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CASE STUDY

Potential application of rain water harvesting technology as an alternative clean water source to mitigate land subsidence

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ABSTRACT

BACKGROUND AND OBJECTIVES: The limited supply of tap water has implications for the massive usage of groundwater in North Jakarta's coastal area, that suffer crucial land subsidence. As a result, it is critical to provide alternate sources of sustainable clean water that can minimize groundwater consumption. Considering the climatological factors, rainwater harvesting technology possesses considerable potential and has been utilized in numerous unplanned, densely populated residential regions near the coast. According to that, this study aims to analyze the contribution of rainwater harvesting technology implementation in terms of supply and utilization aspects to reducing groundwater use and meeting clean water needs for mitigating land subsidence in the coastal area of North Jakarta
METHODS: This study was conducted in North Jakarta coastal area within a radius of 0—2 kilometers, by conducting survey activities on 148 households who live near the location of the technology installation, as well as collecting the depth wells data, and clean water samples. The purpose of the survey activity is to assist in regression analysis and crosstabulation related to the impact of Rain Water Harvesting technology on reducing land subsidence.
FINDINGS: Based on its quality, rainwater harvesting has the potential to support the fulfillment of clean water needs in North Jakarta, especially for sanitation purposes. The quality test results provide additional insight, demonstrating that the clean water derived from the rainwater harvesting system is a safer option for consumption than groundwater from either dug and drilled wells. The groundwater samples tested showed extremely high levels of Total Dissolved Solids (2829 mlligrams per liter), making it extremely dangerous to use for cooking and drinking, as well as sanitation, such as bathing and washing. In terms of quantity, mathematical calculations estimate that the provision of rainwater harvesting installations can support 0.2 percent of clean water for sanitation purposes in each implementation areaThis finding highlights that the perception of rainwater harvesting as a viable solution for fulfilling water demands is a crucial factor influencing the decision to adopt such practices.
CONCLUSION: The expanding rainwater harvesting is very related to the mitigating the land subsidence, through the decreasing depending on extracting groundwater as their source of wáter supply. Respondents selected rainwater harvesting as a solution to the difficulties in satisfying clean water demands caused by multiple factors. To encourage greater adoption of this technology, it is crucial to improve the community's awareness of its effectiveness in addressing their water needs. Strategies such as awareness campaigns, demonstrations, and providing empirical evidence of rainwater harvesting's effectiveness could help shift community attitudes. In contrast, while the views on the benefits, operational ease, and accessibility of rainwater harvesting hold importance, they do not appear to have a direct and meaningful effect on the adoption of rainwater harvesting in this study.

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INTRODUCTION

Land subsidence is a natural phenomenon that contributes to climate change-induced sea-level rise. According to United State Geological Survey (USGS), (2019), this phenomenon can be defined as the downward displacement of the land surface in relation to a specific reference surface, such as mean sea level, geoid, or ellipsoid. The phenomenon of displacement is attributed to the reflection process that happens in each layer of soft soil, with a particular emphasis on impermeable layers like clay or silt, which possess low permeability (Hutabarat, 2017). In fact, land subsidence is a natural phenomenon that occurs frequently in coastal areas as a consequence of tectonic movements (Coudert *et al*., 1995), natural soil consolidations (Tetiani *et al*., 2006), and periodic plate ruptures (Bertrand *et al*., 2011). However, anthropogenic factors drove it to become a natural disaster (Galloway *et al*., 2016), as happened in many coastal areas of metropolitan areas, including Tokyo (Akitaya and Aichi, 2022), Shanghai (Chai *et al*., 2004), Bangkok (Phien-wej *et al*., 2006), Manila (Rodolfo, 2014), Houston (Buckley *et al*., 2003), and Jakarta (Abidin *et al*., 2011). North Jakarta has experienced the most pronounced land subsidence in Jakarta, attributed to a combination of anthropogenic factors and natural geographic conditions. Based on its geographical characteristics, this region has the potential for natural land subsidence because it is traversed by 13 rivers and is dominated by alluvial sedimentary soil types (Ramadhan *et al*., 2015). This potential was further bolstered by the Jakarta Provincial Spatial Plan of 1984, which established the North Jakarta region as Kawasan Andalan, a focal point of urban development occupied by a mix of dense housing, commercial, and industrial areas (Hasibuan *et al*., 2023). This level of density results in construction loads as well as a substantial requirement for clean water (Chandra and Supriharjo, 2013), which the government is actively working to fulfill. As a result, exploitative use of groundwater is one of the main triggers of land subsidence in the region. As per Governor Regulation Number 93 of 2021, the imposition of groundwater usage restrictions is mandated only for buildings situated along arterial roads, even though notable land subsidence rates are present in additional areas. Azzahra (2022) discovered that the average rate of land subsidence in this region area was 11 centimeters per year (cm/y). However, by the year 2022, subsidence in coastal areas has been recorded at 15.6 cm/y (Azzahra, 2022). Associated with these data, the research of Hargianintya *et al*. (2020) found that 44.29 percent (%) of coastal residents rely on groundwater as their main clean water source, which is predicted to reach 1,355 million cubic meters (Mm^3) in 2025 (Cyntia, 2018; Samsuhadi, 2009). The limited reach of tap water, functioning at a mere 65% capacity, is predominantly found in specifically planned residential areas (The DKI Jakarta's Central Bureau of Statistics, 2020). This condition also underlies the regulations for a groundwater-free zone in North Jakarta, as outlined in Governor Regulation Number 93 of 2021. This context suggests that there is a need for alternative sources of clean water that can sustainably alleviate the constraints on clean water supply and minimize groundwater extraction, which is essential for mitigating land subsidence in the coastal areas of North Jakarta. Referring to the region's climatological aspect, which has moderate rainfall of 2,500-3,000 millimeters per year (mm/y) (CBSJP, 2024), rain water harvesting (RWH) technology has the potential to be applied to support these initiatives. RWH technology is a technique that collects rainfall from roof catchments, stores it in tanks, reservoirs, or ground aquifers, and then uses it to meet various daily or monthly clean water needs (UN-Habitat, 2005). This technology aligns with sustainability principles as it operates efficiently to decrease surface runoff. It utilizes environmentally friendly raw materials and is socioeconomically because the materials, construction, and management processes are straightforward and economical (Hamonangan, 2011). The application of RWH technology can save annual water usage by 30%-50% (Campisano, *et al*., 2017), where 500-800 cubic meters (m^3) are stored each year to meet urban water needs (Bashar *et al*., 2018). In a spatial context, this technology is also very suitable for application in areas with moderate to high building density because of the wider water catchment area (Shanableh *et al*., 2018). RWH technology has significant potential in reducing groundwater consumption in North Jakarta's coastal area, where groundwater resources are under pressure, in following aspects (Taftazani *et al*., 2020):

1) RWH systems offer a consistent and eco-friendly alternative for water supply by harnessing rainwater collected from rooftops and various catchment

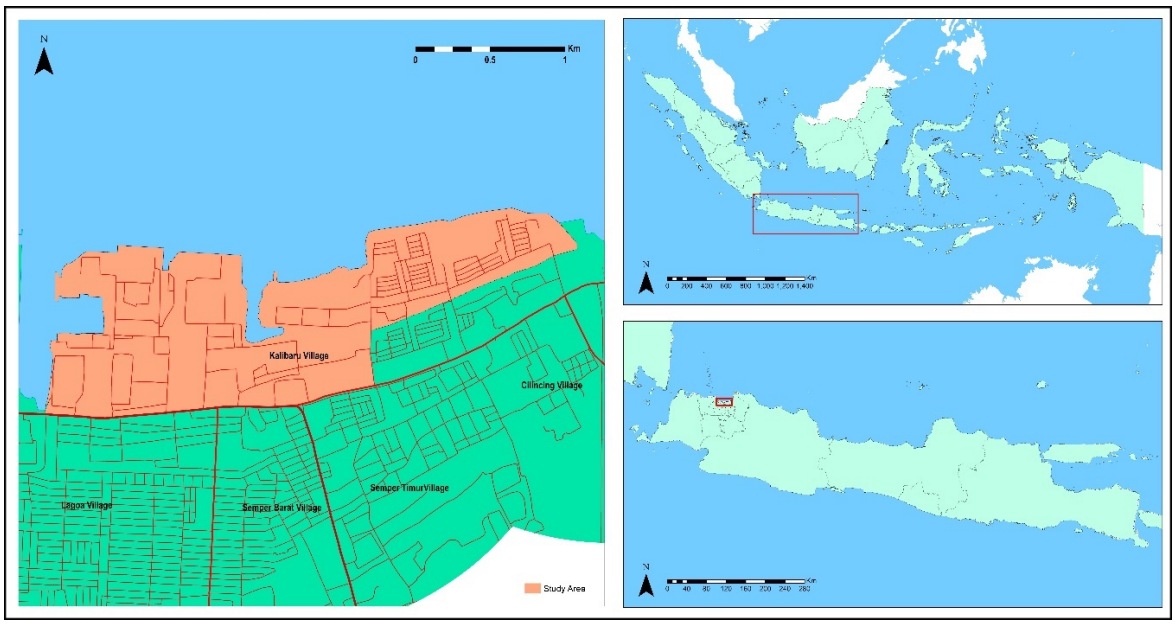

Fig. 1: Geographical location of the study area in North Jakarta Coastal, Indonesia

surfaces.

2) RWH system can help manage stormwater runoff by capturing excess rainwater before it flows into urban drainage systems.

3) Groundwater recharge prevention, RWH can help mitigate this issue by decreasing the reliance on deep aquifers, preventing further depletion

4) The unpredictability of rainfall patterns due to climate change necessitates adaptive solutions. RWH technology offers a means to enhance resilience by establishing an on-site water storage system that collects rainwater during wet seasons for use during dry periods.

Since 2019, this technology has been developed in numerous regions of North Jakarta, including Kalibaru, Cilincing, to support provide clean water in densely populated residential neighborhoods along the coast. This leads to the consideration of whether the evolution of this technology can assist in mitigating land subsidence in North Jakarta by facilitating better access to clean water and decreasing the reliance on groundwater, particularly in the regions where it is implemented. Associated with that, this research focuses on evaluating the implementation of RWH in densely unplanned residential areas along the coast to determine the contribution of its use and provision in supporting North Jakarta's land subsidence mitigation. This contribution focuses on the potential to enhance both the quality and quantity of clean water resources, as well as the community's efforts to implement practices that decrease reliance on groundwater. In other contexts, the supply side focuses on spatial aspects and actor networks, such as the adequacy of installation distribution in relation to the rate of land subsidence, as well as the motivation of collaboration between actors in providing RWH, whether it refers to mitigate subsidence. This study aims to explore the feasibility of implementing RWH technology as a means to address land subsidence issues in North Jakarta, particularly in relation to its provision and utilization. This study has been carried out in the coastal área of Kalibaru, Cilincing, North Jakarta within radius 0—2 kilometers (km) in 2024.

MATERIALS AND METHODS

Study area

This study was conducted in Kalibaru, Cilincing, spesifically in densely unplanned residential areas within a radius of 0-2 km from the coastline that currently have RWH technology (Fig. 1). Situated in the northernmost area of North Jakarta, Kalibaru is flanked by significant districts including Kampung Rawa and Penjaringan, while the Java Sea lies to the north. Its proximity to the coastline is a

Table 1: Survey information collected

Keypoint	Question
Quality potential	What types of clean water sources do you use
	What are the uses of the clean water source that you use
Quantity potential	What is the total volume of clean water you use per month
Implementation of utilization	Do you use rainwater collected in RWH installations
	Do you have difficulty accessing clean water
	What is the total volume of rainwater you use per month
	Is rainwater always available in the RWH installation everyday
	Is the volume of available rainwater sufficient for your monthly needs
	Can using rainwater save the cost of spending clean water per month
	How much expenses can be saved by using RWH
	How much groundwater do you need per month
	What are the uses of groundwater that you use
Quality potential	What types of clean water sources do you use
	What are the uses of the clean water source that you use
Quantity potential	What is the total volume of clean water you use per month

significant factor in the district's geography, as it lies along the northern coastal belt of Jakarta, an area historically shaped by both water resources and urban expansionThis district is part of the extensive landscape of North Jakarta, an area characterized by its blend of industrial zones, housing developments, shopping centers, and waterfront initiatives.

Data collection

Questionnaire survey on 148 households

This study was conducted for four months, from June to September 2024, both for collecting questionnaire survey data, document-review, deep-interview, and observation. Survey activities, observing well depths, and collecting clean water samples The number of wells was 53 units, and the water samples were collected from rainwater in RWH installations, tap water, groundwater, and gallon water consumed by residents. The questionnaire survey was focused on 148 households selected using a purposive sampling method with the criteria of residing in around the RWH installation location within radius a 0-2 km. The number of respondents was calculated using the Isaac and Michael sampling Table (Sugiyono, 2013), which is used to assist researchers in determining the appropriate sample size for surveys, given a specified level of precision (margin of error) and confidence. Featuring a population of 175 households and a 10% error rate, this study was crafted as a case study that zeroes in on a specific community within a designated geographic area, namely households situated within a 0-2 km radius of the RWH installation. The intention was to capture a detailed and contextually relevant understanding of RWH usage and its impact within this localized setting. It provides valuable insights into the community directly impacted by the RWH system.

There are 12 questions in the questionnaire survey form (Table 1), which will be used to analyze the contribution of using RWH technology in supporting the fulfillment of clean water needs and reducing groundwater consumption, both in terms of quality, quantity and application in society.

Field observation

Field observation were conducted using the waterpass-leveling method to collect data on the existing deformation of the North Jakarta Coastal area within a radius of 0-2 km from the coastline. A comparison was made between this data and historical subsidence information for the region, spanning from January 1, 2016, to December 31, 2021. This historical data was collected through Satellite Imagery, which was also instrumental in acquiring land use distribution data for the study area impacted by land subsidence. The land use distribution data, combined with RWH installations data gathered from field observation, were used to evaluate the spatial suitability of providing RWH technology. Aside from these three datasets, this study additionally employs spatial data on North Jakarta coastal morphology obtained through the analysis of Planet-Norwey's International Climate and Forest Initiative (NICFI) and Sentinel-2 satellite photos, as well as Google Earth to observe the natural landscape. Alongside surveys,

sampling, and field observations, the research also involved the collection of data through document reviews.

RWH quantity and quality analysis

A quality analysis was conducted to determine the suitability of rainwater quality in RWH installations as an alternate source of clean water to support the fulfillment of residents' clean water needs. The analysis focuses on three fundamental aspects: physical, chemical, and microbiological characteristics. The results reveal the significant potential of rainwater, especially when juxtaposed with quality evaluations of alternative clean water sources like piped water, groundwater, and bottled water. Physical quality is reflected by five parameters, such as total dissolved solid (TDS), turbidity, color, and odor. Meanwhile, chemical quality refers to two parameters as; potential of hydrogen (pH) and manganese (Mn) level, as well as microbiological quality, which includes total coliform and escherichia coli (E-coli) level. The quality standard used to measure the quality of each parameter was the Minister of Health Regulation Number 2/2023. In other context, quantity analysis was carried out using mathematical calculations using Eq. 1, which developed by Worm and Hattum (2006), to determine the possible volume of rainwater that can be gathered by RWH technology per month. Moreover, the findings from these calculations are evaluated against the average monthly clean water demands of the population to determine the potential for satisfying these needs via RWH technology.

$$Q_{RWH} = P \times A \times C \quad (1)$$

Where,
Q_{RWH}: The potential production of RWH
P : Rainfall (mm/month)
A : Harvesting media area (m^2)
C : Run-off coefisien

The rainfall Intensity (P) refers to rainfall data from the Tanjung Priok Monitoring Station over the last 10 years, from January 2014 to December 2023, in unit of millimeter per month (mm/month). The catchment area (A) denotes the smallest expanse of communal structures at the study location that can be used to collect rainwater, which was 80 square meters (m^2). The run-off coefficient (C) is 0.8-0.9 (Worm and Hattum, 2006), which refers to the type of roof material commonly used by these communal buildings. This coefficient reveals that the roof is capable of collecting around 80% to 90% of the rainfall.

RWH utilization analysis

The analysis method used in this study was a mix-method, with frequency analysis to determine the distribution pattern of RWH users, as well as the types of utilization and difficulties encountered, and binary logistic regression analysis to identify factors influencing the community's decision to use RWH. The choice of binary logistic regression is appropriate for this study, as the dependent variable is binary, categorizing individuals as either users or non-users of the RWH system. This technique enables the assessment of the impact of independent variables on the chances of an individual or household adopting RWH (*P*). The independent variables tested included the community's perceptions of RWH's ability to meet their needs, the perceived benefits of RWH, the ease of operating RWH, and the accessibility of RWH distribution. The study demonstrated that the perception of RWH's effectiveness in addressing needs was the sole significant determinant in the decision to implement RWH. The analysis process began by identifying independent variables considered relevant, which include community perceptions of various aspects of the RWH system, such as the system's ability to meet household water needs (X_1), perceived benefits (X_2), ease of operation (X_3), and accessibility of distribution (X_4). The measurement of this variable utilizes a Likert scale (1-4), where higher numbers indicate a stronger agreement or more positive perception. These variables were selected based on literature indicating that perceptions of new technologies can influence utilization decisions, which is particularly relevant in the context of RWH systems. The binary logistic regression model is perfformed, using Eq. 2 (Peng *et al*., 2002; Villar-Navascués and Fragkou, 2021):

$$Logit(P) = ln(P/(1-P)) = \beta_0 + \beta_1(X_1) + \beta_2(X_2) + \beta_3(X_3) + \beta_4(X_4) \quad (2)$$

The Forward Selection (Wald) technique is utilized to identify the significant variables in the analysis.

Table 2: The results of quality análisis of clean wáter sources

No.	Parameters	Unit	Result	Quality standard
		Physic criteria		
Groundwater				
1.	Temperature	Degree Celsius (^{0}C)	26.3	-
2.	TDS	mg/L	2829**	300
3.	Turbidity	Nephelometric turbidity unit (NTU)	1.99	3
4.	Color	True colour unit (TCU)	tt <0.70	10
5.	Odor	-	Odorless	Odorless
Tap water				
1.	Temperature	^{0}C	26.0	-
2.	TDS	mg/L	133	300
3.	Turbidity	NTU	0.62	3
4.	Color	TCU	tt <0.70	10
5.	Odor	-	Odorless	Odorless
Gallon water				
1.	Temperature	^{0}C	26.1	-
2.	TDS	mg/L	58	300
3.	Turbidity	NTU	0.5	3
4.	Color	TCU	tt <0.70	10
5.	Odor	-	Odorless	Odorless
RWH				
1.	Temperature	^{0}C	26.0	-
2.	TDS	mg/L	20	300
3	Turbidity	NTU	1.59	3
4.	Color	TCU	tt <0.70	10
5.	Odor	-	Odorless	Odorless
		Chemical criteria		
Groundwater				
1.	pH	-	7.55	6.5–8.5
2.	Manganese	mg/L	0.1926*	0.1
Tap water				
1.	pH	-	7.78	6.5–8.5
2.	Manganese	mg/L	tt <0.0027	0.1
Gallon water				
1.	pH	-	7.71	6.5–8.5
2.	Manganese	mg/L	tt <0.01	0.1
RWH				
1.	pH	-	6.69	6.5–8.5
2.	Manganese	mg/L	tt <0.0027	0.1
		Microbiological criteria		
Groundwater				
1.	Total coliforms	Colony/100 mL	> 1,000***	0
2.	E-coli	Colony/100 mL	> 1,000***	0
Tap water				
1.	Total coliforms	Colony/100 mL	1*	0
2.	E-coli	Colony/100 mL	0	0
Gallon water				
1.	Total coliforms	Colony/100 mL	<1.8*	0
2.	E-coli	Colony/100 mL	<1.8*	0
RWH				
1.	Total coliforms	Colony/100 mL	> 1,000***	0
2.	E-coli	Colony/100 mL	34.5**	0

*** parameters exceed quality standard, with the level represented by the number of symbol

In this technique, variables are added to the model individually, utilizing the Wald statistic to evaluate the significance of each independent variable's contribution. This process allows the researcher to select the most influential variables in the decision to use the RWH system, as well as evaluate the relative influence of each variable in the model. The Omnibus Tests of Model Coefficients statistic is utilized to assess the model's fit by examining whether the variables incorporated into the model significantly influence its overall effectiveness. The model is also tested using Cox & Snell R Square and Nagelkerke R Square to provide an indication of how well the independent variables can explain the variation in the dependent variable, which is RWH utilization.

Spatial analysis

The spatial analysis in this study aims to evaluate the adequacy of the RWH installations distribution in North Jakarta in terms of land subsidence rate based on existing land use distribution. The study adopted the synthetic aperture radar (SAR) technique, recognized for its exceptional temporal and spatial resolution along with a swift return time. The data used were historical land subsidence data from 2016 to 2021, which were compared with existing subsidence data from field observations using the waterpass-leveling method. In this case, 20 ascending sentinel-1A terrain observation with progressive scan SAR (TOPS SAR) scenes with VV polarization was used to identifying the history of land subsidence in north Jakarta. The determination of image polarization involved selecting the master and controlled images based on the information derived from the orbit. Data pertaining to the master that covers the research area was gathered ahead of the controlled imagery. During this phase, the perpendicular baseline was evaluated through modifications between the main radar and the control radar, considering how the vertical baseline data affects the coherence value, specifically the correlation coefficient of the SAR image at its least significant area. The next process was the production of the digital surface model, radar data filtering, and multi-looking to reduce the noise phase in the SAR results and convert it to the pixel phase. The result was the multi-looked with the export unwrapped, in which the SAR data was transferred from the ambiguity phase to the absolute phase. This step was required to calculate the height difference from the differential interferometric synthetic apperture radar (DInSAR) procedure or to convert the slope to size using sentinel application platform (SNAP) software's phase-to-displacement tool. During this phase, the perpendicular baseline was evaluated through modifications between the main radar and the control radar, considering how the vertical baseline data affects the coherence value, specifically the correlation coefficient of the SAR image at its least significant area. In the following stage, the results of the land subsidence analysis were overlaid with land use distribution data to determine the function of the land identified as having land subsidence. he overlay technique was implemented through a series of interferogram steps, intended to discern phase and amplitude details from two single look complex (SLC) radars that are significantly correlated. Finally, the land use distribution map was compared to data on the spatial distribution of RWH installations to confirm that its locations are ideal for land use types that suffer significant land subsidence.

RESULTS AND DISCUSSION

Water quality of RWH and other wáter sources

Based on its microbiological characteristics, rainwater was contaminated with 1,000 colonies/100 milliliters (mL) of coliform resulting in the presence of 34.5 colonies/100 mL of E-coli bacteria (Table 3). This number explains that the level of microbiological contamination in rainwater harvested by the RWH system exceeds the quality standards stipulated in Minister of Health Regulation Number 2 of 2023. Consequently, this water cannot be safely used for cooking or drinking without undergoing treatment, due to its potential to pose health risks. Furthermore, the use of rainwater for cooking and drinking is discouraged due to its low TDS level of 20 milligrams per liter (mg/L), which reflects a lack of essential minerals. The Minister of Health Regulation Number 2 of 2023 certified that water suitable for drinking and cooking contains TDS levels ranging from 50 to 300 mg/L. Conversely, several physical characteristics demonstrate that rainwater was appropriate for sanitation use, indicated by turbidity and color measurements that remained within standard limits, and the water being odorless (Table 3). The pH balance level of 6.69 from the quality standard of 6.5-8.5 also indicates that the rainwater in the RWH system has good quality. Manganese levels in this water (<0.0027

Table 3: Monthly rainfall in North Jakarta based on Tanjong Priuk monitoring station (mm)

Month	Year				
	2019	2020	2021	2022	2023
Jan	365.5	504	332.4	0	268.2
Feb	216.9	763.7	466.8	0	496.1
Mar	332.1	220.6	190.1	0	246.7
Apr	132.5	110.6	88.6	0	76.9
May	24.7	52.5	249.7	0	117.7
Jun	5	63.3	130.6	0	90.6
Jul	0	99.9	47	0	11.7
Aug	0	77.9	65.6	0	0
Sep	0	131.9	83.4	0	2.7
Oct	1	101.7	247.2	0	8888
Nov	80	111.2	52	0	204.1
Des	509.3	244.2	162.9	0	7
Monthly average (mm)	138.9	206.8	176.4	0	867.5

mg/L) have an impact on pH balance. The findings indicate that, due to its quality, RWH could effectively meet the clean water requirements in North Jakarta, particularly for sanitation needs. The quality test results provide a more detailed explanation, showing that the clean water produced by the RWH system is a safer option for consumption than groundwater from either dug and drilled wells. The groundwater samples tested showed extremely high levels of TDS (2829 mg/L), making it extremely dangerous to use for cooking and drinking, as well as sanitation, such as bathing and washing. High concentrations of TDS, especially those arising from salts, heavy metals, or other toxic substances, can directly threaten human health (WHO, 2017). The high TDS levels can be induced by sea water intrusion (Suhartono *et al*., 2013), which may increase chloride levels, as one of the TDS' components (O'Connor,1976). High chloride levels in groundwater can cause crenation in skin tissue (Mader, 2004), impaired growth, productivity, and physiological functions of plants (Lacoma, 2022), corrosion in water channels, and stains on clothing and other washable equipment (WHO, 1978). High levels of Coliform and E. coli contamination, measured at 1,000 colonies per 100 mL, along with Manganese concentrations exceeding quality standard limits, clearly indicate the low quality of groundwater (Table 2). This condition implies that using groundwater in North Jakarta is not only capable of causing land subsidence, but also unsafe to use for any purpose. Consequently, the use of this resource should be minimized and substituted with reliable clean water sources, including RWH. When compared to other clean water sources used in the research area, rainwater from the RWH system also has the most balanced pH, although the quality level in other parameters lower than tap water and gallon water (Table 2).

Physically, RWH water, when compared to other water sources, exhibits good quality, not exceeding the required standards. According to the analysis, the TDS levels in RWH water are lower than those in groundwater, surface water, and bottled water. This finding highlights that RWH water is of higher quality based on the TDS metric relative to these alternative water sources. The water quality of RWH, based on turbidity test parameters, shows lower levels than groundwater but higher than bottled and tap water, although still remaining within the required standards. Based on color test parameters, the quality of RWH water is similar to that of other water sources. When evaluating odor test parameters, RWH water is on par with other water sources, demonstrating an absence of odor. Chemically, RWH water, when compared to other sources, exhibits better quality, with all testing parameters meeting the required standards. Test results for manganese reveal that rainwater harvesting (RWH) water outperforms groundwater, which surpasses the set standards.

Water quantity of RWH

According to mathematical estimates, the deployment of RWH installations is projected to provide around 0.2% of clean water for sanitation purposes within each implementation area. The calculation of this proportion involved comparing

Table 4: The difficulty factors to obtaining clean **water**

Difficulty factors	Total	
	n	%
Limited availability	17	77.27
1. Limited piped water	8	47.06
2. The lack operasionalization of piped water	6	35.29
3. Dry wells	2	11.76
4. Unequal distribution of piped water	1	5.89
Unaffordable prices	3	13.64
1. Cost allocation 23% of monthly income	1	33.33
2. Cost allocation 10% of monthly income	2	66.67
Poor quality of main wáter souce	2	9.09
1. Piped water	0	0
2. Ground water	2	100.00

the average monthly rainwater volume collected by each installation with the total monthly clean water sanitation requirements for each region. Each RWH installation can harvest an average of 20,010.24 liters (L) of rainwater per month, with a catchment area of 80 m^2, a run-off coefficient of 0.9, and a monthly rainfall intensity of 277.92 milli meters (mm). The intensity represents the average monthly intensity at the Tanjung Priok Monitoring Station for the last five years (2019-2023), as detailed in Table 3. In this case, each installation supplies the clean water needs of 1 RW with 2,053 households, for a total monthly clean water consumption of 9,700,425 L. Each household requires 4,725 liters/month (L/month) for sanitary needs like washing and bathing.

The discussion implies that the existing RWH installations have not entirely contributed to supporting the provision of clean water in North Jakarta. The reason for the limited supply of installations is the high population density of the residential area where the implementation took place. The use of groundwater for sanitation purposes was also difficult to substitute with rainwater due to its limited volume. This indicates that the current capacity for RWH was not sufficient to effectively mitigate land subsidence in North Jakarta, a problem that has been exacerbated by groundwater over-extraction and the lack of other clean water alternatives.

Respondent characteristics and the acceptance to RWH

Associated with the potential of RWH's quality and quantity, the study found that 22% of 148 respondents used RWH as an alternate source of clean water for bathing and washing. Based on the results of the Crosstabulation analysis, it has been determined that 68.75% of individuals are struggling to satisfy their daily clean water needs. These issues were mainly caused by the limited availability (77.27%), unaffordable prices (13.64%), and poor quality of the main water source (9.09%) (Table 4). These limitations were typically caused by the limited volume of piped water distributed by Perusahaan Daerah Air Minum (PDAM) (47.06%), especially during the dry season, forcing them to scramble for it. Other causes are also due to the lack of operationalization of the piped water system (35.29%), dry wells (11.76%), and unequal distribution of piped water services (5.89%), which only covers 60% of Jakarta and tends to be concentrated in planned areas (CBSJP, 2021). Currently, the drought reflects the repercussions of excessive groundwater withdrawal, especially by private entities, a situation intensified by a densely populated area associated with significant development (Luo *et al.,* 2019). In unaffordable prices context, 66.67% of the population must set aside 10% of their monthly income for clean water demands. In this situation, their monthly income is 189.20 US Dollar/month, less than the Regional Minimum Wage level for the Jakarta region of 319.57 US Dollar (USD) in 2024 (CBSJP, 2024). Furthermore, a significant portion, specifically 33.33%, of those struggling to access clean water because of limited financial resources, earn a monthly income of 40.96 USD, while spending 9.45 USD/month on clean water. The information presented shows that respondents belonging to low-income groups need to dedicate

Table 5: Characteristics of RWH users in North Jakarta

User characteristics	Utilization of RWH			
	Yes		No	
	n	%	n	%
The main water sources				
Piped water (PDAM)	51	73.91	54	68.35
Groundwater (Drill and dug wells)	18	26.09	25	31.65
Family members				
1-3 persons	20	28.99	18	22.78
4-6 persons	44	63.77	54	68.35
7-10 persons	4	5.80	7	8.87
> 10 persons	1	1.44	0	0
Ease of access				
Easy	23	33.33	39	49.37
Difficult	46	66.67	40	50.63

Table 6: Reasons for difficulty: challenges in fulfillment of main water sources

Fulfillment challenges	The main water sources			
	Pipe Water		Groundwater	
	n	%	n	%
Quantity limitation	30	93.75	8	57.14
Low quality	0	0	5	35.71
Expensive cost	2	6.25	1	7.15

23% of their monthly income to fulfill their clean water needs (Table 4), which is well above the 4% limit prescribed by Minister of Home Affairs Regulation Number 21 of 2020.

An evaluation of expected quality and quantity reveals that 46.62% of the 148 households rely on RWH to fulfill their bathing and washing needs with clean water. The frequency analysis results suggest that families who use RWH as an alternate source of clean water, 73.91% utilize piped water as the main water source, with 63.77% having family members of 4-6 people and 66.67% encountering challenges in supplying daily clean water (Table 5).

Chi-square analysis with a probability value of ≤0.05 reveals that the difficulty variable was the sole trigger factor for the usage of RWH. These challenges are often linked to restrictions in water availability, impacting households that utilize piped water (93.75%) and those that source their water from groundwater (57.14%) as their primary supply (Table 6). This indicates that the primary motivation for using RWH is to provide innovative solutions for increasing access to clean water sources.

Furthermore, the crosstab analysis results reveal that the high cost of acquiring piped water was another reason for adopting RWH, which ranges between 6.37 and 18.91 USD per month (Fig. 2). This situation is similarly observed among households that utilize groundwater, where 7.15% report challenges stemming from the expensive nature of securing daily access to clean water. This percentage also demonstrates that groundwater consumers have more economic issues than pipe water users, while being ranked last (Table 6). This situation was stimulated by the disparity in monthly income between the two groups of consumers, even though ≥ 50% of them have the same amount of expenses, 6.37—18.91 USD/month. The analysis found that groundwater customers earn 37.82—63.04 USD per month (57.14%), whereas piped water users earn 69.34—189.11 USD per month (50.00%). Findings from a survey of 148 households indicate that the need for clean water extends to washing, bathing, cooking, and drinking. According to the quality analysis, rainwater gathered from the RWH installation is appropriate for bathing and washing. In contrast, additional treatment is necessary for its use in cooking and drinking.

The key drivers influencing the decision to utilize RWH technology in the coastal areas of North

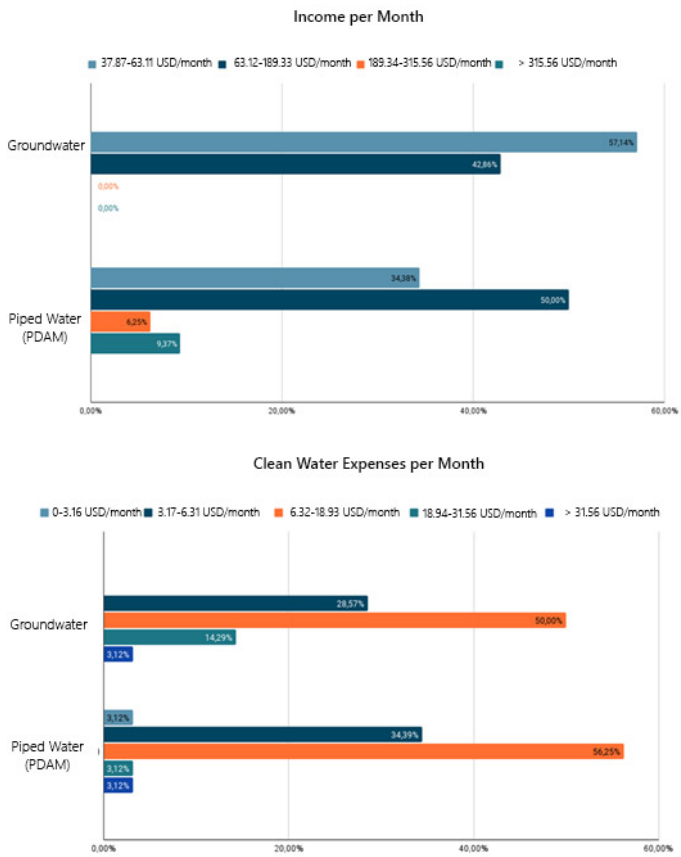

Fig. 2: The Comparison of income and clean water expenses per month in north Jakarta

Jakarta are as; 1) satisfying clean water needs and 2) residents' perceptions of RWH's ability to meet their demands. Respondents opted to implement RWH technology created in their local areas due to the complexities involved in fulfilling their clean water needs, which were influenced by multiple factors. This is relevan with the study by Qi *et.al*. (2019) that local need and commitment to harvest rainwater driven by a critical lack of clean drinking water. The findings of the logistic regression analysis support this claim, demonstrating that the adoption of this technology is affected by residents' views on RWH's effectiveness in meeting their requirements, as indicated by a probility value (p-value) of 0.023 (Table 7). However, other variables, such as perception of RWH's benefits, ease of operation, and accessibility of distribution, did not show significant effects on RWH utilization. The p-values for these variables were greater than 0.05 (probability (p) = 0.143, 0.382, and 0.665, respectively), suggesting that while the community may perceive RWH as beneficial, easy to operate, or accessible, these perceptions do not directly influence their decision to utilize RWH.

Regarding the model fit (Tabel 7), The Exp(B) value of 3.754 means that individuals who perceive RWH as capable of meeting their needs are 3.754 times more likely to adopt RWH compared to those who do not share this perception. This result highlights that the perception of RWH as a viable solution for fulfilling water demands plays a crucial role in the decision-making process regarding its adoption. Furthermore, the Nagelkerke Regression Square (R Square) value of 0.223 indicates that the model explains 22.3% of the variance in RWH utilization. While the model demonstrates a strong link between how RWH is perceived in terms of meeting needs and its adoption, the relatively modest explanatory power suggests that there may be other

Table 7: The logistic regression test results for factors influencing the use of RWH based on community perceptions

Variable	B	Standard error (SE)	Wald	Sig.	Exp(B)	Nagelkerke R square	-2 Log likelihood
Ability to meet the needs	1.323	0.581	5.177	0.023	3.754	0.223	37.489
Constant	-5.253	1.885	7.767	0.005	0.005		
The perceived benefits of RWH	1.281	0.920	1.939	0.164	3.600		
The ease of operating RWH	0.117	0.737	0.025	0.874	1.124		
The accessibility of RWH	0.369	0.538	0.470	0.493	1.446		

unaccounted factors affecting the choice to utilize RWH. This means that improving RWH adoption can be accomplished by enhancing the community's perception that technology can effectively meet their water needs. This is consistent with the study comparing two groups—those using RWH and those not using RWH—both of which demonstrated positive perceptions of the RWH system (Snelling *et al*., 2024). Tactics including educational campaigns, organized demonstrations, and the dissemination of empirical evidence regarding the efficacy of RWH may assist in transforming community attitudes. Conversely, while perceptions about the benefits, ease of operation, and accessibility of RWH are important, even though these factors do not appear to have a direct and significant influence on RWH utilization in this study.

Extracting groundwater

Rapid urbanization and industrial growth in North Jakarta have significantly increased the demand for groundwater. The growth of the population, coupled with the proliferation of businesses and industries in North Jakarta, has led to a marked increase in the demand for water, essential for both domestic consumption and industrial activities. Groundwater often becomes the primary source of water supply, especially in areas with insufficient access to piped water infrastructure. An inadequate water distribution system intensifies the reliance on groundwater, thereby further depleting local aquifers. The combination of high demand and limited alternative water sources leads to the over-extraction of groundwater. Although there is a positive influence of perceptions on the utilization of RWH, the existing usage pattern still shows a reliance on groundwater. On average, households use 174.6 L of groundwater per day, compared to 58 L of rainwater harvested through the RWH technology. This implies that despite the adoption of RWH technology, it currently represents merely around 33% of the total daily water usage. Groundwater remains the predominant source, although residents regard its quality as inadequate. These findings align with the analysis of RWH capacity and availability. All RWH users reported that their current system capacity does not fully meet their daily water needs, which is a significant barrier to further RWH utilization. Further analysis shows that if the RWH system could meet 70-80% of daily water needs, or approximately 116 liters per day (L/day), reliance on groundwater could be significantly reduced. Rainwater harvesting potentialities to reduce over extraction of groundwater (Munna *et al*., 2020). This approach would confront a critical challenge, as a substantial number of households still depend on groundwater for their primary water needs, and the inadequate capacity of RWH systems restricts further application. In this regard, the results of observations of 53 wells utilized by inhabitants, 49.06% have a height of 1.01-3.00 meters (m), followed by 0.15-1.00 m (33.96%) and 3.01-5.00 m (13.21%), as shown in Table 8. The JPES report from 2021 indicates that the depths of wells at 53 observation points were found to be adequate, all being under 10 meters. Additionally, the region was not designated as a groundwater free zone in DKI Governor Regulation Number 93 of 2021 due to unbalanced distribution of pipe water. However, in response to the dramatic acceleration in the pace of land subsidence, Abidin *et al*. (2012) recommended for total restrictions on groundwater use along the coast of North Jakarta.

Land subsidence

These various descriptions and arguments highlight the importance of improving RWH system capacity and availabilityBy establishing sufficient infrastructure for enhanced daily RWH, communities could lessen their reliance on groundwater, thereby offering a more sustainable water solution for households moving forward. The long-term impact is a reduction in land subsidence rates, which have

Table 8: The depth distribution of Wells used by residents

Well depth (m)	Total	
	n	%
0.15-1.00	18	33.96
1.01-3.00	26	49.06
3.01-5.00	7	13.21
5.01-10.00	3	3.77
>10.00	0	0

been increasing at 1-25 cm/y (1991-1997) and 1-28 cm/y (1997-2011) (Abidin *et al*., 2011). This is consistent with the statement of Kumar *et al*. (2017) that groundwater extraction contributes significantly to land subsidence and other surface water pollution, which degrades the environment. Additionally, the geographical deployment of RWH technology is vital for addressing land subsidence issues. The success of this technology is influenced by its positioning, which should align with the urgency of the area's subsidence rate. Based on the results of the spatial analysis, the placement of the RWH installation in the case study location does not significantly contribute to land subsidence mitigation efforts in North Jakarta, considering that the height of the land subsidence ranges from low as 0-0.5 m to moderate (0.5-1 m), as shown in Fig. 3. Nevertheless, its positioning within densely populated and unplanned residential zones tackles the challenges that emerge. In this case, comparison between Figs. 3 and 4 reveals that moderate leve lof land subsidence tend to be found in densely unplanned settlements along the coastal área.

Besides densely unplanned residential areas, a comparison of Figs. 3 and 4 illustrate that industrial and office areas, as well as other built-up areas also have moderate levels (0.5-1 m). The areas exhibiting slight land subsidence (0-0.5 m) were largely comprised of strategically planned communities (Fig. 3). According to Hasibuan *et al*. (2023), the high level of land subsidence in densely unplanned settlement along the North Jakarta coastal area was caused by the massive groundwater extraction due to lack of access to piped wáter. Groundwater emerged as the most viable option for them due to its lower cost and greater accessibility (Hargianintya *et al*., 2020). The policy of limiting groundwater use, as outlined in Governor Regulation Number 93 of 2021, does not designate this area as the groundwater-free zone priority. As per the regulation, the groundwater-free zone in North Jakarta is designated exclusively for arterial routes that experience extensive infrastructure development and elevated mobility levels.

North Jakarta, located along the northern coastline of Jakarta, has undergone rapid urbanization over the past few decades. The region, which was initially known for its large wetlands, productive agricultural lands, and thriving mangrove ecosystems, has been significantly altered, now featuring industrial zones, commercial establishments, housing developments, and infrastructure projects. North Jakarta has seen an expansion of industrial areas, with many factories and shipping ports being concentrated in this part of the city due to its strategic location along the coast. There has been a proliferation of informal residential zones, which has led to an increase in population density, notably in the northern sub-districts. In Kalibaru disstrict (Fig. 4), the city settlement has dominated the área, then folllowed by the industrial áreas. In this study, while the role of RWH was foucused as a potential solution to reduce groundwater dependence, it is acknowledged that mitigating land subsidence requires a multi-faceted approach, including stricter groundwater management policies, urban planning strategies, and long-term monitoring to better address.

Policy implications on RWH implementation to mitigate land subsidence

Governor Regulation number 31/2022 on detail spatial plan of Jakarta emphasizes trategies to meet the clean water needs of all segments of society, both through increasing the water supply capacity from Regional Drinking Water Company and the utilization of alternative technologies. This plan advocates for the advancement of Jakarta's water distribution system, focusing on creating a more efficient infrastructure and extending the pipeline network to areas that have not been adequately served by clean

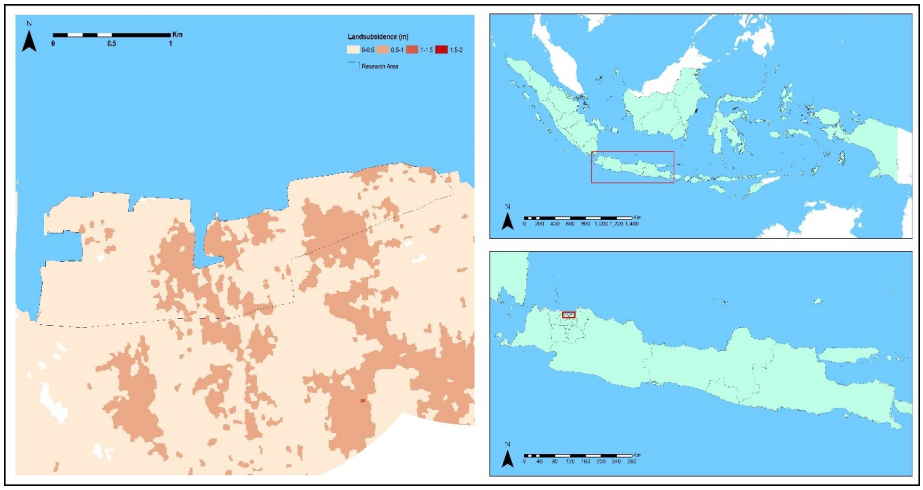

Fig. 3: Landsubsidence in North Jakarta

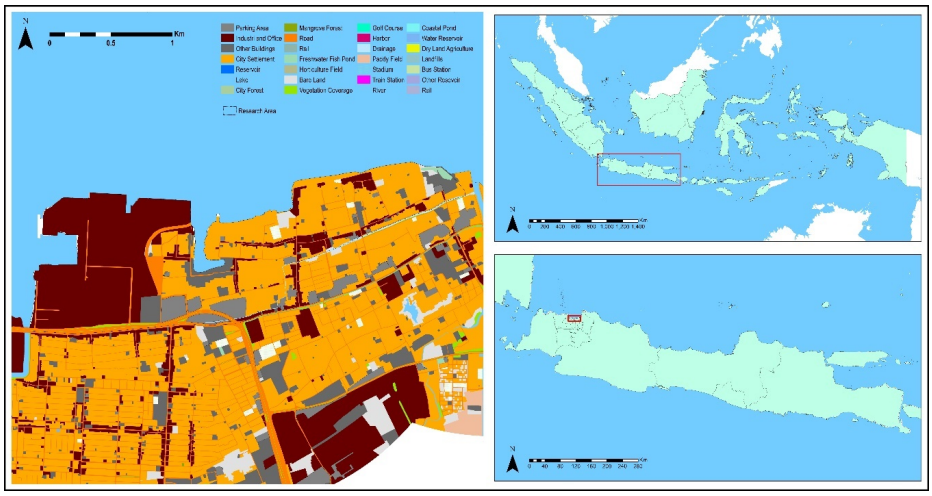

Fig. 4: Land use in the case study location

water. In areas that are already served by the drinking water network, the extraction of groundwater for business purposes is prohibited, and the extraction of groundwater is restricted.

Land subsidence is a complex issue influenced by various factors, and RWH should be considered as part of a broader, integrated approach to addressing environmental and urban challenges. As a result, additional study is necessary to establish a clear relationship between RWH and the reduction of land subsidence. Enhancing the adoption of RWH technology in North Jakarta's coastal areas requires a multi-pronged approach that addresses both technical and socio-economic factors. Several strategies can be considered as below:

1) Expanding RWH

Launching pilot RWH initiatives in well-trafficked areas can provide concrete examples that highlight the technology's effectiveness and benefits. Demonstrating success through these projects can enhance credibility and stimulate greater adoption (Alazzam *et al*., 2024).

2) Incentives and subsidies

To make RWH systems more affordable, especially in low-income areas, government subsidies, tax incentives, or low-interest loans could be introduced. Beside that RWH investation, operation, and maintenance are low cost (Richards *et al*., 2021).

3) Awareness and education campaigns

Raising awareness of the benefits associated with RWH is vital, especially regarding its impact on reducing dependence on groundwater and helping to manage flood risks.

4) Policy and regulatory support

The introduction of policies that promote RWH, such as building codes that require or incentivize RWH systems in new developments, could significantly boost adoption. Establishing a supportive regulatory framework necessitates effective collaboration between local governments, the private sector, and environmental agencies. By expanding RWH systems would provide an alternative source of water, reducing the demand for groundwater. This reduction in groundwater extraction can slow the decline of the water table and mitigate the risk of over-extraction, which is a major contributor to land subsidence. Implementing this approach would aid in reinforcing the ground level and preventing further environmental and structural degradation due to sinking land. Rainwater Harvesting offers a sustainable, resilient, and cost-effective solution to urban water management challenges. By reducing dependence on conventional water sources, mitigating land subsidence, enhancing water security, and reducing urban flooding, RWH can contribute significantly to achieving sustainability in urban water management (Furumai, 2008).

CONCLUSION

In Jakarta, particularly in the northern region, the accelerated urbanization and heightened water needs have caused a considerable reliance on groundwater for consumption and industrial activities. The excessive pumping of groundwater causes the soil to compact, which results in the land sinking over time. This has led to alarming rates of subsidence in some areas of North Jakarta, with the ground sinking by several centimeters each year. To effectively combat land subsidence, it is essential to decrease the over-extraction of groundwater resources. Implementing more sustainable water management practices, such as promoting, expanding and improving rainwater harvesting usage, could help alleviate the pressure on groundwater resources. Given these challenges, the implementation of rainwater harvesting offers a promising approach that can directly affect the rate of land subsidence while fostering sustainable urban growth in the region.The rapid growth of the population and industries in North Jakarta has placed a high demand on water, with many residents and businesses relying on groundwater extracted from deep wells. Over time, excessive groundwater pumping causes the soil to compact, leading to the gradual sinking of the land, which has been measured at alarming rates in certain areas. The main cause of land subsidence in this region is attributed to the depletion of groundwater resources. The height of the land subsidence ranges from low (0-0.5 m) to moderate (0.5-1 m) in North Jakarta. Rainwater harvesting involves collecting and storing rainwater for later use, reducing the demand for groundwater. Introducing rainwater harvesting systems in urban settings like North Jakarta can help diminish the reliance on groundwater, which may lead to a direct decrease in the occurrence of land subsidence. By providing an alternative water source, rainwater harvesting directly limits the over-extraction of groundwater, which is a key factor in land subsidence. The more rainwater is harvested and utilized, the less groundwater needs to be extracted, helping maintain the natural equilibrium of the region's hydrological system. The introduction and scaling up of rainwater harvesting could encourage community participation in urban water management. By participating in educational programs and local initiatives, community members can gain a deeper understanding of the critical role that water conservation and environmental sustainability play in their lives. This community-driven approach helps foster a sense of collective responsibility in tackling both land subsidence and broader environmental challenges. The introduction of policies aimed at promoting rainwater harvesting, paired with educational efforts to raise awareness of its benefits, has the potential to significantly reduce groundwater extraction and enhance sustainability in urban ecosystem. This study primarily focuses on the perceptions of RWH systems among residents on one subdistrict of North Jakarta;

therefore, the findings may not be directly applicable to other regionsIn light of the specific circumstances surrounding the study area, it is essential to conduct further research to assess the practical deployment and scalability of RWH systems across a more extensive geographic landscape. Future investigations should assess the direct impact of RWH adoption on reducing groundwater extraction and mitigating land subsidence, contributing to a more comprehensive understanding of its potential in addressing these environmental challenges.

AUTHOR CONTRIBUTIONS

H.S. Hasibuan, the corresponding author, has contributed in supervising the data analysis, interpreted the results, and writing the final manuscript. B.N. Ellizandri has analyzed data and writing the draft manuscript,. F.W. Asrofani has analyzed data respondents and interpreted the results.. G.A.Y. Putra has collected spatial data and GIS mapping and visualization.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

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ABBREVIATIONS

%	Percent
^0C	Degree Celcius
CBSJP	Central Bureau of Statistic of Jakarta Province
cm/y	Centimeter per year
DKI	Daerah Khusus Ibukota
DInSAR	Diffential interferometry synthetic aparture radar
E-coli	Escherichia coli
JPES	Jakarta Province Environmental Service
km	Kilometer
L	Liter
L/day	Liter per day
L/month	Liter per month
m	Meter
m^2	Square meter
m^3	Cubic meter
mg	milligram
mg/L	Milligram per liter
mL	Milliliter
mm	Millimeter
mm^3	Million cubic meter
mm/month	Millimeter per month
mm/y	Millimeter per year
Mn	Manganese
NICFI	Norwey's International Climate and Forest Initiative
NTU	Nephelometric Turbidity Unit
P	Probability

PDAM	Perusahaan Daerah Air Minum
pH	Potential of hydrogen
p-Value	Probability value
R Square	Regression square
RW	Rukun Warga
RWH	Rain Water Harvesting
SAR	Synthetic aparture radar
SLC	Single look complex
SNAP	Sentinel application platform
TCU	True colour unit
TDS	Total dissolved solids
TOPSAR	Terrain Observation with Progressive Scan Synthetic Aparture Radar
UN	United Nation
USD	United State Dollar
USD/month	United State Dollar per month
USGS	United State Geological Survey
WHO	World Health Organization

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