Sustainable Water Resources Management (2024) 10:131
https://doi.org/10.1007/s40899-024-01112-4

ORIGINAL ARTICLE

Can we ensure access to water for all? Evidence from Batang coastal area, Indonesia

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Received: 19 April 2023 / Accepted: 18 May 2024

Abstract

Drinking water supplies located along the coast of Indonesia face susceptibility to saltwater pollution due to seawater intrusion, including in the coastal area of Batang, Indonesia. Therefore, this study aims to determine the community's ability to access water in the Batang coastal area following the seawater intrusion phenomenon. First, an interpolation in ArcGIS based on the electrical conductivity measurements of 40 wells was done to identify and visualize areas affected by seawater intrusion. Furthermore, we interviewed 116 respondents and employed the contingency valuation method to calculate and analyze the public willingness to pay (WTP) for improving drinking water sources contaminated with saltwater due to seawater intrusion. The results showed that the groundwater near the coast was already contaminated with salt water, with the highest electrical conductivity value reaching 3999 µmhos/cm. Furthermore, the economic valuation analysis results show that the expected WTP of the entire population for enhancing water quality is IDR 17,830 (~1.1€). The expected WTP of the population affected and not affected by the intrusion is IDR 31,150 (~2€) and IDR 14,800 (~0.9€), respectively. Compared with the minimum wage in Batang in 2022, i.e., IDR 2,132,535, the expected WTP for the entire population, the population affected, and not affected by the intrusion, were 0.84%, 1.46%, and 0.69%, respectively. This study offers valuable insights for future investigations and serves as a foundational reference for local governments and communities in their efforts to enhance water quality in natural ecosystems through more comprehensive and efficient strategies.

Keywords Economic valuation · Willingness to pay · Seawater intrusion · Coastal environment · Batang

Introduction

Access to clean and uncontaminated water is a fundamental requirement for maintaining good health and overall well-being. The demand for water is increasing due to the rapid rise of the population, urbanization, and expanding water requirements from the agriculture, manufacturing, and energy sectors (Vörösmarty et al. 2000; McDonald et al. 2011; Vaseková 2022; Krishnapillai et al. 2023; United Nations 2024). In many developing countries, population growth, rapid urbanization, economic development, a lack of effective governance, the encroachment of saline into freshwater sources, the accumulation of sediment in deltaic regions, and the limited availability of water resources have all indirectly contributed to inequality of access and inefficient management of water resources (Ringler et al. 2016; Saha et al. 2021; Benaafi et al. 2023). In addition, groundwater quality is deteriorating as a result of both natural and man-made pollutants, which is further decreasing the amount of usable freshwater (Benaafi et al.

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2023). Climate change and sea level rise also introduce an additional level of complexity, may result in seawater intrusion, and will affect the availability of drinking water (Sallenger et al. 2012; Sweet et al. 2017; Alameddine et al. 2018; Safi et al. 2018; Lin et al. 2019; Sarupria et al. 2023; Ningsih and Mutaqin 2024; Widantara and Mutaqin 2024).

Coastal areas worldwide have the potential to experience seawater intrusion, a process by which saltwater from the ocean or estuaries enters freshwater systems (Fetter 2001; Rushton 2003; Davie 2008; Werner et al. 2013; Singh 2014; Purnama and Cahyadi 2019). Seawater intrusion is often considered the only factor causing the saltwater pollution phenomenon. However, saltwater pollution can also be caused by (1) fossilized water that was trapped on land in the past, (2) the rapid evaporation of lagoons, marshes, lakes, and other enclosed areas, (3) the spraying of seawater along the coast, (4) storms and tides that happen on low-lying coasts and estuaries, (5) groundwater dissolving diapir (salt dome) and evaporite rock, and (6) the return of salty groundwater and rock salt from the past, (7) agricultural waste, domestic waste, and industrial waste, as well as (8) backwater effect, which refers to a distinct phenomenon wherein the migration of saline water occurs near the river mouth due to an inadequate supply of fresh water to counterbalance the incoming tidal water from the sea (Custodio 1993; Todd and Mays 2005; Werner et al. 2013; Singh 2014; Mahmuduzzaman et al. 2014; Alameddine et al. 2018; Safi et al. 2018; Loc et al. 2021). However, natural-static fossil water and the dynamics of the groundwater interface due to groundwater extraction, seasons, or tides are the main causes of saltwater existence on land (Vandenbohede and Lebbe 2006; Kim et al. 2009; Purnama and Marfai 2012; Werner et al. 2013; Singh 2014). Due to its dynamic nature, saltwater pollution due to seawater intrusion is hazardous and needs to be anticipated as early as possible. This is also one of the targets declared by the United Nations Sustainable Development Goals, which aim to improve water quality by reducing pollution by 2030 (United Nations 2024).

Human activities may accelerate the seawater intrusion phenomenon, mainly due to excessive groundwater exploitation, the rapid development of settlements in urban areas, and shrimp and fish farming businesses on the coast (Werner et al. 2013; Singh 2014; Safi et al. 2018). In the early stages, there was a decrease in the groundwater level in the community's wells, so the volume of groundwater decreased. As a result, the pressure of fresh water in the soil is decreased, and saltwater from the sea may infiltrate into the land (Vandenbohede and Lebbe 2006; Kim et al. 2009). However, natural environmental factors like the rocks along the coast, the rate at which groundwater flows to the sea, backwater effects, and changes in groundwater levels in coastal areas can also lead to seawater intrusions (Singh 2014; Mahmuduzzaman et al. 2014; Alameddine et al. 2018; Safi et al. 2018; Loc et al. 2021). In the case of the Indonesian coastal area, almost all areas on the northern coast of Java Island have been polluted by salt water, which is generally caused by fossil water (Kloosterman 1989; Rahmawati et al. 2013). The northern coast of Java is an alluvial plain formed by fluvio-marine processes. In this coastal aquifer, there are lenses of marine clay deposits, which in these lenses are trapped salty fossil water since this formation was formed during sea inundation (Mutaqin et al. 2015; Septiangga and Mutaqin 2021). However, sea water has also been detected in several places on the north coast of Java, including in the Batang coastal area (Nirwansyah and Suwarsito 2020; Wibisana 2022; Brillyanto 2022).

Batang is located on the north coast of Java Island and is located between 109° 40′ 24″ and 110° 03′ 12″ East Longitude and 06° 52′ 01″ and 07° 11′ 47″ South Latitude (Fig. 1). Based on its hydrogeological aspect, Batang consists of two aquifer systems: unconfined and confined aquifers, which have a discharge of 427 million m^3/year and 8 million m^3/year, respectively (Setiadi 2003; Marfai et al. 2021). The potential for deep groundwater in the four coastal sub-districts in Batang, i.e., Batang, Gringsing, Subah, and Tulis, varies greatly. The thickness of the shallow aquifer in the Batang coastal sub-district varies from 0.3 to 44 m at a depth range of 0–58 m. Meanwhile, the thickness of the deep aquifer is in the range of 10–138 m, with a depth of between 40 and 187.5 m (Batang Environmental Agency 2009). However, until now, there has been a lack of research on saltwater pollution in the Batang coastal area (Wibisana 2022; Brillyanto 2022). This condition is very worrying since the industrial sector in Batang is growing due to the existence of a steam power plant (PLTU) and the establishment of the Batang Industrial Estate (Mutaqin et al. 2015). Likewise, the local government plans to build office and hotel superblocks that require water. If the development of this area is not anticipated as early as possible, the problem of seawater intrusion will get worse. Indeed, various movements have overcome this problem, such as the movement to save water through infiltration wells, biopores, or biopore infiltration holes. However, the effectiveness of this movement is still questionable because it is not known with certainty the distribution of seawater intrusion on the mainland of Batang or the level of community willingness to pay to improve the condition of their water sources. As a result, it's important to visualize the area that the intrusion has affected and to conduct an economic analysis of the community's willingness to spend more money on repairing water sources. Moreover, about 54.31% of people in Batang used water from wells, 24.14% used water from the Community-Based Drinking Water and Sanitation Provision Program, and 21.55% used water from

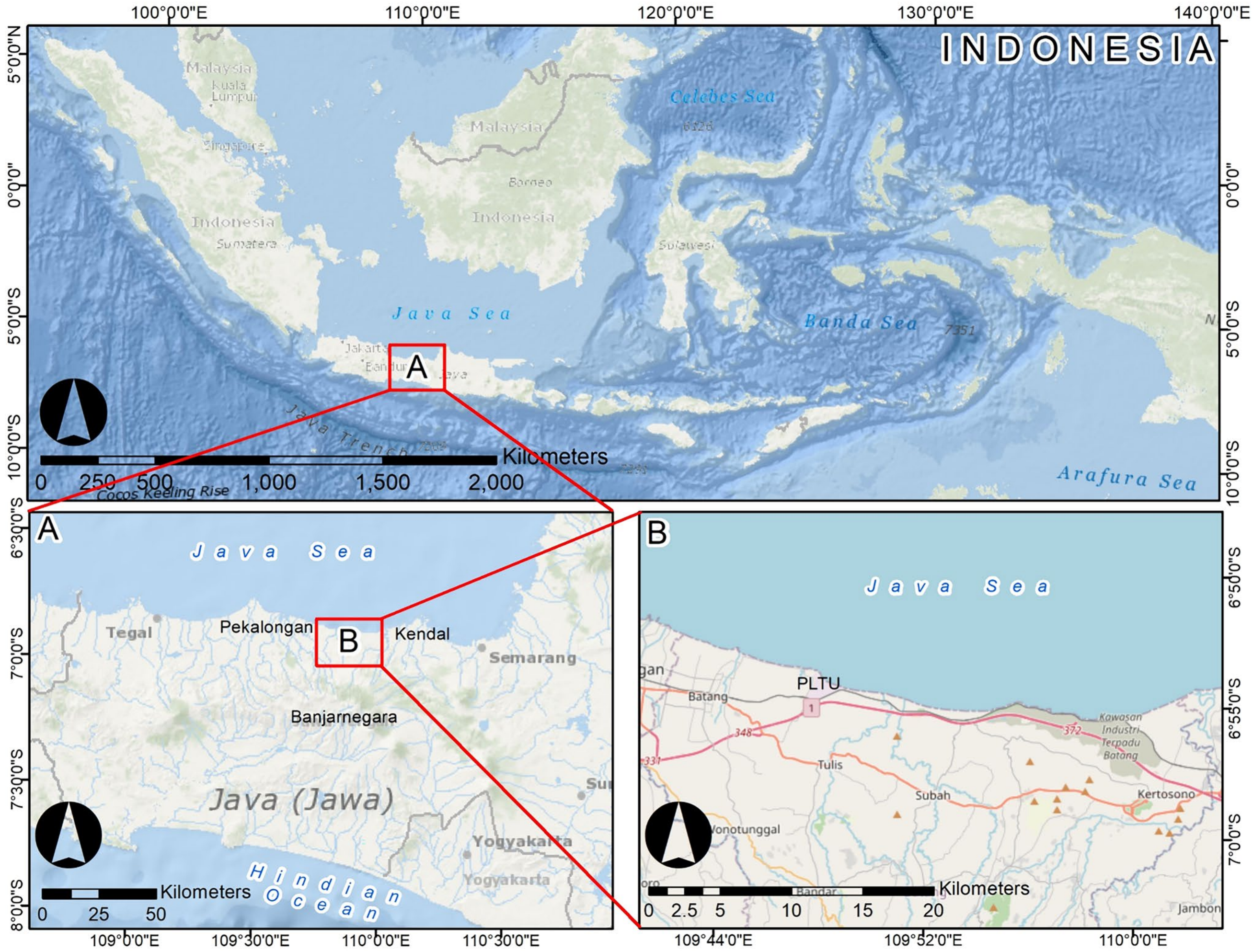


Fig. 1 Study area in Batang Regency (**a**), which is divided into coastal, lowland, and mountainous regions with a steam power plant (PLTU) situated in the coastal part (**b**)

regional drinking water companies (Statistics of Batang Regency 2022).

Researchers have conducted numerous studies to understand the willingness to pay (WTP) for enhancing water quality. The measurement methods frequently employed in previous research include the Life Satisfaction Approach, Contingent Valuation Method, point and interval data model, and choice experiments (Hanley et al. 2005; Polyzou et al. 2011; Tussupova et al. 2015; Jianjun et al. 2016; Fontainhas et al. 2016; Aguilar et al. 2018; Saz-Salazar et al. 2019; Dessale et al. 2022; Galarza Arellano et al. 2023; Hao et al. 2023). The existing body of research pertaining to the WTP for water quality enhancements primarily centers on economically advanced regions, with limited attention given to emerging countries and their financially disadvantaged areas (Dessale et al. 2022; Galarza Arellano et al. 2023; Hao et al. 2023). Hence, it is crucial to understand the various viewpoints of stakeholders in the management of water resources through the evaluation of the willingness to pay (WTP) (Tussupova et al. 2015; Phan et al. 2021; Dessale et al. 2022; Galarza Arellano et al. 2023). Understanding this concept is essential for developing a viable, enduring plan to tackle the increasing water demands resulting from socio-economic advancement (Phan et al. 2021; Sarupria et al. 2023; Benaafi et al. 2023; United Nations 2024), particularly in the Batang coastal areas of Indonesia, which is still classified as a developing nation. Hence, this study aims to determine the community's ability to access water in the Batang coastal area following the seawater intrusion phenomenon. Do the communities have the necessary financial resources to restore the drinking water sources that seawater intrusion has compromised? The results can be used to better identify the proper policy choice that may be applied in the future and the level of service to be provided, making coastal water projects both sustainable and replicable, either on a larger scale or in other coastal areas in Indonesia.

Methods

Identification of seawater intrusion

The identification of seawater intrusion is based on the electrical conductivity of water, which significantly correlates with the concentration of total dissolved solids in groundwater (Karuppaiah and Gopal 2023; Ma et al. 2024). Electrical conductivity refers to a substance's ability to facilitate the flow of an electrical current. In the context of solutions, the existence of charged ion species within the solution contributes to its conductive nature (Freeze and Cherry 1979; Kamal et al. 2020). The higher the number of ions in the water, the higher the electrical conductivity. Natural waters have an electrical conductivity range between 50 and 1500 µmhos/cm; therefore, water with an electrical conductivity of fewer than 1500 µmhos/cm is considered tasteless, 1500–3000 µmhos/cm is considered brackish, and if the electrical conductivity is more than 3000 µmhos/cm, it tastes salty (Walton 1970; Purnama and Marfai 2012; Purnama and Cahyadi 2019; Kamal et al. 2020). We conducted electrical conductivity measurements in wells located along the coastal areas of Batang. We determined the wells through systematic random sampling. We create a grid on the research area map, ensuring a field size of 3 km × 3 km. A well is randomly determined on each grid, for which the electrical conductivity will be measured. We then interpolated electrical conductivity data from 40 wells, measured between June 26–30, 2022, using the Topo to Raster function in ArcGIS. We used the Topo to Raster tool because its design prioritized computational efficiency for local interpolation methods such as Inverse Distance Weighted, while preserving the surface continuity of global interpolation methods like Spline and Kriging (Mutaqin et al. 2019; Shehata et al. 2024). We could refer to the method as a discretized thin plate spline method (Wahba 1990), and its modified roughness penalty enables the digital elevation model (DEM) to accurately depict the rapid changes in terrain. Topo to raster is a method that uses input data to create a raster with interpolated values. It enforces restrictions to ensure that the resulting raster accurately represents a connected drainage structure and correctly depicts ridges and streams (Shehata et al. 2024). Even though the Topo to Raster feature does not honor input data values, it instead produces a hydrologically correct, smoothed surface that is useful for this study (van der Waal et al. 2023).

Determination of samples and respondents

The population in this study is all the communities in the Batang coastal area, which is administratively located in the north, bordering the Java Sea. We determined the sample size using the quota sampling technique. In this case, the researcher has determined the sample size first. Non-probability sampling, known as sample quota, involves selecting a predetermined number of samples from the population under study, and this is done if the population number is uncertain (Wulandari 2022). The administrative area boundaries of the six sub-districts in the Batang coastal area, namely Batang, Banyuputih, Gringsing, Kandeman, Subah, and Tulis sub-districts, divide the population into subgroups (Fig. 2). Each sub-district had 19–20 samples, so there were 116 samples representing the entire population. The analysis of the community's willingness to pay (WTP) to determine the ability and willingness of the community to pay for the provision of clean water was represented by 116 respondents. We carry out in-depth interviews with stakeholders to analyze the data from WTP, in addition to using the questionnaire. The purpose of doing this is to verify the respondents' responses. The stakeholders in question come from government circles, including representatives from villages, districts, and institutional apparatuses.

Economic valuation and willingness to pay (WTP)

The Contingent Valuation Method (CVM) can be used to study community or individual preferences for discomfort since personal preferences for an object are not the same; hence, the concept of benefit is interpreted in different ways (Munasinghe 1993; Dessale et al. 2022; Windayati et al. 2022; Galarza Arellano et al. 2023). CVM is a potential technique to measure the value of goods that are not exchanged in the market or do not have a market price (He and Zhang 2021; Galarza Arellano et al. 2023). CVM uses surveys and interview techniques to estimate the value individuals or communities place on increasing or decreasing environmental quality in a hypothetical market (Dessale et al. 2022; Windayati et al. 2022). According to Whittington et al. (1993), resource and environmental economists in industrialized nations are increasingly using CVM to estimate the benefits of environmental development and public goods. This study applied the CVM theory, utilizing the willingness to pay (WTP) welfare measure, to analyze the willingness to pay. WTP is the amount an individual or group of people is willing to pay to restore the conditions of welfare or satisfaction they originally got, which in this case is a source of drinking water (Pearce and Turner 1990; Owusu et al. 2011; Pramaningsih et al. 2018; Windayati et al. 2022;

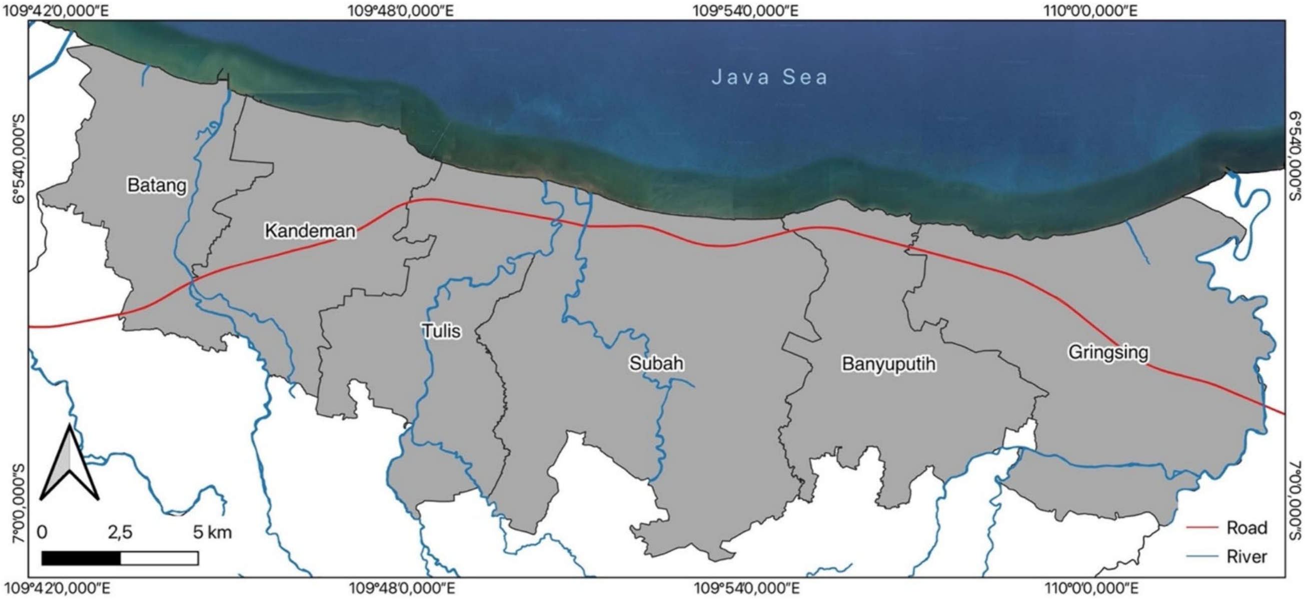


Fig. 2 Samples and respondents were chosen based on the population that lives in the six sub-districts in the Batang coastal area, i.e., Batang, Banyuputih, Gringsing, Kandeman, Subah, and Tulis sub-districts

Krishnapillai et al. 2023). Each individual determines their own WTP based on factors such as environmental harm, discomfort, or changes in welfare due to resource use or management, and this is because there is no market price for these values (Whittington et al. 1993; Owusu et al. 2011; Alameddine et al. 2018; Safi et al. 2018; Windayati et al. 2022; Krishnapillai et al. 2023).

The CVM theory emphasizes a direct environmental object valuation technique that involves asking residents about their willingness to pay. It highlights individual preferences for assessing public objects with a standard value of money so that all non-traded commodities can be estimated for their economic value (Owusu et al. 2011; Alameddine et al. 2018; Safi et al. 2018; Windayati et al. 2022; Krishnapillai et al. 2023). The implementation of CVM to measure the economic value of changes in welfare includes the following stages:

1. Forming a hypothetical market: in this research, the hypothetical market formed is a market with different conditions from the current condition of water sources. We asked the respondents to listen to or read the statements in the questionnaire, assuming that they would build a water supply installation by drilling wells or distributing water from a water treatment plant at the community's expense. Based on this statement, a measure of consumer behavior will be obtained in a hypothetical situation, not an actual one (Dessale et al. 2022; Windayati et al. 2022; Galarza Arellano et al. 2023).
2. Get the bid value: after the respondent is given a detailed and precise description of the water condition they will receive after the water installation is built from the Regional Drinking Water Company, as well as the compensation that must be borne, the offer value is given to the respondent. This study employed the bidding method, offering a range of WTP values (Jordan and Elnagheeb 1993; Owusu et al. 2011; Pramaningsih et al. 2018; Windayati et al. 2022; Krishnapillai et al. 2023).
3. Calculating the expected WTP, which is determined by the formula (1) as follow:

$$EWTP = \sum_{i=1}^{n} Wi.Pfi \tag{1}$$

where EWTP is the expected WTP, W is the lower limit of the WTP class, Pf is the relative frequency of the class in question, n is the number of classes, and i is the ith class. Furthermore, the research framework related to this research is shown in Fig. 3.

Results and discussion

Seawater intrusion analysis

As previously stated in the method section, the high and low electrical conductivity values highly depend on the amount of ion concentration and water temperature (Karuppaiah

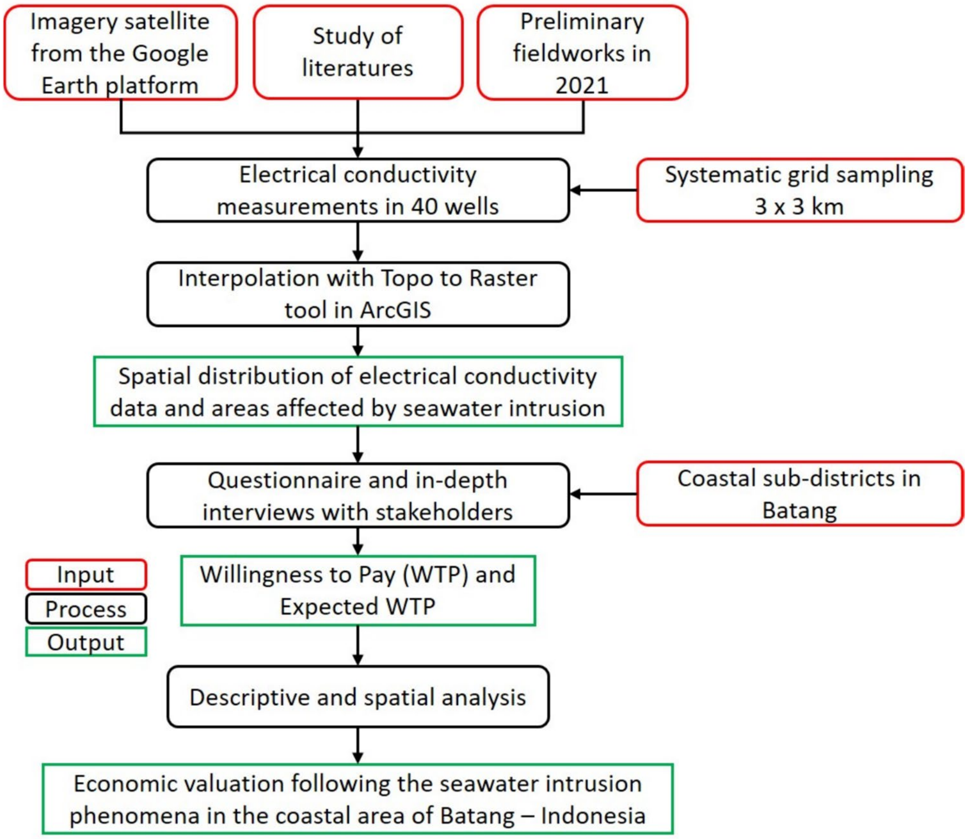
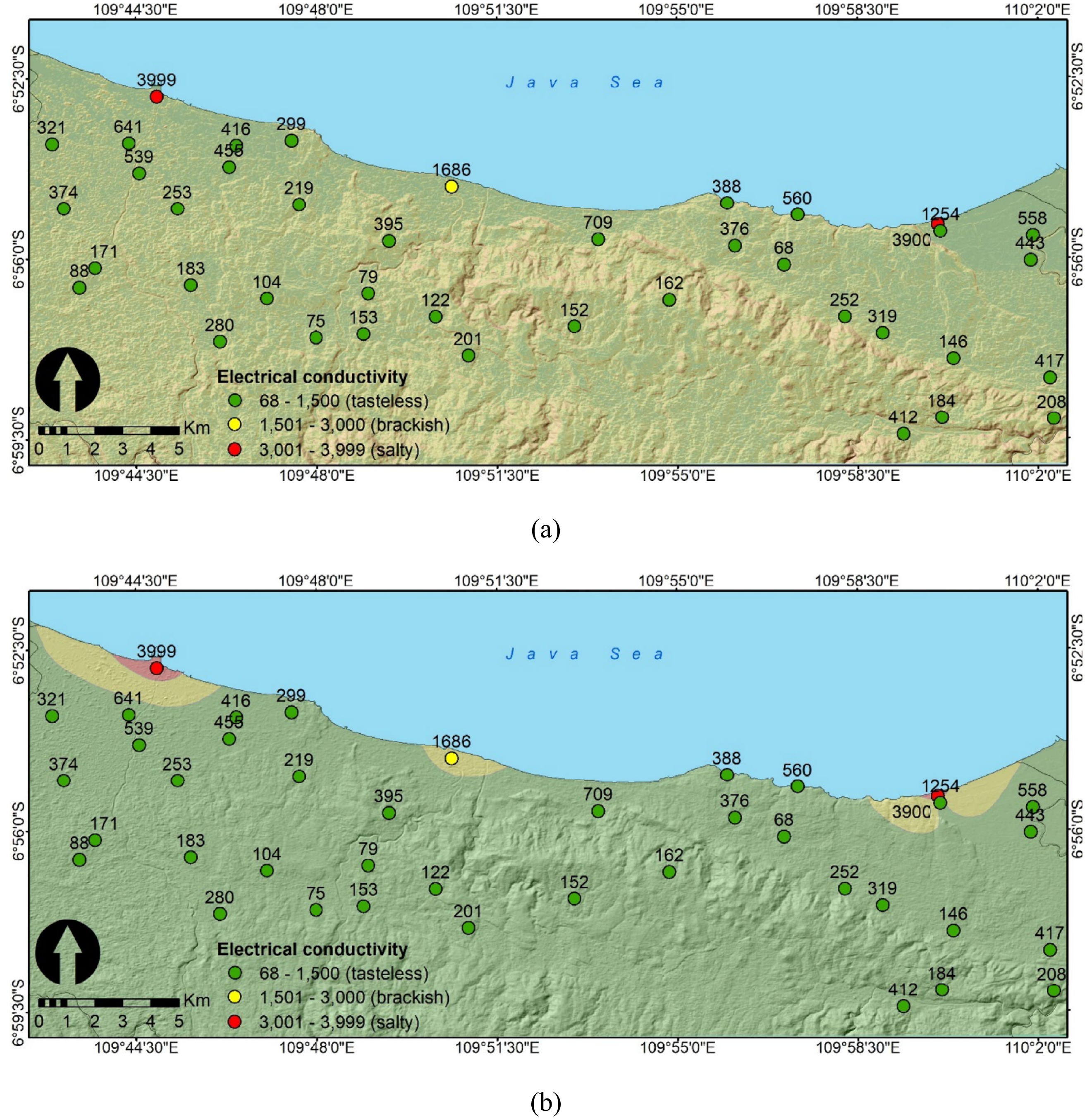


Fig. 3 The research framework to reach aims

and Gopal 2023; Ma et al. 2024). The measurement results indicate that the groundwater temperature remains within the normal range, indicating that the high electrical conductivity value is primarily due to the magnitude of the ion concentration. Furthermore, field measurements show groundwater in the study area on June 26–30, 2022, has the lowest and highest electrical conductivity values of 68 µmhos/cm and 3999 µmhos/cm, respectively (Fig. 4). Figure 4 illustrates the significant impact of groundwater with increased electrical conductivity in 2022 on the northern regions of Batang, Subah, and Gringsing sub-districts, all classified as low-lying areas. This phenomenon occurred in close proximity to the shoreline, implying that these regions have experienced seawater intrusion. Other areas that are not situated in low-lying areas, specifically Banyuputih, Kandeman, and Tulis sub-districts, continue to possess fresh-tasting groundwater. From this phenomenon, it is evident that the distance from the shoreline and the topographic characteristics play a crucial role in determining the variations in groundwater electrical conductivity in the research area. Proximity to the shoreline directly correlates with increased electrical conductivity levels in groundwater (Werner et al. 2013; Singh 2014; Alameddine et al. 2018; Safi et al. 2018). Our findings are consistent with similar studies conducted elsewhere, including in regions such as Southern Italy, South Portugal, Thailand, Mexico, and Western Australia. Proximity to the shoreline increases the susceptibility of an area to seawater intrusion (Satriani et al. 2012; Peinado-Guevara et al. 2012; Martínez-Moreno et al. 2017; Costall et al. 2018; Vann et al. 2020).

The high electrical conductivity of groundwater in nearshore areas with low-lying terrain is mostly due to the effect of the sea, both in the past and present. This influence leads to elevated quantities of sodium and chloride ions in the groundwater, resulting in increased water salinity. It is well established that an increase in groundwater salinity leads to a corresponding rise in electrical conductivity (Purnama and Marfai 2012; Purnama and Cahyadi 2019). Insufficient rainfall and river flow during the dry season or east monsoon do not effectively recharge groundwater, leading to the intrusion of saline water with high electrical conductivity (Mirza 2004; Saha et al. 2019; 2021). To address saltwater intrusion in the Batang coastal area, it is necessary to implement substantial policy changes. The area's intended development as an industrial sector for steam power plants, an integrated industrial zone, and office and hotel superblocks makes it particularly important (Mutaqin et al. 2015; Wibisana 2022; Brillyanto 2022). These activities are strongly linked to the increase in water usage and can have a substantial impact on the transformation of



(a)

(b)

Fig. 4 Electrical conductivity (EC) in the study area is divided into 3 categories: < 1500 µmhos/cm (tasteless); 1500–3000 µmhos/cm (brackish); and > 3000 µmhos/cm (salty). Spatial distribution of sample EC data (**a**) and areas affected by seawater intrusion (**b**)

agricultural land into developed land (Benaafi et al. 2023; Sarupria et al. 2023; Ningsih and Mutaqin 2024; Widantara and Mutaqin 2024). A food shortage may be the secondary effect of these events due to insufficient agricultural land and water resources. This issue has become a top concern in the National Adaptation Programmes of Action in various underdeveloped nations in South and Southeast Asia (Saito 2013).

It is recommended that the government prioritize improving water pollution infrastructure and using a customized construction method. This involves giving priority to the construction of water pollution management infrastructure based on the specific water pollution features observed in different geographical regions (Hao et al. 2023; Benaafi et al. 2023). Additionally, experts advise implementing strong governance, efficient policies, and a variety of adaptations to tackle the problem of saltwater intrusion in the Batang coastal area. These adaptations may include practical protective measures or modifications to the natural environment, along with the establishment of alternative sources of drinking water (Hoque et al. 2016; Saha et al. 2021; Benaafi et al. 2023).

Willingness to pay (WTP) analysis

The results of the implementation of CVM in this study are as follows:

1. Hypothetical market: respondents gain insight into the caliber and volume of water sources and can assess whether the local government intends to enlarge the distribution network of drinking water facilities in the vicinity.
2. Acquired bid value: The questionnaire asked respondents about the monetary value they are willing to pay for improved water quality.
3. Expected WTP: the actual WTP of respondent i is thought to be between the answer choices given (lower limit of WTP class, t_{il}) and the next answer choice (upper limit of WTP class, t_{iu}) (Tenaw and Assfaw 2022; Bashe et al. 2022; Dessale et al. 2022).

Table 1 displays the distribution of respondents' willingness to pay (WTP) based on different WTP categories, with the aim of determining the expected WTP (EWTP) of respondents in 2022. According to the calculation results, the estimated value of the EWTP in Batang's coastal area is IDR 17,830, which is approximately equivalent to 1.1€. According to Table 1, the majority of individuals residing in the coastal areas of Batang Regency demonstrate a willingness to pay for the provision of clean water, while just 24.1% of the population express a lack of willingness to do so.

Table 1 Distribution of respondents' WTP and EWTP values in coastal areas of Batang in 2022

WTP Class (IDR)	Frequency	Percentage (Pf) (%)	EWTP (IDR)
0	28	24.1	0
5000–10,000	20	17.2	850
11,000–20,000	12	10.3	1100
21,000–30,000	21	18.1	3780
31,000–40,000	19	16.5	4960
41,000–50,000	0	0	0
51,000–60,000	16	13.8	7140
Total	116	100	17,830

Source: data processing in 2022

In order to gather more information regarding the amount individuals are willing to pay for the enhancement of water conditions, a calculation of willingness to pay (WTP) is conducted for both areas impacted by seawater intrusion and places unaffected by the intrusion. Individuals residing in areas impacted by the intrusion have a willingness to pay (WTP) value of IDR 31,150, according to the calculation results. On the other hand, as shown in Tables 2 and 3, people who live in areas where intrusion has not had an impact have a willingness to pay (WTP) value of IDR 14,800. As a result, the WTP value of the population living in the area where the intrusion has occurred is higher than that of the population living in the unaffected area. This aligns with the findings explained by Jordan and Elnagheeb (1993), Owusu et al. (2011), Alameddine et al. (2018), Safi et al. (2018) and Krishnapillai et al. (2023), who assert that the willingness to pay (WTP) of individuals residing in less favorable regions tends to exceed that of individuals residing in areas with more favorable conditions.

We use the total willingness to pay (WTP) to compute the WTP of the entire consumer surplus population.

Table 2 Distribution of EWTP values of respondents in areas affected by the intrusion in 2022

WTP class (IDR)	Frequency	Percentage (Pf) (%)	EWTP (IDR)
0	1	4.3	0
5000–10,000	0	0	0
11,000–20,000	1	4.3	440
21,000–30,000	8	34.8	7350
31,000–40,000	6	26.2	8060
41,000–50,000	0	0	0
51,000–60,000	7	30.4	15,300
Total	23	100	31,150

Source: data processing in 2022

Table 3 Distribution of EWTP values of respondents in areas not affected by the intrusion in 2022

WTP class (IDR)	Frequency	Percentage (Pf) (%)	EWTP (IDR)
0	25	28	0
5000–10,000	19	20.4	1100
11,000–20,000	16	17.2	1320
21,000–30,000	12	12.9	2940
31,000–40,000	12	12.9	4340
41,000–50,000	0	0	0
51,000–60,000	8	8.6	5100
Total	93	100	14,800

Source: data processing in 2022

Various factors, such as household income, the age and education level of the household head, their perception of the current clean water quality, and uncertainty about the quantity and quality of water they consume, determine an individual's willingness to pay (WTP) for improved clean water quality (Tenaw and Assfaw 2022; Bashe et al. 2022; Dessale et al. 2022). Individuals with higher incomes and younger members of the community tend to exhibit a greater level of concern for environmental quality compared to individuals with lower incomes and older individuals (Tenaw and Assfaw 2022; Bashe et al. 2022; Dessale et al. 2022). The families' propensity to provide financial support for water conservation programs is directly impacted by their perception of the caliber of potable water as well as their awareness regarding the volume and quality of water they now consume (Dessale et al. 2022; Galarza Arellano et al. 2023). Furthermore, those in the community who have received a higher level of education demonstrate a greater level of interest and involvement in environmental conservation initiatives compared to those with lower levels of education (Jordan and Elnagheeb 1993; Owusu et al. 2011; Windayati et al. 2022; Vaseková 2022; Krishnapillai et al. 2023). Ensuring a secure water supply is considered a crucial goal under the Millennium Development Goals (United Nations 2024). Hence, the willingness of people to pay is of utmost importance in the advancement of market-oriented water delivery systems (Tussupova et al. 2015). Examining the determinants of communities' willingness to pay (WTP) for improvements in water quality is essential for protecting water quality and formulating effective governance solutions (Saha et al. 2021; Hao et al. 2023).

Limitations of this study

It is crucial to recognize the constraints of this study and contemplate potential directions for additional inquiry in subsequent research. By integrating additional approaches with electrical conductivity, we can improve seawater intrusion evaluation. We can learn more about seawater intrusions by using geoelectrical surveys and investigations, such as vertical electrical soundings data, time domain electromagnetic techniques, electrical resistivity imaging, and analyzing soil and water samples in the lab. Previous studies by Satriani et al. (2012), Peinado-Guevara et al. (2012), Martinez-Moreno et al. (2017), Costall et al. (2018) and Vann et al. (2020) have utilized these methods to address knowledge gaps in this field. Furthermore, previous studies have confirmed that contingent valuation methodologies might result in overestimated assessments of people's willingness to pay. To reduce the likelihood of this happening, it is recommended to conduct preliminary surveys before gathering official data, employ in-person surveying techniques, and structure the willingness to pay question as a vote with the inclusion of a "no vote" or "do not know" option (Arrow et al. 1993; Wang 1997; Carson et al. 1998; Khong et al. 2018). Furthermore, according to our findings, we believe there is a need for increased promotion and educational campaigns in the Batang coastal region to raise awareness and foster understanding among people about the importance of improving water quality. Water quality is a crucial feature that requires expert management, particularly in light of the climate change phenomenon (Hoque et al. 2016; Benaafi et al. 2023).

Conclusions

Our findings indicated that the groundwater in close proximity to the shoreline and low-lying areas in Batang, i.e., Batang, Subah, and Gringsing sub-districts, was already tainted with saltwater, with the maximum electrical conductivity value reaching 3999 µmhos/cm. Furthermore, the economic assessment indicates that the entire population's expected willingness to pay (WTP) for improving water quality in six sub-districts along Batang coastal areas is IDR 17,830 (about 1.1€). The expected WTP for the population impacted by the intrusion is IDR 31,150 (equivalent to about 2€), whereas the WTP for the population not affected by the intrusion is IDR 14,800 (equivalent to approximately 0.9€). These findings indicate that the individuals not impacted by the intrusion had a lower expected WTP than the intrusion-affected group. Furthermore, the expected WTP of the unaffected group was even lower than the expected WTP of the entire population residing in the coastal area of Batang. The expected WTP for the overall population, the population affected by the intrusion, and the population not affected by the intrusion compared with the minimum wage of Batang in 2022 were 0.84%, 1.46%, and 0.69%, respectively. This study provides useful insights for future research and acts as a fundamental reference for local governments and communities in their endeavors to improve water quality in natural ecosystems through more comprehensive and efficient tactics. Furthermore, to improve the assessment of seawater intrusion's consequences, we recommend integrating additional methods and combining them with electrical conductivity measurements to streamline future research. To overcome the limitations of our study in identifying seawater intrusion, different geoelectrical survey methods, such as vertical electrical soundings, time-domain electromagnetic surveys, electrical resistivity imaging, soil properties and water sample analyses, can be employed.

Acknowledgements Universitas Gadjah Mada funded this research through the Postgraduate School Research Grant 2022, with Setyawan Purnama as the principal investigator. The author thanks master students of Environmental Science for their help and assistance during the data collection, as well as Kendji Girac, Black M, and Nadin Amizah for their support during the writing process. Additionally, the authors thank anonymous reviewers for their helpful comments on this paper.

Author contributions The authors confirm their contribution to the paper as follows: study conception and design: SP, BWM, RH; data collection: SP, BWM, RH; analysis and interpretation of results: SP, BWM, RH, VAP; draft manuscript preparation: BWM, SP, RH. All authors reviewed the results and approved the final version of the manuscript.

Data availability The published article includes all the data generated or analyzed during this study.

Declarations

Conflict of interest The authors declare that they have no conflict of interest.

Compliance with ethical standards The authors were compliant with the ethical standards.

Ethical approval Our paper does not have negative societal impacts. There were no humans or animals used in this research.

Consent for publication All authors are aware of this submission.

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