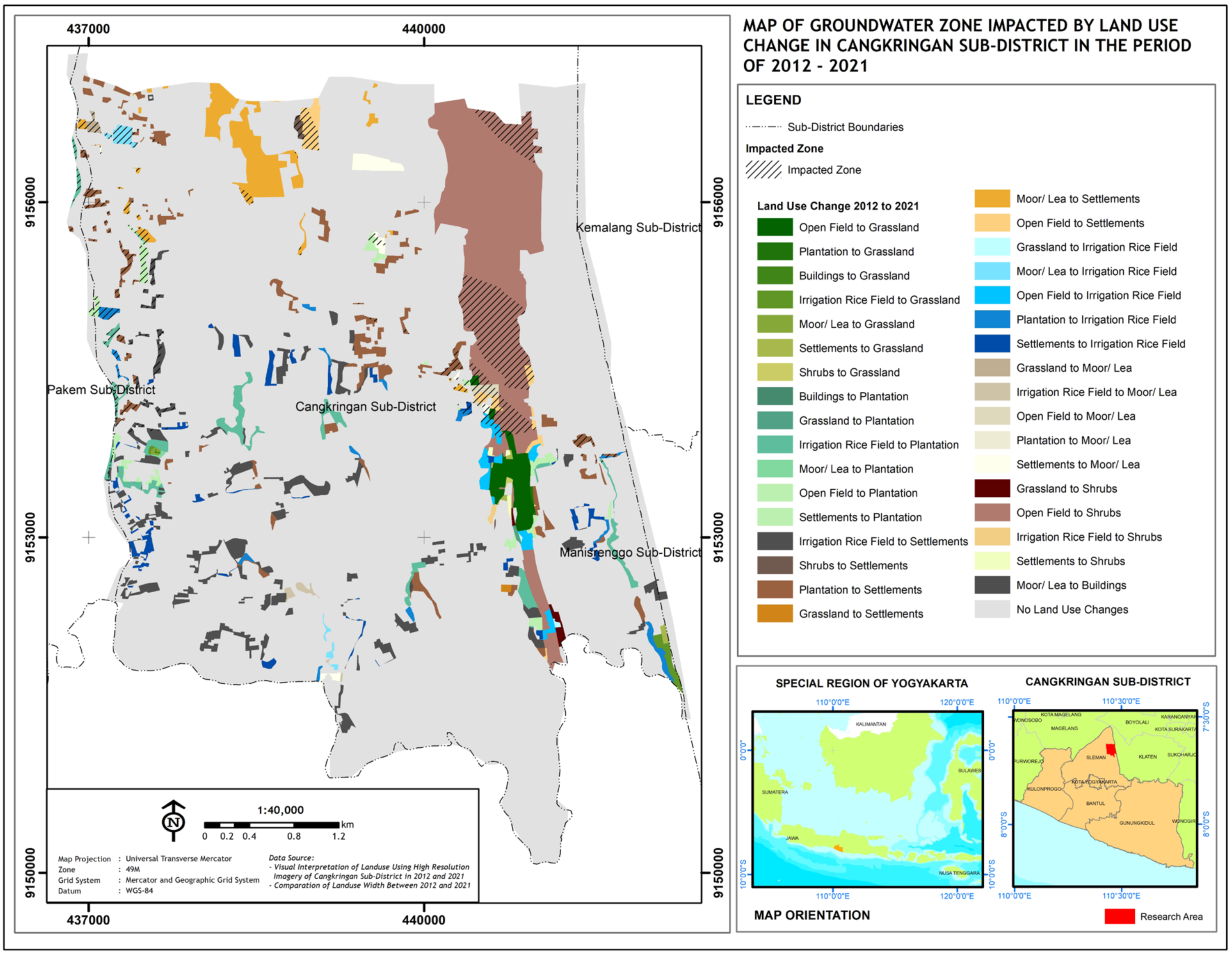


Figure 10. Spatial Pattern of Groundwater Zone Impacted by Land Use Change in 2012 and 2021.

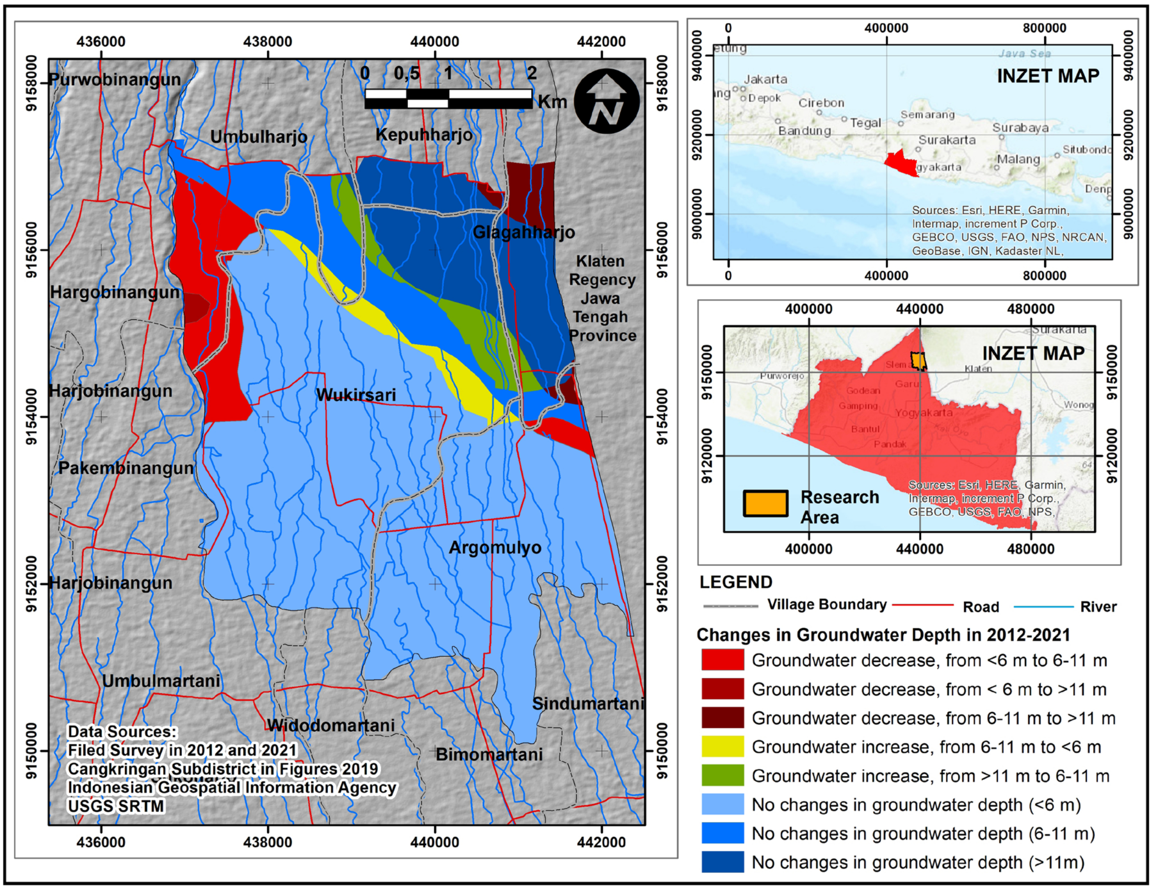


Figure 11. Changes in Groundwater Depth in 2012 and 2021

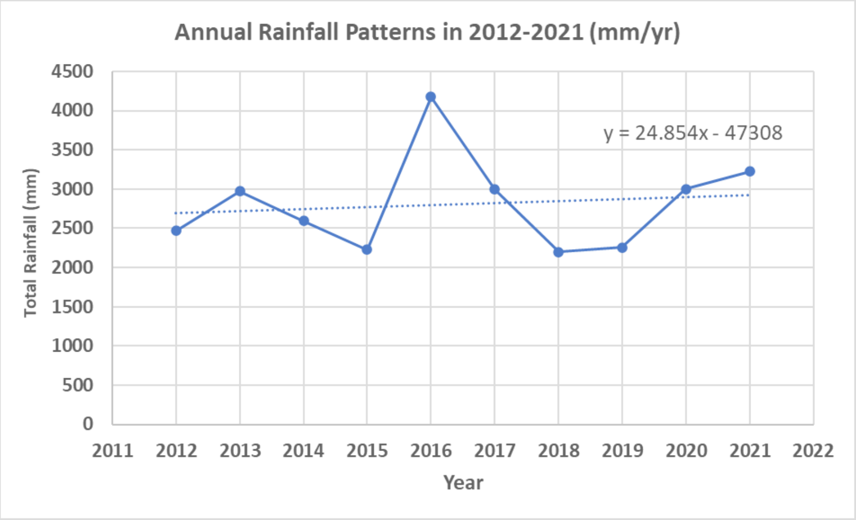


Figure 12. Annual Rainfall Patterns in 2012-2021 in the Research Area

The highest annual rainfall occurred in 2016, while the lowest occurred in 2018. The trend of yearly rainfall patterns from 2012 to 2021 has increased, although it was not significant. Increased annual rainfall does not cause groundwater in all locations to become shallower. There are locations where groundwater deepens. Groundwater deepening generally occurs when the land has changed from non-developed to residential areas. Massive groundwater utilization in residential areas causes the degradation of groundwater quality (Hendrayana et al., 2021; True Purba, 2021). Based on the image, It is also known that locations where groundwater increases in depth are only found in a few river channels. Based on the results of previous studies, river channels impact groundwater depth dynamics (El Garouani et al., 2023; P. J. S. Kumar, 2022). Surface water in river channels serves as an input for surrounding groundwater. Based on Figure 11, the study areas of which river channel tends to be tight does not experience groundwater deepening. Groundwater tends to remain and become shallower.

4. Conclusion

According to the results of the study, it is evident that the predominant type of land use in the study area in 2012 and 2021 was in the form of residential shrubs. Changes in groundwater depth in the study area in 2012 and 2021 were classified into three categories: fixed, deeper, and shallower.

Changes in land use in the study area did not significantly impact changes in groundwater depth. The results of the cross-tabulation analysis showed that 11.46% of the study areas experienced groundwater deepening, 7.73% experienced groundwater siltation, and 80.81% remain unchanged in groundwater depth. It was likely caused by the high rainfall in the study area; aquifer material in the study area also had an excellent ability to drain groundwater from the upper slopes of Merapi Volcano. Moreover, land use change had no significant impact on the dynamics of groundwater depth in the study area. Groundwater that deepens is found in areas where river flow patterns are sparse, while regions with fixed or increasingly shallow groundwater levels were characterized by denser river flow patterns.

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