Vol. 17 No. 1 (2026) 26-34

Jurnal Riset
Teknologi Pencegahan Pencemaran
Industri

Journal homepage: https://www.jrtppi.id

Evaluation Study of Critical Zones and Damaged Zones of Semarang City Groundwater Utilization Based on Geospatial Modeling

Widya Kurniawan*, Tri Retnaningsih Soeprobowati, Fahrudin

Universitas Diponegoro

ARTICLE INFO

Article history:
Received February 04, 2026
Received in revised form March 04, 2026
Accepted April 04, 2026
Available online May 04, 2026

Keywords:
Evaluation, Damaged Zone, Groundwater, Aquifer.

ABSTRACT

The Energy and Mineral Resources Office of Central Java Province has proposed the evaluation of the CAT Semarang-Demak groundwater conservation zone for the 2022 fiscal year. There it was announced that the evaluation in the Semarang-Demak Groundwater Watershed (CAT) in Semarang City, there is already a critical utilization zone (mera). Groundwater withdrawal, which tends to be more intensive over time, will have an impact on the quantity, quality, and carrying capacity of the local environment, and can lead to groundwater level subsidence and land subsidence. As an effort to fight and anticipate further environmental damage, groundwater management in Semarang City needs to be evaluated. This evaluation uses a geographic information system (GIS)-based approach method in making a spatial model of the damaged groundwater utilization zone in the Semarang City Groundwater Basin. This evaluation was carried out to determine the distribution and characteristics of the aquifer, hydrogeological conditions, groundwater and environmental conditions, groundwater protected areas, water needs for the community and its development. The results of the Evaluation, Mapping, and Analysis Study of Damaged Zones for Groundwater Utilization in Groundwater Catchment Areas in Semarang City can be used as a reference for the Central Java Provincial Government in making groundwater management policies according to its authority.

1. INTRODUCTION

The determination of utilization zones in Semarang City will certainly have an impact on the policy of prohibiting groundwater withdrawal, especially in the business sector. The dependence on clean water needs in Semarang City, most of which is still sourced from groundwater, so the zoning in the evaluation report of the Central Java Provincial Energy and Mineral Resources Office for the 2022 fiscal year needs to be updated in accordance with current actual conditions.

The fulfillment of clean water needs in Semarang City has become a serious problem, especially since the issuance of the Decree of the Minister of Energy and Mineral Resources Number 259.K/MEM. G-GL 01/2022 concerning Standards for the Implementation of Groundwater Exploitation Permits. The regulation explains that in critical and damaged utilization zones, new groundwater exploitation permits are no longer allowed and in the process of extending the groundwater discharge will be reduced to 50% of the previous permit discharge. The determination of groundwater utilization zones in Semarang City as critical and damaged zones can have an impact on the sustainability of community and industrial activities in Semarang City because the need for clean water sources in Semarang City is increasing from time to time. In this case, the zoning of groundwater use that has been determined needs to be evaluated whether the zoning that has been determined is in accordance with current conditions or not.

*Correspondence author.
E-mail: w.kurniawan87@gmail.com (Widya Kurniawan)
doi: https://doi.org/10.21771/jrtppi.2026.v17.no1.p1-19

Accreditation number: (Ristekdikti) 158/E/KPT/2021

Kendal Regency, Semarang Regency, Demak Regency, Grobogan Regency, Blora Regency, and Semarang City are part of the Semarang-Demak Groundwater Watershed (CAT). Based on the Regulation of the Minister of Energy and Mineral Resources No. 2 of 2017 concerning Groundwater Watersheds, where groundwater basins are areas limited by hydrogeological boundaries, where all hydrogeological events occur such as the process of refueling, draining, and releasing groundwater. Groundwater that can be used by the people of Semarang City is sourced from 2 (two) groundwater, namely: free groundwater or shallow soil, and depressed groundwater or deep groundwater. Groundwater in the city of Semarang comes from replenishment from the Ungaran mountains in the west which flows following the flow pattern of the Garang watershed and in the east which flows according to the flow pattern of the Babon watershed. Meanwhile, free groundwater or shallow groundwater comes from rainfall that falls above Semarang City, so the potential is greater, and most (80%) of the people of Semarang City take advantage of this type of free groundwater, because in addition to being easy and cheap to get it, the quality is also better (Noviana, 2017). The northern part of Semarang City is generally a fairly large plain and formed by alluvial deposits, while the southern part is Quaternary volcanic sedimentary rocks produced by G. Ungaran activity and Tertiary sediments

In response to these problems, the government through the Ministry of Energy and Mineral Resources has established a zoning-based groundwater management policy, as stipulated in the Regulation of the Minister of Energy and Mineral Resources Number 31 of 2018 concerning Guidelines for the Determination of Groundwater Conservation Zones. This policy aims to control the use of groundwater through the division of safe, vulnerable, critical, and damaged zones. The implementation of the policy at the regional level is realized through the preparation and evaluation of groundwater conservation zones in each groundwater basin, including the Semarang-Demak CAT which has been evaluated by the Central Java Provincial Energy and Mineral Resources Office.

Although the evaluation report of the CAT Semarang-Demak groundwater conservation zone prepared by the Energy and Mineral Resources Office has provided a zoning map as a basis for management, the rapid hydrogeological dynamics and the ongoing rate of soil subsidence indicate that the zoning needs to be evaluated and updated periodically. Changes in groundwater table conditions, increasing utilization pressures, and the development of geospatial monitoring technology demand a more comprehensive and adaptive evaluation approach to actual conditions and future projections.

A number of previous studies have examined groundwater subsidence and landslides in Semarang City with various approaches, such as groundwater trend analysis, simple modeling, and the use of remote sensing data. However, some of these studies still have limitations, including the use of temporal data, the integration of InSAR-based land subsidence data with hydrogeological data simultaneously, and the absence of geospatial modeling that is able to project the development of groundwater conservation zones in the future. Thus, the relationship between groundwater dynamics, soil subsidence, and its implications for changes in groundwater conservation zones has not been fully answered comprehensively.

Based on these conditions, a study is needed that not only re-evaluates groundwater conservation zones based on applicable regulatory provisions, but also integrates groundwater level data, InSAR-based land subsidence data, and geospatial modeling to produce an overview of existing conditions and projections of the development of groundwater conservation zones. This approach is expected to provide a stronger scientific basis in supporting sustainable groundwater management policies in Semarang City, especially in efforts to mitigate land subsidence and environmental degradation.

The purpose of the research is to update the map and analyze the damaged zones of groundwater utilization from the Map of Groundwater Utilization and Conservation Zones in the Semarang-Demak Groundwater Basin (CAT) in Semarang City in 2022 based on indicators of groundwater level subsidence and groundwater quality (Minister of Energy and Mineral Resources No. 31 of 2018). Projecting the development of damaged zones for groundwater utilization in Semarang City based on the comparison of groundwater level subsidence and geospatial analysis. Determine the relationship between land subsidence and groundwater subsidence to determine the relationship between

the subsidence parameters and the development of damaged zones for groundwater utilization. Formulate groundwater policy recommendations in order to minimize groundwater level decline due to excessive groundwater utilization.

2. METHODS

This study uses a quantitative-spatial approach with a geospatial analysis method based on Geographic Information System (GIS) to evaluate and remap groundwater conservation zones in Semarang City, especially in the Semarang-Demak Groundwater Basin (CAT) area. The evaluation is carried out by integrating indicators of groundwater level conditions, groundwater quality, land subsidence, and changes in environmental conditions, in accordance with the provisions of the Minister of Energy and Mineral Resources Regulation Number 31 of 2018. The data used consists of primary and secondary data. Primary data includes groundwater levels from selected monitoring wells and groundwater quality in the form of Total Dissolved Solid (TDS) and Electrical Conductivity (DHL) values obtained through field measurements. The sample wells were selected using the purposive sampling method by considering the geographical distribution of the northern, central, and southern regions of Semarang City, the type of aquifer (free and depressed), the availability of continuous historical data, and the variation in groundwater utilization pressure in residential, industrial, and mixed areas. Meanwhile, secondary data includes historical groundwater level data from related agencies, InSAR-based land subsidence data, geological and hydrogeological maps, administrative boundaries, and previous zoning evaluation reports. Secondary data validation is carried out through coordinate system alignment, temporal conformity checks, and cross-comparison with primary data to ensure data consistency and reliability.

Data processing and analysis are carried out using ArcGIS software through the stages of spatial interpolation, parameter classification, weighting, and overlay analysis. Groundwater level point, TDS, DHL, and subsidence data were interpolated using the Inverse Distance Weighting (IDW) method to produce a continuous distribution map depicting the hydrogeological conditions of the study area. Furthermore, each parameter is classified into safe, vulnerable, critical, and damaged categories, then normalized and weighted according to the weighting matrix of the Minister of Energy and Mineral Resources Regulation No. 31 of 2018. The weighted parameter maps are integrated using the weighted overlay technique to produce an evaluation map of existing groundwater conservation zones and a remapping zoning map that reflects actual conditions. In addition, correlation analysis and linear regression were carried out to examine the relationship between groundwater subsidence and land subsidence, as well as projections of the development of conservation zones based on temporal trends of historical data. The results of the analysis are then evaluated for their suitability with the applicable policy provisions, so that they can be used as a basis for recommendations for more adaptive and sustainable groundwater management.

In the results and discussion section, the interpretation focuses not only on presenting the broad tabulation values of conservation zones, but also emphasizes comparative analysis between periods to identify the dynamics of zoning changes in more depth. The results of the remapping showed an increase in the area of critical zones and damaged zones compared to the previous zoning, especially in areas with consistent trends in groundwater level decline and high rates of land subsidence, such as the northern and central parts of Semarang City. On the other hand, safe zones and vulnerable zones tend to be relatively stable, so the increase in critical and damaged zones reflects the pressure on groundwater utilization that is structural and sustainable. Change analysis also takes into account the relative percentage change, thus providing a more accurate picture of the extent of degradation of groundwater conditions compared to using only absolute area.

To identify the factors that contribute to zoning change, an analysis of the contribution of the driving factors was carried out using a correlation and regression approach, with zoning scores as dependent variables, as well as groundwater subsidence, InSAR-based land subsidence rates, and groundwater quality (TDS and DHL) as independent variables. The results of the analysis show that groundwater subsidence is the dominant factor influencing the shift in conservation zones, with a greater contribution than changes in groundwater quality. In addition, the

rate of land subsidence acts as a reinforcing factor that accelerates the transition to more critical conditions, especially in areas with depressed aquifer systems. Thus, this analysis is able to quantitatively separate the contribution of each factor, thereby providing a more comprehensive understanding of the mechanism of changing groundwater conservation zones and supporting the formulation of more targeted management policies.

3. RESULT AND DISCUSSION

Evaluation of Damaged Zones for District-Based Groundwater Utilization in Semarang City and recommendations

Based on the 2025 Semarang City Groundwater Utilization Zoning Map and the 2022 Semarang City Groundwater Utilization Zone Map, it is known that there are changes in zoning and its area, especially in the damaged zone. Zones that are damaged in groundwater utilization will certainly affect groundwater management policies. The occurrence of damaged zones is characterized by extreme groundwater level subsidence (MAT), increased concentrations of solutes (such as chloride or TDS) due to seawater intrusion, and damaging environmental impacts such as *subsidence*. Given that these zones have exceeded the aquifer's carrying capacity threshold, normal interventions are no longer adequate, so *special urgent treatment* is required that includes a total ban on new groundwater withdrawals, progressive discharge reductions or cessations of use for existing users, and the implementation of restoration programs such as the construction of artificial injection and recharge wells that serve to return surface water to damaged aquifers. Its main goal is to prevent broader infrastructure losses, restore freshwater reserves, and secure the sustainability of water resources.

The efforts that have been made from 2022 to 2025 will affect zoning changes. If viewed on a more micro scale (per sub-district), then the change in the area of the damaged zone for groundwater use will be seen that there is an addition of sub-districts that have damaged zones for groundwater use. The addition of sub-districts with damaged zones is also followed by a reduction in damaged zones and the addition of critical zone areas which indicates that the gradual efforts made are good enough. The area of damaged zones for groundwater use starting in 2022 has decreased. The change in damaged zones in groundwater utilization from 2022-2025 can be seen in table 18 and figure 18.

Table 1.
Changes in the Area of Damaged Zones for Groundwater Utilization in Semarang City in 2022 and 2025

Yes	Broken Zones in 2022			Broken Zone in 2025		
	Districts	Width	%	Districts	Width	%
1	Fat	15,430251	45,69%	Fat	5,24	20,12%
2	Gayamsari East	3,905382	11,56%	Gayamsari East	1,56	6,00%
3	Semarang Central	4,184886	12,39%	Semarang Central	2,28	8,77%
4	Semarang North	0,172855	0,51%	Semarang North	1,75	6,72%
5	Semarang South	4,182486	12,39%	Semarang South	10,59	40,68%
6	Semarang West	0	0,00%	Semarang West	0,05	0,18%
7	Semarang	0	0,00%	Semarang	0,21	0,79%
8	Spraying	5,893143	17,45%	Spraying	4,36	16,75%
	Quantity	33,769003	100,00%	Quantity	26,03	100,00%

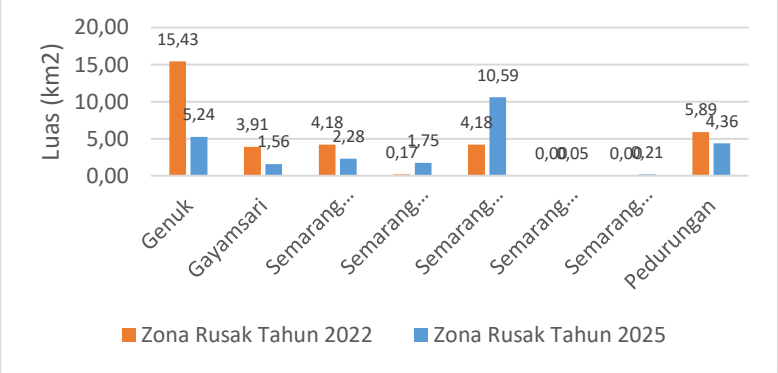

Figure 1. Comparison of Groundwater Utilization Zoning Areas in 2022 with 2025

The sub-district level groundwater utilization zone (AT) in Semarang City shows worrying dynamics of change between the projections for 2022 and 2025. The AT utilization zones are generally divided into Safe Zones, Vulnerable Zones, Critical Zones, and Damaged Zones. In 2022, several sub-districts in the Lower Semarang area (e.g. North Semarang and Genuk) have been identified as Critical and Damaged Zones due to

Groundwater Level Reduction (MAT) and severe seawater intrusion, driven by high industrial and domestic demand. Meanwhile, the southern region tends to still be included in the category of Safe or Vulnerable Zones, which function as the main remuneration area of the Groundwater Watershed (CAT).

As a result, in 2025 there will be a decrease in the area of Damaged Zones in 2025 compared to 2022, followed by an increase in critical and vulnerable zones. In 2022 the Damaged Zone covers only 10% of the total area of the CAT, by 2025 the area is estimated to have been reduced to 6.5%. This change shows that the rate of groundwater extraction in the 2022-2025 period has set existing provisions and limits so that the groundwater system in Semarang City is not damaged.

The reduction in the area of the Damaged Zone by 2025 shows a reduction compared to 2022 is an indicator of the significant success of the implementation of strict groundwater conservation policies (such as permit restrictions and diversion of water sources) as well as the technical improvement programs carried out. Positive implications of this trend include stabilizing the rate of *land subsidence* in some areas and the gradual restoration of groundwater quality from seawater intrusion.

Nonetheless, the threat to the sustainability of water resources is still high. Coping strategies going forward should focus on institutionalization measures that have been successful, such as maintaining a permanent ban on drilling new wells in areas of former Damaged Zones and Critical Zones. Then it is hoped that the community will continue to comply with groundwater management policies in damaged zones, including the prohibition on granting new permits for groundwater exploitation. Meanwhile, applications for the extension of existing permits will only be granted a maximum of 50% of the debris previously permitted. In addition, the applicant is required to build an infiltration well as a form of contribution to groundwater conservation.

Correlation of Groundwater Level Decline with Soil Level Degradation

Groundwater subsidence in major cities tends to experience a consistent decline from year to year. Semarang City is one of the cities that receives special attention related to groundwater problems because its condition is quite severe even compared to other big cities. Data related to changes in the groundwater level of Semarang City from 2021 to 2023 shows a consistent trend of groundwater level decline presented in the figure.

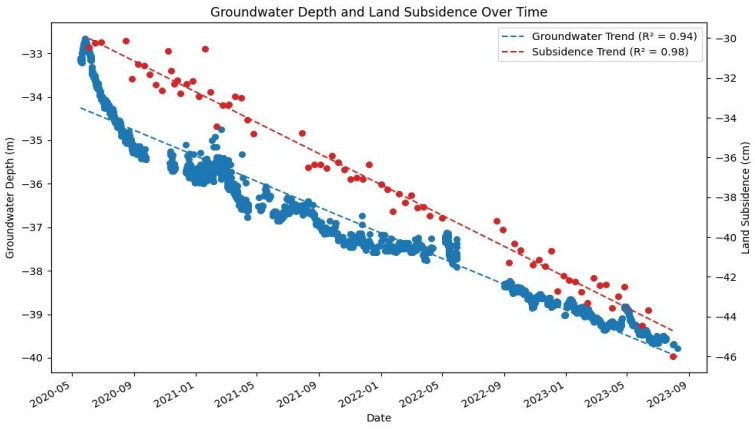

Figure 2. Graph of groundwater subsidence and MAT subsidence before projection (Geosystem and Geoenvironment)

The chart above shows a chart that has not yet been projected on the Groundwater Level (MAT) trend. Then projections are carried out using the Simple Linear Regression method to predict the depth conditions of the MAT in the future as a scientific basis to determine the potential of new Fault Zones. In addition, this graph can estimate the value of land subsidence in the next few years, as in 2026 it is estimated that land subsidence will reach 44 cm from the initial condition.

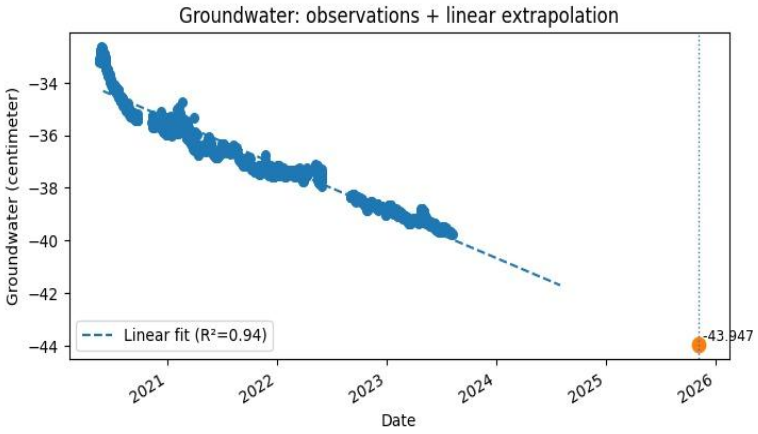

Figure 3. Groundwater level decline trend after projection

Land subsidence is also a hot issue in Semarang City and also always experiences consistent land subsidence from year to year. Based on the processing of InSAR data from 2021 to 2023, it was found that areas in Semarang City experienced land

subsidence along with the range of land subsidence values per year. Based on data processing related to land subsidence several years earlier, a trend was obtained that showed a significant decrease every year and it is estimated that by 2026 the land subsidence will reach 55 cm from the original land height presented in the figure.

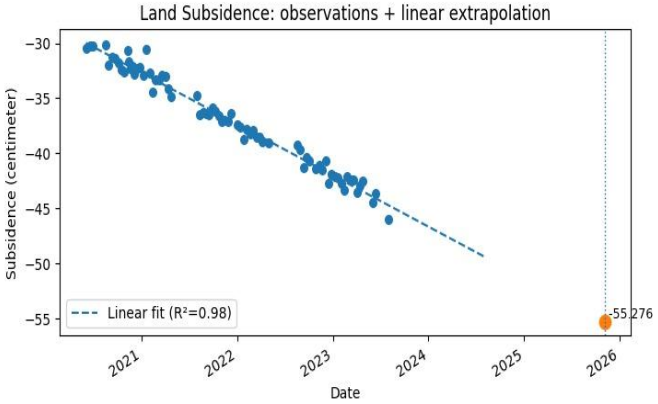

Figure 4. Land subsidence trend from 2022 – 2025

The phenomenon *of land subsidence* has a very close relationship in determining the Damaged Zone in the Groundwater Watershed (CAT). The decline in MAT, triggered by the exploitation of groundwater beyond natural regeneration capabilities, causes the hydrostatic pressure in the aquifer layer to decrease. This void forces the sedimentary layers (clay and mud) between the aquifers to compact (*compaction*). This condition is in line with the city of Semarang with its geological conditions which tend to be dominated by alluvium deposits in the form of materials released by sand, clay, and mud. The loose material then experiences pressure which then triggers *soil subsidence*. Therefore, *land subsidence* is not the cause, but rather the visual and geological impact of the damage to the groundwater system. Therefore, the relationship between groundwater level subsidence and land subsidence is interrelated, which is shown by the same downward trend in Figure 22. Thus, it can be concluded that the trend of land subsidence in this study area can be one of the parameters that indicate the condition of groundwater level subsidence.

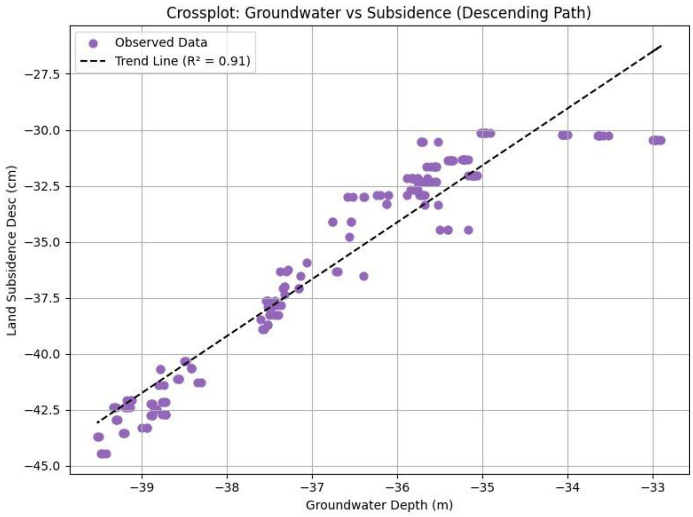

Figure 5. Correlation of face drop and groundwater level subsidence in Semarang City in 2020 - 2023

Groundwater utilization zones are classified as Critical Zones or even Damaged Zones when the rate of MAT decline and *land subsidence* reaches a threshold that endangers infrastructure and the environment. This linkage requires local governments to make land *subsidence data* one of the main and most important indicators in mapping and determining the boundaries of Damaged Zones, so that countermeasures can be directly focused on controlling groundwater withdrawal in the zone.

From the data that has been projected using the linear regression formula and groundwater level subsidence which is then correlated with both, it is estimated that in 2026 the MAT will drop to 44 cm and the land subsidence to 55 cm.

Groundwater Management Policy Model Based on Evaluation Results

The results of the evaluation of the groundwater utilization zone in 2022–2025 show that Semarang City is still in a condition that requires special attention to groundwater exploitation. Although the area of the Damaged Zone decreased from 10% in 2022 to 6.47% in 2025, the increase in the Vulnerable and Critical zones shows that the pressure on the aquifer system is still ongoing. Linear regression projections show that by 2026 groundwater levels are expected to decrease by ±44 cm and land level drops reach ±55 cm. The results of the correlation analysis between groundwater level subsidence and subsidence showed a

strong positive relationship, confirming that groundwater exploitation is the dominant factor that triggers sediment compaction and soil subsidence.

Based on these findings, it is necessary to formulate a management policy that is oriented towards short-term and sustainable mitigation. The following policy is formulated by considering the hydrological conditions, geological characteristics of Semarang City, changes in the zoning of groundwater utilization, and the geological impacts that have been identified.

Zone-Based Groundwater Withdrawal Control Policy

This policy is prepared based on the level of aquifer damage and the zoning status of groundwater utilization. This arrangement aims to reduce pressure on critical areas, control exploitation, and accelerate the recovery of aquifer systems.

1. Broken Zone
   a. Prohibition on issuing new permits for industrial, commercial, and other large facilities.
   b. The restriction on permit renewal is only given a maximum of 50% of the previous release.
   c. The obligation to install infiltration wells or *refill wells* to increase local remuneration.
   d. Divert water sources of all large users to PDAM or surface water networks.
2. Critical Zone
   a. Restrictions on the issuance of new permits are only for essential needs.
   b. Groundwater level monitoring is carried out every three months.
   c. The setting of disincentive tariffs for large users to suppress groundwater extraction.
3. Vulnerable Zones and Safe Zones
   a. Groundwater extraction is allowed with the obligation to install a *digital flowmeter*.
   b. Usage reporting every six months.
   c. Development of green infrastructure such as biopores, infiltration pathways, and green open spaces to strengthen natural refineries.

Policy of Transferring Water Source Consumption to PDAM

The results of the study show that the reduction of damaged zones by 2025 is related to the increase in water utilization of PDAM. Some of the policies that need to be implemented are:

1. Strengthening the capacity of PDAM in the downstream Semarang area, especially industrial areas.
2. The obligation to use *a hybrid scheme* with a minimum portion of 70% PDAM and a maximum of 30% groundwater, is gradually lowered for the Critical Zone and stopped in the Damaged Zone.
3. Provide tariff incentives for industries that have fully switched to PDAM.

GIS and InSAR Based Integrated Monitoring Policy

This policy utilizes GIS and InSAR-based technology to assess changes in groundwater and soil surface spatially. This policy is important for the long term because geological and hydrological changes are dynamic. The things that can be monitored through this study are:

1. Monitoring of soil deformation using InSAR is carried out periodically every semester.
2. Integration of all MAT data, water quality, and subsidies into the geospatial information system of local governments.
3. The determination *of the trigger value* is in the form of:
   a. Decrease in MAT >20 cm/year → reclassification zone
   b. Land subsidence >6 cm/year → is categorized as an area with a high risk of damage.

Technical Engineering Policy (Geological Remediation)

Technical measures are needed to improve the condition of the aquifer and reduce the rate of land subsidence, namely:

1. The implementation *of mass recharge wells* in the zone showed a strong correlation between MAT decline and soil subsidence.
2. Optimizing *rainwater harvesting* integrated with urban drainage.
3. Restrictions on the construction of high-rise buildings in highly subsidized areas such as North Semarang and Genuk.

Law Enforcement and Public Engagement Policy

The following policies emphasize the importance of law enforcement and community participation, namely:

1. Enforcement of administrative sanctions against users who do not report groundwater use or manipulate data.
2. Community involvement in groundwater conservation programs through education and corporate CSR.
3. The creation *of a web-based early warning system* to provide information on land subsidence to the community.

Table 2.
Semarang City Groundwater Management Policy Model Matrix

Zone	Key Issues	Policy Objectives	Technical Policy	Regulatory Policy/ Administration	Expected Output
Damaged Zone	High MAT reduction, subsidy >6 cm/year	Aquifer restoration and damage termination	Infiltration wells, refill wells, surface load limiting	Ban on new permits, 50% restriction on layoffs, full transition to PDAM	Hydrostatic pressure recovery and soil stabilization
Critical Zones	Significant decline in MAT, subsidy risk	MAT shrinkage rate control	Infrastructure Monitoring, Infrastructure	New permit restrictions, disincentive levels	Reducing exploitation pressure
Vulnerable Zones	Gradual downtrend of MAT	Prevention of entering the Critical Zone	Installation of flowmeter, biopore, RTH	6-month periodic reporting	Groundwater level stability
Safe Zone	Remuneration is still sufficient	Long-term conservation	Artificial infiltration, RTH protection	Handling of light permits	Balance of aquifer systems
All Zones	Poor data quality and controls	Integrated management	InSAR and GIS Periodic Dashboard	Law enforcement, electronic reporting system	Continuous monitoring system

Comparative Interpretation of Zoning Change

The results of the remapping not only show a recurrence of the tabulation values of zone changes (safe, vulnerable, critical, and damaged), but also indicate a significant shift when compared to zoning in the previous period. Comparatively, there was an increase in the area of critical zones and damaged zones, while safe zones and vulnerable zones were relatively more stable. The most prominent changes were identified in areas with consistent trends in groundwater level and high rates of land subsidence, especially in the northern and central parts of Semarang City. When analyzed based on inter-period comparisons, the increase is not only seen from the absolute area, but also from the percentage of relative change, which indicates that there is a structural and sustainable pressure on groundwater utilization, not just temporary fluctuations.

To understand the causes of zone shifts in more depth, an analysis of the contribution of driving factors was carried out using a quantitative approach through correlation and regression. The independent variables used include groundwater subsidence, the rate of land subsidence based on InSAR data, and groundwater quality represented by TDS and DHL values, while the dependent variables are in the form of groundwater conservation zoning scores. The results of the analysis show that groundwater level subsidence is the dominant factor that affects zoning changes, with a greater contribution than the groundwater quality factor. In addition, the rate of land subsidence has been shown to reinforce these impacts, especially in areas with depressed aquifer systems, thereby accelerating the transition from vulnerable zones to critical and damaged zones.

However, the projection of the development of groundwater conservation zones in this study is based on the assumption of the sustainability of historical trends, so it contains a certain degree of uncertainty. This uncertainty is influenced by various factors, such as changes in groundwater management policies, variations in pumping intensity, and regional development dynamics that can significantly affect hydrogeological conditions. Therefore, the results of the projections obtained are more accurately understood as indicative scenarios that describe the possible direction of development of groundwater conservation conditions, rather than as a deterministic or definite prediction.

CONCLUSION

Based on the results of the research conducted with the title "Evaluation Study of Critical Zones and Damaged Zones for Groundwater Utilization of Semarang City Based on Geospatial Modeling", it can be concluded as follows:

1. There has been a change in the zoning of groundwater use in Semarang City based on changes in intake discharge, changes in water surface position, and changes in groundwater quality, as well as the rate of land subsidence. In 2025, the groundwater utilization zone will be divided into 4 zones, namely the safe zone with an area of 187.7 km2 or 55.94%, the vulnerable zone with an area of 77.91 km2 or 23.22%, the critical zone with an area of 48.24 km2 or 14.38%, and the damaged zone with an area of 21.7 km2 or 6.47% of the total area of Semarang City.
2. The change in the groundwater utilization zone in Semarang City increased by 42 km2, the area of vulnerable zones increased by 54.9 km2, the area of critical zones increased by 23.05 km2, and the area of damaged zones decreased by 12.07 km2. If the policy is still adhered to by the community, the damaged zones will be reduced in the next few years
3. To reduce the addition of damaged zones or reduce damaged zones, policies can be implemented including a ban on granting new permits for groundwater exploitation. Meanwhile, applications for the extension of existing permits will only be granted a maximum of 50% of the debris previously permitted. In addition, the applicant is required to build an infiltration well as a form of contribution to groundwater conservation.
4. Based on the correlation graph between groundwater level subsidence and subsidence in Figure 22, it can be seen that the two variables show a positive relationship. This means that the greater the groundwater level subsidence (MAT), the greater the value of land subsidence that occurs. The trend pattern of the two shows alignment, where the decrease in hydrostatic pressure due to the decrease in MAT triggers the commotion of the sediment layer, so that the soil surface also decreases. This correlation reinforces that land subsidence is not a stand-alone phenomenon, but rather a direct geological response to the degradation of aquifer systems due to overexploitation of groundwater. Thus, the decrease in MAT contributes significantly to the acceleration of the rate of land subsidence in Semarang City
5. Policies that need to be carried out based on the 2025 groundwater utilization zone are, controlling groundwater intake based on zones, transferring water source consumption to PDAM, integrated monitoring based on GIS and InSAR, technical engineering policies, as well as law enforcement and community involvement. This aims to restore a more balanced groundwater system and reduce the effects of face drop and groundwater level drop

REFERENCES

Arofah, T. T., Awaluddin, M., and Nugraha, A. L. 2017. Analysis of the Distribution of Modern Minimareket Based on Sig (Geographic Information System) in Kudus Regency. Journal of Geodesy Undip October 2017, 6(6), 1–8.

Ammar, A., Askar, Munir H.B., A., & Sahara. 2022. Analysis of Groundwater Conservation Zone Mapping in South Sulawesi Province Using the Qgis Application. Jft: Journal of Physics and Its Applications, 9(1), 55-64. https://doi.org/10.24252/jft.v9i1.26495.

Bertrand, G., Petelet-Giraud, E., Cary, L., Hirata, R., Montenegro, S., Paiva, A., Mahlknecht, J., Coelho, V., & Almeida, C. 2022. Describe the risk of groundwater contamination in southern coastal metropolitan cities through the application of environmental geochemical and social data in decision trees and geographic information systems. Water Research, 209: p.117877. https://doi.org/10.1016/j.watres.2021.117877

Bouderbala, A. 2020. Groundwater quality assessment of coastal alluvial aquifer Wadi Hachem, Tipaza, Algeria. Environmental and Socio-Economic Studies, 8(4): 11–23. https://doi.org/10.2478/about-2020-0020

Box, G.E., & Jenkins, G.M. (1976). Time Series Analysis: Forecasting and Control. Holden Day.

International Treatment. 2019. Handbook of Climate Vulnerability and Capacity Analysis Version 2.0: Informing Community-Based Adaptation, Resilience, and Gender Equality.

Energy and Mineral Resources Office of Central Java Province. 2022. Evaluation of Groundwater Utilization and Conservation Zones in Semarang-Demak Groundwater Basin (CAT), CAT Pekalongan-Pemalang, CAT Karanganyar-Boyolali.

Energy and Mineral Resources Office of Central Java Province. 2022. Evaluation of Groundwater Utilization and

Conservation Zones in Semarang-Demak Groundwater Basin (CAT), CAT Pekalongan-Pemalang, CAT Karanganyar-Boyolali.

Semarang City Spatial Planning Office. 2024. Regional Long-Term Development Plan 2025-2045.

Ferretti, A., Prati, C., & Rocca, F. (2001). Permanent diffusers in SAR interferometry. IEEE Transactions on Geoscience and Remote Sensing, 39(1), 8–20. https://doi.org/10.1109/36.898661

Ghazavi, R., and Ebrahimi, Z. 2015. Assessing Groundwater Vulnerability to Contamination in Dry Environment Using DRASTIC and GOD Models. International Journal of Enviro Science Technology. 12, 2909-2918.

Ghosh, S. 2019. Access to Water and Sanitation is Not Enough, but Its Management to End the Crisis. IJSR, 8(2): 80-82. https://www.ijsr.net/archive/v8i2/ART201 94883.pdf

Hendrayana, H. 2012. Introduction to Groundwater Modeling. Department of Geological Engineering, Faculty of Engineering, Gadjah Mada University, Yogyakarta.

EIGHT. 2020 . Progress report The results of monitoring land subsidence in several major cities on the island of Java based on remote sensing satellite data Pengertian.

Montgomery, D.C., & Runger, G.G. (2014). Applied Statistics and Probabilities for Engineers (6th edition). John Wiley & Sons.

Morris, B.L., Lawrence, A.R., Chilton, P.J., Adams, B., Calow, R.C., and Klinck, B.A. (2003). Groundwater and its susceptibility to degradation: A global assessment of the problem and options for management. Early Warning and Assessment Report Series, RS.03-3. United Nations Environment Programme, Nairobi, Kenya; p. 140.

Noviana, A. (2017). Groundwater Potential of Semarang City. Journal of the Bogor Agricultural University.

Semarang City Government. (2021). Semarang City Regional Spatial Plan 2011-2031.

Semarang City Government. (2024). Regional Long-Term Development Plan for 2025-2045.

Purnomo, S. N. & Lo Weicheng. (2021). Groundwater Modeling in Urban Development to Achieve Groundwater Resource Sustainability: A Case Study of Semarang City, Indonesia. Air MDPI, vol. 13, 1395. https://doi.org/10.3390/w13101395

Putranto, T.T., Widiarso, D.A., Yuslihanu, F. (2016). Study of Groundwater Vulnerability to Contaminants Using Drastic Methods in Pekalongan City. Engineering, 37(1): 26-31. https://doi.org/10.14710/teknik.v37i1.9637

Srinivas, R., Bhakar, P., & Singh, A.P. (2015). Groundwater quality assessment in selected areas of Rajasthan, India uses fuzzy multi-criteria decision-making tools. International Conference on Water, Coastal and Marine Engineering Resources (ICWRCOE 2015). Elsevier Inc. United States. https://doi.org/10.1016/j.aqpro.2015.02.129

Sound. (2017). Dangers of Groundwater Pumping on Soil Subsidence in Soft Soil Layers. Proceedings of Symposium II – UNIID 2017 e-ISBN: 978-979-587-734-9

Wardhana, R.R., Warnana, D.D., & Widodo, A. (2017). Investigation of Seawater Intrusion in Groundwater with 2D Resistivity Method in East Surabaya Area. ITS Engineering Journal, 6(1): C18-C83.

Waruwu, M. (2023). Educational research approach: qualitative research method, quantitative research method and combination research method (Mixed Method). Journal of Tambusai Education, 7(1), 2896–2910.

Yuwono, B. D. (2013). Correlation of Land Degradation with Groundwater Degradation in Semarang City. Diponegoro University. Journal of TEKNIK – Vol. 34 No.3 of 2013, ISSN 0852-1697 188.