International Journal of Electrical Engineering, Mathematics and Computer Science

E- ISSN: 3048-1945
P- ISSN: 3048-1910

Analysis of the Impact of Urban Sprawl on Groundwater Reserves in Kendari City Using Google Earth Engine (2000–2024)

Asramid Yasin* [1]

[1] Environmental Science Study Program, Universitas Halu Oleo, Kendari City, Indonesia
Email: asramidyasin@uho.ac.id

Abstract : This study analyzes the impact of *urban sprawl* on groundwater reserves in Kendari City using *the platform Google Earth Engine* (GEE) with analysis period of 2000 and 2024. *Urban sprawl* is characterized by an increase in built-up land area estimated through *the Normalized Difference Built-Up Index* (NDBI), while groundwater reserves are projected through estimated *baseflow groundwater runoff* obtained from FLDAS (*Famine Early Warning Systems Network Land Data Assimilation System*) data. The results show a significant increase in NDBI values from 2000 to 2024, indicating a massive expansion of built-up areas. Conversely, *baseflow values* have decreased consistently, with the average *baseflow* decreasing from 0.00002685 kg/m²/s (2000) to 0.00001894 kg/m²/s (2024), reflecting pressure on the aquifer system due to reduced infiltration areas. Pearson correlation analysis revealed a significant weak negative effect between NDBI and *baseflow* in 2000 (r = -0.219; *p-value* = 0), which changed to a weak positive effect in 2024 (r = 0.126; *p-value* = 0), indicating a shift in hydrological dynamics due to the accumulated impacts of urbanization. This finding confirms that *urban sprawl* has reduced groundwater recharge capacity and threatened the sustainability of clean water supplies. The study recommends the need for sustainable spatial planning policies and groundwater conservation strategies to mitigate these negative impacts.

Keywords: *Urban Sprawl* , Groundwater, *Google Earth Engine* , NDBI, *Baseflow* , Kendari

1. INTRODUCTION

Urban development is an inevitable global phenomenon, driven by population growth and economic activity. The massive and often uncontrolled urbanization process has given rise to a spatial phenomenon known as *urban sprawl* . *Urban sprawl* is characterized by the geographic expansion of urban areas into peri-urban and suburban areas, characterized by a dispersed, low-density pattern and a heavy reliance on private vehicles (Brueckner, 2000). This phenomenon not only changes the physical landscape of an area but also places significant pressure on natural resources, particularly groundwater resources.

Groundwater plays a crucial role as a source of clean water for more than half the world's population, including for domestic, industrial, and agricultural needs in urban areas (Famiglietti, 2014). Overexploitation, coupled with a reduction in catchment areas due to land conversion into impervious surfaces *such* as residential areas, roads, and commercial areas, threatens the sustainability of groundwater reserves. This reduction in catchment areas hinders the aquifer *recharge process* , resulting in a decrease in *the water table* , seawater intrusion in coastal areas, and even land subsidence *(* Li *et al* ., 2017).

Kendari City, the capital of Southeast Sulawesi Province, is the epicenter of growth and development in the region. Over the past two decades, Kendari City has undergone significant physical transformation. Rapid population and economic growth have driven urban expansion into areas previously occupied by green spaces, forests, and agricultural areas (Kadir *et al* ., 2021). This development pattern exhibits strong *urban sprawl characteristics* , with development tending to spread to the city's outskirts. Kendari's coastal

Received: August 16, 2025
Revised: August 30, 2025
Accepted: September 14, 2025
Published: September 20, 2025
Curr. Ver.: September 27, 2025

DOI : https://doi.org/10.62951/ijeemcs.v2i3.311

location further exacerbates the vulnerability of its groundwater resources to the negative impacts of this expansion, particularly the threat of seawater intrusion if groundwater extraction is not balanced with its *recharge capacity* .

Understanding the spatial dynamics *of urban sprawl* and its correlation with groundwater reserves is urgent. However, conventional monitoring using field surveys for both aspects is costly, labor-intensive, and time-consuming. In this context, advances in remote sensing *and* Geographic Information Systems (GIS) technology offer a revolutionary solution. Cloud computing *platforms* such as GEE provide the ability to analyze large-scale, multi-temporal satellite data efficiently and quickly (Gorelick *et al* ., 2017). By leveraging satellite data such as Landsat and Sentinel, which have been available in long archives since 1972, land cover changes and built-up area development can be accurately analyzed over long time periods.

Based on the description, the research entitled "Analysis of the Impact of *Urban Sprawl* in Influencing Groundwater Reserves in Kendari City Using *Google Earth Engine* for the Period of Years (2000 and 2024)" was designed. This research aims to: (1) Calculate *the Baseflow Groundwater Runoff value* of Kendari City in Years (2000 and 2024), (2) Map and calculate the NDBI value of Kendari City in Years (2000 and 2024) and (3) Analyze the influence between the increase in built-up land area (NDBI) with changes in *baseflow estimates* (groundwater reserves) using the Pearson correlation test in Kendari City. The results of this research are expected to be a scientific basis and important policy recommendations for city planners and stakeholders in formulating sustainable development strategies and water resource conservation in Kendari City.

2. RESEARCH METHODS

Research Time

This research was conducted in 2025 with the selected time period for satellite imagery data analysis covering the years 2000 and 2024. The year 2000 was chosen as the starting point (*baseline*) because it represents the initial conditions before the acceleration of development and urbanization in Kendari City at the beginning of this millennium. In addition, Landsat 5 Level 2 satellite data from that year was available with good coverage and adequate resolution for land cover analysis. Meanwhile, the year 2024 was chosen as the end point of the analysis to capture the accumulative impact of the *urban sprawl process* over a period of 24 years. The use of 2024 data (which will use Sentinel-2 MSI imagery) is expected to provide the most up-to-date and relevant picture of current conditions.

Research Location

The research location focuses on the Administrative Area of Kendari City, Southeast Sulawesi Province, Indonesia (Figure 1). Kendari City is located between 3°54'30" - 4°10'30" South Latitude and 122°23'30" - 122°39'30" East Longitude. Geographically, Kendari City has unique topographic characteristics, consisting of lowland areas on the coast and hills on the mainland, with altitudes varying from 0 to 200 meters above sea level (masl) (BPS Kendari City, 2023).

Figure 1. Map of Research Location (Kendari City) from Satellite Imagery in the Years (2000 and 2024)

The selection of Kendari City as the research location was based on several strategic considerations. First, as the provincial capital, Kendari is experiencing rapid population growth and physical development, characterized by the conversion of green spaces and catchment areas into massive built-up areas (Kadir *et al* ., 2021). Second, its geological characteristics, dominated by aquiferous rock formations, make groundwater a vital resource yet vulnerable to anthropogenic pressures. Third, its location on the coast of Kendari Bay increases its vulnerability to the impacts of seawater intrusion if groundwater levels decrease significantly (Arfan *et al* ., 2020). Fourth, from a methodological perspective, its relatively small administrative area, despite its high land use dynamics, makes it an ideal location for analysis using medium-resolution remote sensing techniques.

Research Design

This study employed a quantitative observational design with a spatial-temporal analysis approach. The study aimed to examine the impact of urban sprawl *on* the dynamics of groundwater abundance *or* soil reserves indirectly using remote sensing and hydro-meteorological data. The analysis was conducted computationally on the GEE *platform* for the years 2000 and 2024.

Variables and Data Collection Techniques

The data used consists of primary data (satellite imagery) and secondary data (assimilation models). All data is accessed and processed within the GEE *platform* .

1. Determination of *Area of Interest* (AOI)

The AOI or study area in this study is the administrative boundary of Kendari City, Southeast Sulawesi Province, Indonesia, which is imported as a vector *geometry polygon* using the *Draw a Rectangle tool* in GEE to determine the area to be analyzed, so that the analysis only focuses on the predetermined study area. The use of AOI ensures spatial consistency and computational efficiency throughout the analysis process, and clear boundaries facilitate the process of *clipping raster* data and avoid bias due to areas outside the study (Gorelick *et al* ., 2017).

2. Groundwater reserve data (dependent variable)

Groundwater conditions are modeled indirectly through *Baseflow Groundwater Runoff estimation* . *Baseflow* is a component of river water flow that originates from the slow release of groundwater into the river (*groundwater discharge*) and is recognized as a reliable proxy for estimating *recharge* and reserves or groundwater abundance in a watershed (Dingman, 2015). Surface flow (*runoff*) data is obtained from:

- FLDAS is a modeling system that integrates observational and satellite data to produce estimates of hydrologic components such as *runoff* (McNally *et al* ., 2017). Monthly *runoff data* from FLDAS (in kg m^{-2} s^{-1} or mm/s) are accessed directly from the NASA/FLDAS/NOAH01/C/GL/M/V001 catalog in GEE.
- The data was then temporally filtered for the year 2000 and the year 2024. The data for each year was then composited or averaged to produce a total or annual average value.
- Use *chart* For know mark from time to time , in matter This daily in One year .
- Limit on *region* , with use tool statistics *ee.Reducer.mean ()* For take average value , and set *system:time_start* For x -axis .
- Determine Name *series* with *setSeriesNames* .
- Determine legend x- axis , Y -axis , and title chart with *setOptions* .
- The FLDAS dataset has resolution low which is 11132 m/ pixel . So the data is needed repaired through interpolation with method *inverseDistance ()* .
- Method *inverseDistance ()* requires : sample, mean value , and mark standard deviation .

Urban data *sprawl* (independent variable)

The development of built-up land is analyzed in the following manner:

- Use NDBI method for know distribution land woke up along with its density .
- NDBI values range from -1 to 1, where the more approach value 1, then the more congested land awakening .
- NDBI is calculated using the algorithm in GEE with the formula equation (1) (Zha *et al* ., 2003):

NDBI = (SWIR 1 - NIR) /(SWIR 1 + NIR)…….(1)

Where:
NDBI = *Normalized Difference Built-Up Index*
SWIR 1 = *Short-Wave Infrared*
NIR = *Near-Infrared*

- In 2000 data , using *USGS Landsat 5 Level 2, Collection 2, Tier 1* .
- Before using the Landsat 5 dataset, then cloud need deleted with method deletion cloud .
- After the Landsat 5 dataset is cleaned from clouds , then insert NDBI formula , where on Landsat 5 the SWIR 1 position is at SR_B5 and NIR is at SR_B4.
- Visualize Landsat 5 and NDBI data and calculate the average NDBI value .
- In 2024 data , using *MSI's Harmonized Sentinel-2: Multi-Spectral Instrument, Level-2A (SR)* .
- Before using the Sentinel-2 dataset, then cloud need deleted with method deletion cloud .
- After the Sentinel-2 dataset is cleaned from clouds , then insert NDBI formula , where on Sentinel-2 the SWIR 1 position is at B11 and NIR is at B8.
- Visualize Sentinel-2 and NDBI data and calculate the average NDBI value .
- ▪ Data Analysis Techniques

1. Estimation of *baseflow groundwater runoff*

runoff data from FLDAS were aggregated into annual data for the period of 2000 and 2024. *Baseflow* as a groundwater proxy was then separated from total *runoff* using the Lyne & Hollick (1979) digital *filter method* implemented in the GEE *script* . This method is widely used in hydrology to separate the fast flow (*surface runoff*) and base flow (*baseflow*) components of a *time series* of discharge data (or in this case, *runoff*).

2. Spatial analysis *of baseflow* using the *inverseDistance() method*

To create a spatial distribution map of the estimated *baseflow , the baseflow* points from each FLDAS pixel are interpolated using the *inverseDistance() method* (Inverse Distance Weighting/IDW) available as a function in GEE. This method assumes that the value at an unsampled location is a weighted average of the values of the surrounding sample points, with the weight decreasing with increasing distance (Shepard, 1968). This interpolation produces *a surface raster* showing spatial variation of groundwater abundance across the AOI.

3. Analysis of changes and correlations
   - Built-up Land Change: The built-up land area is the result of classification and the average NDBI value for AOI calculated for the years 2000 and 2024. Changes are analyzed statistically and spatially.
   - *Baseflow* Change : The interpolated *baseflow values for both years were analyzed for changes.*
   - Correlation Analysis: The relationship between the increase in built-up land area or NDBI with changes in estimated *baseflow* (groundwater reserves) was analyzed using the Pearson correlation test to measure the strength and direction of the relationship (Jacobson, 2011; Schueler *et al* ., 2009; Helsel *et al* ., 2020; Schober *et al* ., 2018; Gorelick *et al* ., 2017; Arnold *et al* ., 1998).

3. RESULTS AND DISCUSSION

Baseflow Groundwater Runoff of Kendari City in 2000 (January-December)

Baseflow Groundwater Runoff is a vital component of river flow that serves as an indicator of the health of a region's groundwater reserves. A decrease *in baseflow* is an early warning that groundwater balance is being disturbed, often due to human activities such as *urban sprawl* . Based on the *baseflow graph* (Figure 2) for Kendari City in 2000, fluctuations in groundwater flow values are visible, expressed in kg/m2 / s. The highest *baseflow value* occurred in June 2000, indicating a high contribution of groundwater to river flow during that period, possibly due to the high intensity of rainfall in the previous months. This value then experienced a significant decrease in July and August, indicating a period where groundwater *recharge was reduced, possibly related to the dry season or decreased rainfall.*

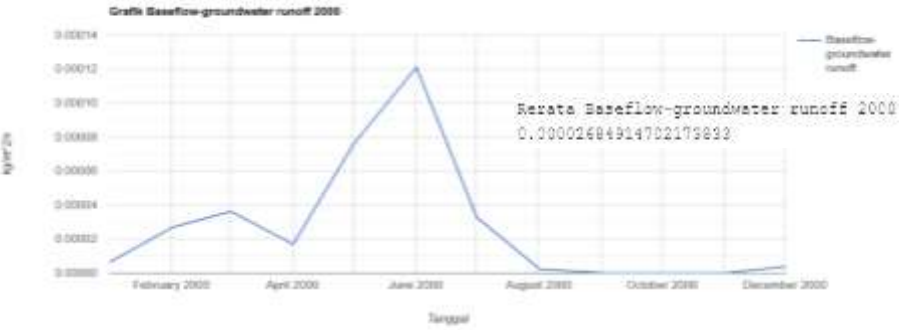


Figure 2. Graph of *Baseflow Groundwater Runoff* Values in Kendari City in 2000 (January-December)

There was a slight increase in February 2000 and March 2000, which can be interpreted as a response to seasonal rainfall, before decreasing again in April 2000. The lowest values occurred in September 2000 and October 2000, indicating conditions where groundwater reserves were very minimal. Overall, this pattern reflects the dynamics of tropical hydrology in Kendari City, which is strongly influenced by seasonal variability.

baseflow values , ranging from 0.00014 kg/m2 / s to nearly 0, indicate that groundwater's contribution to total river flow is relatively small but vital for maintaining river flow during the dry season. These results align with studies indicating that urban areas such as Kendari are experiencing pressure on groundwater resources due to urbanization and climate variability (Rahman *et al* ., 2022). Understanding this *baseflow variability* is crucial for planning sustainable water resource management, groundwater conservation, and drought mitigation in the region.

The average value of 0.00002685 kg/m ^{2} /s provides a quantitative picture of the average contribution of groundwater to river flow throughout the year. Despite the sharp fluctuations, the presence of this *baseflow* is crucial for maintaining river flow (*streamflow maintenance*) during the dry season, preventing rivers from drying out completely, and supporting water availability for aquatic ecosystems (Nathan & McMahon, 1990). The observed pattern is consistent with the hydrological characteristics of tropical regions which are strongly influenced by seasons, where groundwater availability is highly dependent on the temporal and distribution of rainfall.

- *Baseflow Groundwater Runoff* in Kendari City in 2024 (January-December)

Based on the analysis of *the baseflow* or groundwater *runoff graph* (Figure 3) for Kendari City in 2024, a pattern of fluctuations in groundwater discharge values was observed that was lower and stable overall when compared to historical data in 2000. The highest *baseflow value* was recorded in March 2024, reaching around 0.00006 kg/m2 / s, but this value was still significantly lower than the peak *baseflow* that occurred in the period in 2000. This pattern was then followed by a gradual decline until it reached its lowest point in August 2024 to November 2024, which approached the value of 0 kg/m2 / s.

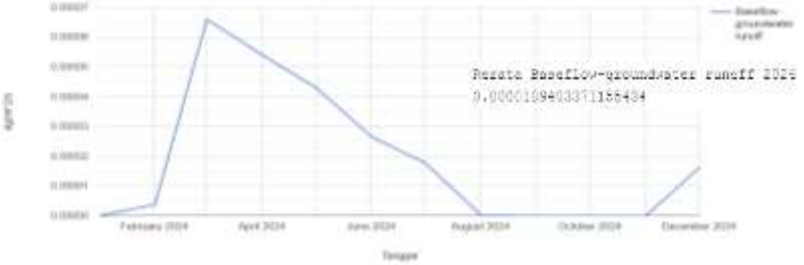


Figure 3. Graph of *Baseflow Groundwater Runoff Values* for Kendari City in 2024 (January-December)

Decrease *in magnitude* This *baseflow* indicates increasing pressure on the aquifer system in Kendari City. The consistent downward trend from April 2024 to November 2024, without significant recovery during typically rainy months, could be an indicator of reduced groundwater *recharge* . This is strongly suspected to be related to several factors, including increased impermeable land cover (urbanization) that reduces infiltration, climate variability causing changes in rainfall patterns, and possibly also the result of overexploitation of groundwater to meet domestic and urban needs (Setiawan *et al* ., 2023).

Baseflow values consistently below 0.00005 kg/m2 / s for most of the year indicate a weakening aquifer buffer capacity. This is concerning because *baseflow plays* a crucial role in maintaining river flow during the dry season. Low baseflow increases vulnerability to hydrological drought and can exacerbate the clean water crisis in urban areas (Adji & Bahtiar, 2021). Therefore, these findings highlight the urgency of implementing stricter groundwater conservation policies and developing sustainable water resource management strategies that consider the impacts of urbanization and climate change.

The average value of 0.00001894 kg/m2 / s, lower than in 2000, confirms the long-term declining trend in groundwater availability in this region. This condition exacerbates Kendari City's hydrological vulnerability to drought and threatens *the sustainability* of clean water supplies, especially during the prolonged dry season (Priyanto *et al* ., 2022). This finding aligns with previous studies reporting declining groundwater levels and pressure on water resources due to population growth and massive land-use changes in urban areas in Indonesia.

- Visualization of NDBI Kendari City 2000 (January-December)

NDBI or Normalized Difference Built-up Area Index is an index used in remote sensing . *sensing*) to identify and map built-up areas (such as settlements, cities, roads, factories, and other infrastructure) from satellite imagery. Simply put, NDBI is a digital detection tool that distinguishes areas filled with buildings and asphalt from green areas (vegetation) or water. NDBI values range from -1 to 1, where high positive values indicate the presence of built-up areas, while negative values tend to indicate non-built-up land cover such as vegetation or water. Based on the NDBI visualization of Kendari City in 2000 generated through GEE, it can be seen that the study area shows a variation in index values between -0.229 and 0.049. Positive NDBI values indicate the presence of built *-up areas* , while negative NDBI values are generally associated with water surfaces or vegetation. The relatively low range of values and tending towards zero indicates that in 2000, built-up land cover in that location was still limited or not very dominant compared to other land cover classes (Figure 4).

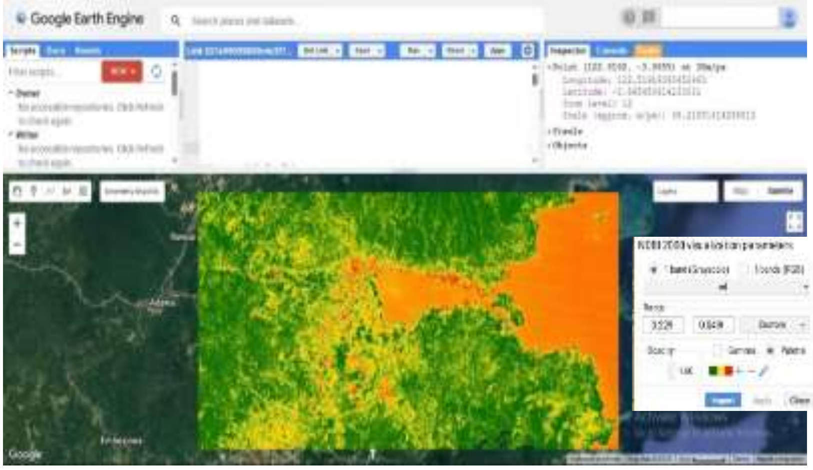


Figure 4. Landsat 5 Satellite Image Map Level 2 for NDBI Kendari City 2000 (January-December)

An analysis of the distribution of built-up areas in Kendari City in 2000 was conducted using Landsat 5 Level 2 satellite imagery with a spatial resolution of 38 meters per pixel. Each pixel in the image represents an area of 1,444 m² on the Earth's surface, with a zoom level of 1.5 m² . *level*) 12 on the GEE *platform* to ensure a sufficiently detailed display. 1 *band composition* (*Grayscale*) is used to distinguish surface features, where water appears in variations of orange. Vegetation such as mangroves or primary vegetation is identified in green, while urban areas and infrastructure of Kendari City are marked with high reflectance in yellow to red (the redder the denser the built-up area). This finding is in line with the research of Zha *et al* ., (2003) which states that NDBI is an effective indicator for mapping urban and residential areas. The low NDBI value in the 2000 period may reflect the early phase of urban development or the dominance of non-built-up land during that period.

- Kendari City NDBI Visualization for 2024 (January-December)

Based on the GEE visualization presented, the NDBI value for Kendari City in 2024 can be interpreted. NDBI is a spatial indicator widely used to map built-up areas by utilizing a combination of *bands. shortwave infrared* (SWIR) and *near-infrared* (NIR) from Sentinel-2 satellite imagery MSI: *Multi-Spectral Instrument* , *Level-2A (SR)* . NDBI values range from -1 to 1, where high positive values indicate the presence of built-up areas, while negative or near-zero values are generally associated with vegetation, water, or open land (Figure 5).

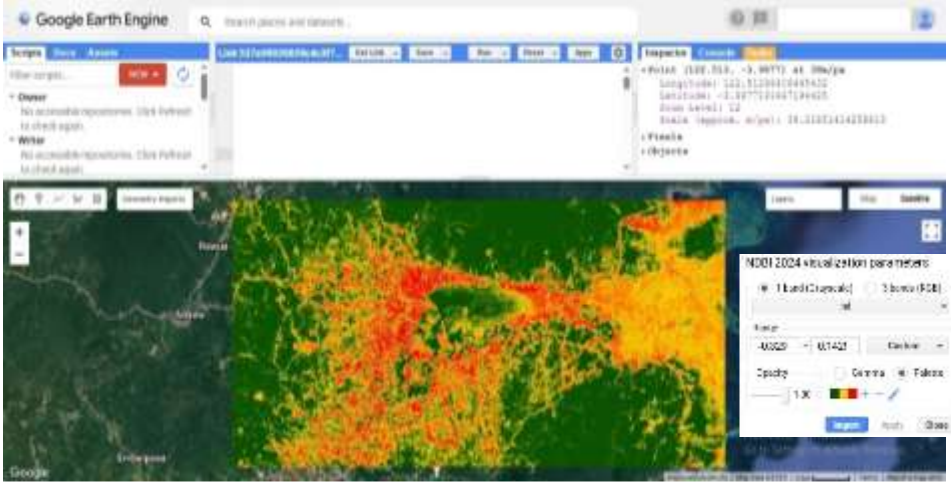


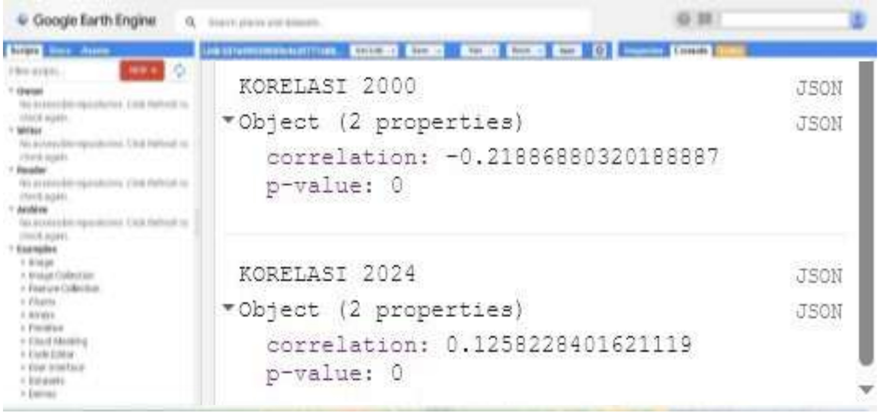
Figure 5. Sentinel-2 MSI Satellite Image Map : Level-2A (SR) for NDBI Kendari City in 2024 (January-December)

The range of NDBI values obtained for classification is from -0.3295 to 0.1425. The minimum value of -0.3295 indicates areas with strong non-built-up characteristics, such as water or very dense vegetation, while the maximum value of 0.1425 indicates the presence of built-up areas, although with a less intense intensity. The distribution of values within this range indicates that the analyzed area is dominated by non-built-up land, with some scattered built-up areas. With a spatial resolution of 38 meters per pixel with a zoom level (*zoom level*) 12 on the GEE *platform* to ensure a sufficiently detailed display. A 1- *band* (*Grayscale*) composition is used to distinguish surface features, where water appears in varying shades of yellow to orange. Vegetation such as mangroves or primary vegetation is identified in green, while urban areas and infrastructure in Kendari City are marked with high reflectance in yellow to red (the redder the denser the built-up area).

This finding is consistent with the study by Zha *et al* ., (2003) who first proposed the NDBI and stated that positive values indicate built-up areas, while negative values indicate water or vegetation. Furthermore, the range of values observed in this study is also in line with the results of Chen *et al* ., (2022) who applied NDBI to medium-resolution imagery to monitor urban development in tropical regions, where NDBI values are often lower due to high vegetation cover mixed with settlements.

- The Influence of Increased Built-Up Land Area (NDBI) on Changes in *Baseflow Estimation* (Groundwater Reserves) Using Pearson Correlation Test in Kendari City

Based on the results of statistical analysis using the Pearson correlation test run through the GEE *platform* (Gorelick, *et al* ., 2017; Google Developers, 2023), revealed a significant change in the dynamics of influence between the two variables studied and between the two time periods studied, namely 2000 and 2024. In 2000, the correlation coefficient showed a value of -0.219 with *a p-value* = 0, indicating a weak but statistically significant negative influence between the observed variables. This implies that an increase in one variable corresponds to a decrease in the other variable (Figure 6).



```
KORELASI 2000
▾Object (2 properties)
   correlation: -0.2188688032018887
   p-value: 0

KORELASI 2024
▾Object (2 properties)
   correlation: 0.1258228401621119
   p-value: 0
```

Figure 6. Results of Statistical Analysis Using Pearson Correlation Test Through the GEE *Platform*

Conversely, in 2024, there was a change in the direction of the influence to positive with a correlation value of 0.126, which was also statistically significant (*p-value* = 0). Although the strength of the correlation is categorized as weak, the change in sign from negative to positive indicates a shift in the pattern of influence between variables during the two periods. This transformation may reflect changes between the increase in built-up land area (NDBI) and changes in estimated *baseflow* (groundwater reserves), which influence the interaction between variables in a spatial context. High statistical significance (*p-value* ≈ 0) in both periods strengthens the validity of the results obtained, although the magnitude of the correlation is not included in the strong category.

4. AND IMPLICATIONS

Based on the results of the research conducted, it can be concluded that *urban Sprawl* has had a significant impact on the decline in groundwater reserves in Kendari City during the period 2000 and 2024. Analysis using the GEE *platform shows that there is an increase in the area of built-up land as reflected in the increase in the NDBI value, while the estimated baseflow groundwater runoff* as a proxy for groundwater reserves has decreased consistently with the average baseflow decreasing from 0.00002685 kg/m^2/s (2000) to 0.00001894 kg/m^2/s (2024) but is still in the safe category to meet the raw water needs of the Kendari City community.

The Pearson correlation test results revealed a shift in the pattern of influence between the two variables. In 2000, the influence between NDBI and *baseflow* was weakly negative but significant (r = -0.219; *p-value* = 0), indicating that an increase in built-up area tended to be followed by a decrease in groundwater reserves. In 2024, although the correlation remained weak (r = 0.126; *p-value* = 0), there was a shift in the direction of the influence to positive, which is thought to reflect changes in hydrological dynamics due to the accumulated impacts of urbanization and land-use change.

These findings indicate that land conversion to built-up areas has reduced groundwater infiltration and *recharge capacity* , threatening the sustainability of clean water supplies, particularly during the dry season. Therefore, this study emphasizes the importance of sustainable spatial planning policies, controlling urban expansion, and groundwater conservation strategies to mitigate the negative impacts *of urbanization. sprawl* in Kendari City. The implications of this research can serve as a basis for city planners and stakeholders in formulating adaptive and sustainable water resource management policies.

THANK-YOU NOTE

The researcher would like to thank PT. Askbeard Berkah Konsultan for the knowledge and insight provided to the researcher so that this research could run well and be successful.

BIBLIOGRAPHY

Adji, TN & Bahtiar, IY (2021). Groundwater discharge as a driver of water quality in tropical rivers: a review of challenges and opportunities in Indonesia. *Environmental Reviews* , 29(4), 505-519. https://doi.org/10.1139/er-2021-0006

Arfan, A., Takaijudin, H. & Yusof, KW (2020). A review of seawater intrusion in coastal aquifers. *IOP Conference Series: Materials Science and Engineering* , 849(1), 012037. https://doi.org/10.1088/1757-899X/849/1/012037

Arnold, J.G., Srinivasan, R., Muttiah, R.S. & Williams, J.R. (1998). Large area hydrologic modeling and assessment part I: Model development. *Journal of the American Water Resources Association* , 34(1), 73-89. https://doi.org/10.1111/j.1752-1688.1998.tb05961.x

Central Statistics Agency (BPS) of Kendari City. (2023). *Kendari City in Figures 2023*. Kendari: BPS Kendari City. Retrieved from https://kendarikota.bps.go.id/publication.html

Brueckner, J. K. (2000). Urban sprawl: diagnosis and remedies. *International Regional Science Review* , 23(2), 160–171. https://doi.org/10.1177/016001700761012710

Chen, Y., Huang, X. & Li, Z. (2022). A comparative study of urban index methods for mapping urban areas using medium-resolution satellite images. *GIScience & Remote Sensing* , 59(1), 1015-1034. https://doi.org/10.1080/15481603.2022.2082991

Dingman, S. L. (2015). *Physical Hydrology* (3rd ed.). Waveland Press.

Famiglietti, J. S. (2014). The global groundwater crisis. *Nature Climate Change* , 4(11), 945–948. https://doi.org/10.1038/nclimate2425

Google Developers. (2023). *Earth Engine Reducers* . Google Earth Engine Documentation. Retrieved from https://developers.google.com/earth-engine/guides/reducers_intro

Gorelick, N., Hancher, M., Dixon, M., Ilyushchenko, S., Thau, D. & Moore, R. (2017). Google Earth Engine: Planetary-scale geospatial analysis for everyone. *Remote Sensing of Environment* , 202, 18–27. https://doi.org/10.1016/j.rse.2017.06.031

Helsel, DR, Hirsch, RM, Ryberg, KR, Archfield, SA & Gilroy, EJ (2020). *Statistical methods in water resources* . US Geological Survey Techniques and Methods, book 4, chap. A3. https://doi.org/10.3133/tm4A3

Jacobson, C.R. (2011). Identification and quantification of the hydrological impacts of imperviousness in urban catchments: A review. *Journal of Environmental Management* , 92(10), 1438-1448. https://doi.org/10.1016/j.jenvman.2011.03.018

Kadir, A., Salam, R. & Iswandi, I. (2021). Analysis of land cover changes and land use directions in Kendari City. *Jurnal Planologi* , 18(1), 1-14.

Li, Y., Zhu, X., Sun, X. & Wang, F. (2017). Landscape effects of environmental impact on bay-area wetlands under rapid urban expansion and development policy: A case study of Lianyungang, China. *Landscape and Urban Planning* , 99(2), 154–162. https://doi.org/10.1016/j.landurbplan.2010.10.005

Lyne, V. & Hollick, M. (1979). Stochastic time-variable rainfall-runoff modelling. *In* Proceedings of the Institute of Engineers Australia National Conference (Publication No. 79/10).

McNally, A., Arsenault, K., Kumar, S., Shukla, S., Peterson, P., Wang, S., Funk, C., Peters-Lidard, C.D. & Verdin, J.P. (2017). A land data assimilation system for sub-Saharan Africa food and water security applications. *Scientific Data* , 4(1), 1-19. https://doi.org/10.1038/sdata.2017.12

Nathan, R. J. & McMahon, T. A. (1990). Evaluation of automated techniques for base flow and recession analysis. *Water Resources Research* , 26(7), 1465–1473. https://doi.org/10.1029/WR026i007p01465

Priyanto, A., Santosa, LW & Wijayanti, P. (2022). Long-term baseflow decline and its impact on water security in tropical urban watersheds: Case study of Kendari City, Indonesia. *Sustainable Water Resources Management* , 8(4), 108. https://doi.org/10.1007/s40899-022-00699-w

Rahman, A., Hidayat, F. & Sutjiningsih, D. (2022). Analysis of baseflow contribution to river discharge in urban tropical watersheds: A case study of Kendari City, Indonesia. *Journal of Sustainable Water Resources Management* , 8(4), 32. https://doi.org/10.1007/s40899-022-00725-x

Schober, P., Boer, C. & Schwarte, L. A. (2018). Correlation coefficients: Appropriate use and interpretation. *Anesthesia & Analgesia* , 126(5), 1763-1768. https://doi.org/10.1213/ANE.0000000000002864

Schueler, T.R., Fraley-McNeal, L. & Cappiella, K. (2009). Is impervious cover still important? Review of recent research. *Journal of Hydrologic Engineering* , 14(4), 309-315. https://doi.org/10.1061/(ASCE)1084-0699(2009)14:4(309)

Setiawan, B., Purmono, H. & Wijaya, AF (2023). The impact of rapid urbanization on groundwater recharge and baseflow in tropical coastal cities: Evidence from Kendari, Southeast Sulawesi. *Journal of Hydrology: Regional Studies* , 47, 101402. https://doi.org/10.1016/j.ejrh.2023.101402

Shepard, D. (1968). A two-dimensional interpolation function for irregularly-spaced data. *In* Proceedings of the 1968 ACM National Conference, 517-524. https://doi.org/10.1145/800186.810616

Zha, Y., Gao, J. & Ni, S. (2003). Use of normalized difference built-up index in automatically mapping urban areas from TM imagery. *International Journal of Remote Sensing* , 24(3), 583-594. https://doi.org/10.1080/01431160304987