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Disparities in drinking water services: Private well dependence and public supply inequities in Western Sweden

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ABSTRACT

Studies show that minority and low-income populations often receive lower quality drinking water, increasing their risk for waterborne diseases and adverse health effects. However, most research on this topic has focused on the United States, Canada, South Africa, and India, leaving Scandinavia unexplored. This study examines whether similar disparities exist in Sweden by analysing drinking water access in the Gothenburg region. Using geospatial analysis to intersect drinking water provision areas with socio-economic data, we compare private well-users with municipally supplied populations and then assess whether disparities also appear within municipal supply systems, considering water quality parameters, water price, and pipe breaks. The analysis reveals two key patterns. First, untreated drinking water use among private well-owners is slightly more common in socio-economically advantaged communities, contrasting with evidence from other regions where exposed private well-use is typically associated with disadvantaged groups. Second, within the municipal supply, we find no clear regionwide trends, although the tail end of the distribution shows disparities between the wealthiest and less affluent municipalities, especially in microbial and chemical test results with noted issues and in pipe-break frequency. Sweden's high-resolution socio-economic data and municipal collaboration in sharing drinking water service areas enable these detailed assessments without relying on coarse geospatial proxies. By identifying disparities in both private and municipal drinking water access, this study provides a structured approach that can support Swedish water-expansion planning and contributes to emerging discussions on water justice in high-income countries.

1. Introduction

Providing safe drinking water is essential and one of the primary goals of the UN (United Nations, 2021). Many countries have a well-functioning water supply that fulfils the recommended quality standards. However, even though the quality standards are fulfilled, there can be large differences in the quality of the service provided on a national, regional, or even local level. Such differences are due to different preconditions linked to the water sources as well as the treatment and distribution of water. As a consequence, the service provided to consumers may differ significantly.

Since safe drinking water is a public health issue, it should be equally distributed in a just society. Boone et al. (2009) define just distribution as "an equal distribution of benefits and burdens among individuals or groups". In the case of drinking water supply, injustice may occur if people are supplied with water from water sources with different exposure to contamination sources, differences in the effectiveness of the treatment applied, and the general status of the water supply infrastructure. These potential causes of injustice can be quantified in, e.g., the number of unmonitored wells per income unit, or mg of Nitrate per litre and income unit. This type of analysis can be conducted to evaluate whether the level of safety and quality of drinking water supply is equitably distributed among users within a certain region.

Several studies have found that minority and low-income populations are often supplied with a lower drinking water quality and are therefore exposed to higher risks for drinking water-related diseases and outbreaks (Bae and Lynch, 2022; Delpla et al., 2015; Mueller and Gasteyer, 2021). For example, disparities in nitrate levels were reported for larger percentages of Hispanic populations in the United States of America (Balazs et al., 2011; Schaider et al., 2019). Balazs et al. (2012) found that higher arsenic levels were most common in areas serving socio-economically disadvantaged communities. Pace et al. (2022) concluded that communities of colour were disproportionally impacted by poor water quality and that domestic well users have the highest

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concentrations of arsenic, nitrate, and Cr(VI)-concentrations. Similarly, Hales et al. (2003) reported higher risks (3.76 times higher) of drinking-water contamination for deprived communities in New Zealand.

However, most of these studies have been conducted in the US, followed by Canada, South Africa, India, and New Zealand. Except for New Zealand, the remaining countries have a higher inequality index than most countries in the European Union (World Bank, 2022), and it is no surprise that social inequalities are also visible in the drinking water supply. European studies addressing the correlation between socio-economic status and pollutant exposure, outside issues related to drinking water, show mixed results (e.g., Montazeri et al., 2019; Vrijheid et al., 2012).

Scandinavian countries are often associated with low levels of social inequality (World Bank, 2022). Nevertheless, a study from 2008 showed higher general health inequalities related to income in Scandinavian countries compared to other European countries (Mackenbach et al., 2008). To date, no study has been performed on drinking water-related inequities in Scandinavia. Scandinavian countries offer an interesting case also due to the higher level of social equality.

The overall aim of this paper is to analyse socio-economic disparities in the supply of drinking water in Sweden by using a case study region. To identify disparities, we assess whether indicators of (environmental) justice (including income, age, education, employment status, gender, and place of birth) correlate with (a) the type of water supply (private well or municipal drinking water supply), (b) the quality of the drinking water, (c) the price of water, and (d) the experienced pipe breaks.

Some population groups are particularly vulnerable to the health impacts of poor drinking water quality, e.g., infants, elderly, and pregnant women. To promote equity, rather than equality, it is important to assess the provision of drinking water based on consumer needs (Perreault, 2014). This understanding can help local authorities to develop measures for improving municipal drinking water systems.

2. Study Area

The case study area covers the 13 municipalities of the extended Gothenburg region in South-West Sweden (Fig. 1). Approximately 1.05 million people live in an area of 5000 km^2, comprising roughly 10% of the Swedish population. It is a mix of urban and rural areas and covers different degrees of urbanization, including the city of Gothenburg, which is Sweden's second-largest city, as well as various towns and villages. Geographically, the area comprises islands, coastal areas, and inland areas. The 13 municipalities were selected to represent the Swedish rural-urban gradient, with drinking water sources of different types and sizes.

The water supply in the region of study includes municipal drinking water supplies (MDWS) and private wells (see Table 1). Around 90% of the households are supplied by MDWS, which use source water from lakes, rivers, groundwater (mainly glacio-fluvial deposits), or a combination of these, including artificial infiltration to groundwater aquifers. The remaining 10% of the households are supplied by private wells, most commonly drilled deeply into fractured bedrock or, to a lesser degree, shallow dug wells, typically in glacial deposits.

An important distinction between the two types of water supply is that households connected to MDWS receive treated and continuously monitored drinking water, whereas those relying on private wells

Table 1
Types of drinking water supplies in the study area.

Type of supply	Type of source water	Treatment	Management characteristics	Percentage of people supplied
Municipal drinking water supply	(i) Surface water (lakes or rivers), (ii) groundwater (glaciofluvial deposits), (iii) artificial infiltration	Treatment options ranging from less advanced with few barriers (commonly due to good raw water quality) to advanced treatment with conventional treatment (coagulation and filtration) as well as membrane filtration and additional barriers	Monitoring required, ranging from daily to weekly monitoring	90 %
Private wells	Exclusively groundwater (97% in fractured rock aquifers, and 3% in glacio-fluvial deposits)	No treatment	No monitoring, although monitoring is recommended every three years	10 %

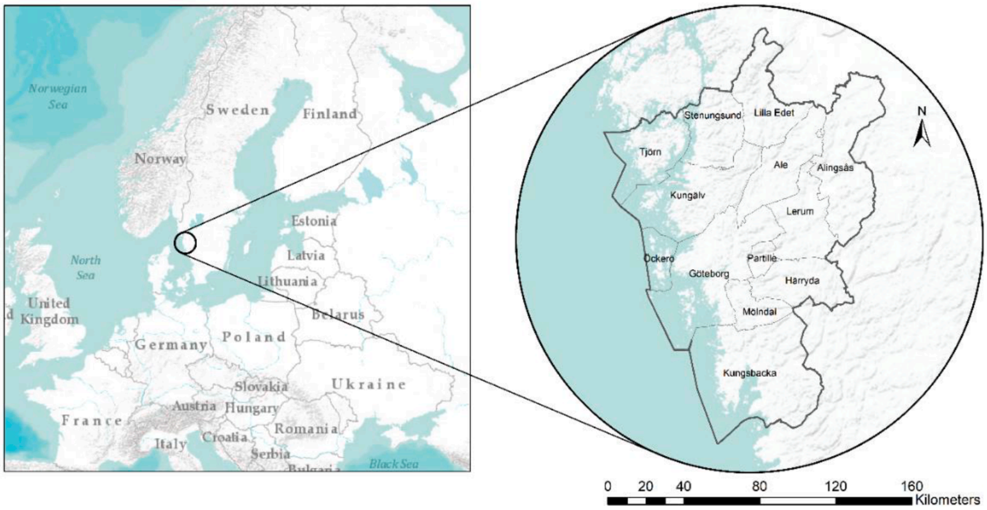

Fig. 1. Study area in the extended Gothenburg region in South-West Sweden. The area comprises 13 municipalities.

typically consume untreated raw water. Private wells fall under the homeowner's responsibility, and although regular testing is recommended, monitoring is often infrequent or not carried out at all (Schulte-Herbrüggen et al., 2024). National data indicate that untreated private wells frequently fail to meet drinking-water standards. In a database by the Geological Survey of Sweden (SGU) including 78 300 analyses, only around 45 percent of wells with complete sampling packages are classified as safe, while the remaining 55 percent show chemical or microbiological problems (Maxe, 2021). Microbial contamination is particularly common, with *E. coli* detected in roughly 11 percent of wells and coliform bacteria in about 50 percent of samples, and chemical issues such as elevated iron, manganese, nitrate, arsenic, or uranium occurring in a substantial share. These findings highlight that households relying on private wells face substantially higher water-quality risks than those connected to municipal supplies.

Additionally, in the cases where private wells are monitored, it is often not done frequently, and there is no professional organization in charge since the monitoring of private wells falls under the owner's responsibility (Swedish Food Agency, 2022). These wells are not regulated by the Swedish Food Agency's Drinking Water Ordinance (LIVSFS 2022:12), since they provide, on average, less than ten cubic meters per day, supply less than 50 people, and are not used for commercial or public purposes. Even though the National Food Agency recommends that homeowners test the quality of the water abstracted from their wells every third year (Schulte-Herbrüggen et al., 2024), many owners omit this recommendation. We should notice that homeowners do not break the law when they do not monitor the water quality within the recommended interval.

There are also differences between the different MDWS concerning the type of water sources used and the treatment. Some municipalities have recently improved their treatment facilities, integrated more advanced treatment steps providing additional barriers to manage varying source water quality, and can therefore be considered to provide safer water. A summary of the characterization of the types of drinking water supplies is provided in Table 1.

The reason why 10% of the households are not connected to the MDWS is the low population density of some areas and the distance to the distribution system managed by the MDWS. Private wells used for drinking water supply are exclusively located in rural areas. Gothenburg regions' connection level aligns with the connection percentage at national level which is also 10% (Maxe, 2021).

Overall, the population in the Gothenburg area has been growing in the past decade, and is expected to continue growing in the future. In addition, the municipalities have plans to extend the public water supply system and connect areas not serviced (i.e., connecting houses with private wells to the municipal drinking water system). To a large degree, these plans prioritize the connection of newly built areas but also focus on areas where the on-site-sewers are not working properly, or the recipient is very sensitive, and thus must be connected to the public water and wastewater supply.

3. Materials and Methods

3.1. Data

We identified various data sources to estimate the service area boundaries to the MDWS and private wells, the socio-economic characteristics of the population served, and water quality data (Table 2).

Table 2
Data overview for the assessment.

Data	Computation	Source
Service area boundaries of MDWS	Format conversion and harmonisation of municipality-provided boundary files (GIS and CAD) to a common GIS format and coordinate reference system.	Provided by the 13 municipalities
Private wells	-	SGU[1]
Socio-economic data	Population-weighted	Swedish Statistics
Delivered drinking water quality and pipe breaks	VASS-data assigned to each reported unit	VASS[2]
Economic data on water distribution	Prices are cross-referenced for each municipality	VASS[2]

[1] SGU Geological Survey of Sweden

[2] VASS = Statistics on water and wastewater supply in Sweden (managed by Svenskt Vatten, the national association for water and wastewater utilities)

3.1.1. Service area boundaries of areas connected to the municipal water supply

Previous studies often approximated the areas supplied by a drinking water treatment plant (service area boundaries) based on the zip-code scale (Marcillo et al., 2021) or city and county scale considering the location of their legal entity (Schaider et al., 2019). These approximations inevitably lead to inaccuracies in the spatial localization of the service area boundaries and, thus, the extent of the supplied population (Austin et al., 2025). In this study, the geospatial data on the areas connected to the MDWS was provided (on-request) by each of the thirteen municipalities. We converted and harmonised all files to a common GIS format and coordinate reference system and verified the results through overlay checks and basic topology/area checks to ensure the converted polygons matched the source datasets. The geospatial data display the areas connected to a specific drinking water treatment plant. The use of these fine-scaled datasets allows for more accurate and detailed analysis.

3.1.2. Private well data

The Swedish Geological Survey has an open data registry on all wells in Sweden (SGU, 2022). The wells are categorized as household, agricultural, energy, and others. Since we are only interested in household wells, we excluded the wells belonging to the other categories. We extracted data for over 15 549 georeferenced wells in our case study area. However, some private wells are still in the register even though the wells are no longer used for drinking water provision. Therefore, we deleted all private wells which fall within the service area boundaries of the MDWS. Within these service areas, registered wells are likely to be inactive or used for non-potable purposes (for example garden water), and including them would overestimate self-supply.

3.1.3. Socio-economic data

Swedish Statistics provides open-source socio-economic data (such as income, population statistics, education, etc.) in small units of demographic statistical areas. These areas have between 700 and 2700 inhabitants. The divisions consider geographical conditions to follow streets, waterways, and railways. Furthermore, Swedish Statistics used urban areas and electoral districts to create the statistical areas. The latest openly available data is from 2018 and was used in this study. Since the demographic statistical areas have different sizes and numbers of inhabitants, we calculated the relative share of people for each demographic parameter in per cent. Table 3 provides an overview of the socio-economic parameters and their unit.

3.1.4. VASS performance indicators for municipal drinking water systems

There are two types of drinking water in the case study area. Private wells use the raw water directly for the drinking water supply, and houses connected to the MDWS are supplied with treated and monitored drinking water.

To evaluate municipal drinking water systems, we used data from VASS (Vatten- och Avloppsstatistiksystemet), a national database managed by Svenskt Vatten, the Swedish Water and Wastewater Association. VASS collects annual performance and operational data from Swedish water and wastewater utilities. The database includes standardized key performance indicators related to water quality, pipe

Table 3
Description of socio-economic parameters and their unit.

Socio-economic parameter	Description	Variable/Category
Income	≤ 167 400 SEK/ (year*consumption unit[1])	Low
	167 401 – 241 464 SEK/ (year*consumption unit[1])	Medium low
	241 465 – 333 192 SEK/ (year*consumption unit[1])	Medium high
	≥ 333 193 SEK/ (year*consumption unit[1])	High
Education	Maximum education level reached of people between 25 and 64 years old	Pre-Highschool Highschool < 3 years after high school > 3 years after high school
Age Category	Refers to age reached at the end of the year	0 – 6 7 – 15 16 – 19 20 – 24 25 – 44 45 – 64 over 65
Employment Status	Refers to the employment status of people from 20-64 years old	Employed Unemployed
Sex		Male Female
Place of Birth	Population by country of birth	Sweden Nordic countries without Sweden (i.e., Denmark, Norway, Finland, Iceland) EU (without Nordics and Sweden) outside the EU

[1] (a consumption unit refers to a person in a household)

failures, and costs. These indicators enable utilities to monitor their own systems over time and benchmark against other facilities. Table 4 provides an overview of the key water quality indicators that we used.

VASS reports chemical water quality as annual counts of examinations and their overall outcomes. The data indicate how many chemical examinations were performed on distributed drinking water and how many were classified as satisfactory with comments or unsatisfactory. These outcomes are aggregated across parameters, and the dataset does not identify which parameter triggered the classification. The chemical indicators should be interpreted as a general measure of chemical compliance issues rather than contaminant-specific exposure.

Private wells are considered unmonitored since the Geological Survey of Sweden monitors only some aquifers continuously in the Gothenburg region and that does not include wells drilled into the bedrock. The monitored aquifer network is sparse and does not systematically include parameters directly related to human health.

3.2. Methods

All data was collected, joined, and processed in the geographic information system ArcMap 10.5. The statistical analysis was done with Python.

3.2.1. Assignment of socio-economic data

We first identified all built-up areas within the study region using a residential building/built-up layer from the Swedish Mapping, Cadastral and Land Registration Authority. Using data obtained directly from municipalities, we mapped the exact boundaries of areas connected to the municipal drinking water supply (MDWS). All remaining built-up areas, not covered by the MDWS polygons, were assumed to rely on self-supplied water via private wells. This approach estimates the self-supplied population from where people live relative to service-area coverage, rather than from counts of registered wells, because well registration is voluntary and does not capture all private wells. We then overlaid this information with demographic statistical areas, which provide population counts and socio-economic data. For each statistical area, we determined the proportion of the population using municipal supply versus private wells. The built-up layer was used as a practical settlement mask to avoid allocating population based on uninhabited land areas. This allowed us to link each supply type with corresponding socio-economic characteristics and to prepare data for further comparative analysis.

Since the MDWS often supplies many different units of demographic statistical areas, and the areas supplied by MDWS are not congruent with these units, population estimates must be calculated. Therefore, to estimate the value for each socio-economic parameter, we calculated after Pace et al. (2022) the weighted averages using the contribution of each unit of demographic statistical areas within the serviced area as:

$$W_{SE} = \frac{\sum_i^n (w_i \cdot X_i)}{\sum_i^n w_i} \tag{1}$$

where W_{SE} is the weighted socio-economic parameter, w_i is the population weight per demographic statistical area, i is the demographic statistical area, and X_i is the socio-economic variable from the demographic statistical area i.

Table 4
VASS key indicators used in the study.

	Key water indicators	Description	Unit
Fees	Connection fee (A)	Connection fee for Type A houses (single-family homes, e.g., villa)	SEK
	Connection fee (B)	Connection fee for Type B houses (multi-family buildings with 15 apartments)	SEK
	Water and wastewater fee	Consumption fee for water and sewage	SEK/m^3
	Annual fee (A)	Total annual cost for Type A houses (single-family homes, e.g., villa)	SEK/year
	Annual fee (B)	Total annual cost for Type B houses (multi-family buildings with 15 apartments)	SEK/year
Pipes	Pressure complaints	Number of complaints about water pressure	#
	Pipe breaks (network)	Number of pipe breaks/water leaks in the water distribution network	#
	Pipe breaks (service lines)	Number of pipe breaks/water leaks on service lines	#
Water quality	Quality complaints	Number of complaints about drinking water quality	#
	Chemical tests (total)	Total number of chemical examinations on drinking water. Raw water not included	#
	Chemical tests w/ comments	Number of chemical examinations on drinking water deemed satisfactory with comments	#
	Chemical tests unsatisfactory	Number of chemical examinations on drinking water deemed unsatisfactory	#
	Odor tests (total)	Total number of odor tests conducted	#
	Odor tests w/ comments	Number of odor examinations deemed satisfactory with comments	#
	Odor tests unsatisfactory	Number of odor examinations deemed unsatisfactory	#
	Microbial tests (total)	Total number of microbiological examinations on drinking water. Raw water not included	#
	Microbial tests w/ comments	Number of microbiological examinations on drinking water deemed satisfactory with comments	#
	Microbial tests unsatisfactory	Number of microbiological examinations on drinking water deemed unsatisfactory	#
	Chemical tests (raw water)	Number of chemical examinations on raw water	#
	Microbial tests (raw water)	Number of microbial examinations on raw water	#

3.2.2. *Characterization of connected and self-supplied populations*

For each group, absolute counts and relative proportions were computed for the main socio-economic and demographic indicators: income, age, education, employment status, country of origin, and gender.

To determine whether the observed distributions differed significantly, Pearson's Chi-square tests of independence were applied to each categorical variable. In addition, Cramér's V was calculated for each test to assess the magnitude of the associations, since large sample sizes can yield statistically significant χ^2 results even when differences are small. The tests compared observed category frequencies with those expected under the null hypothesis that water-supply type and socio-economic category are independent. We used $p < 0.001$ as a conservative threshold given the number of comparisons and the large sample size. All tests were conducted in Python.

3.2.3. *Comparing socio-economic profiles of MDWS areas with differing water services*

Correlation Analysis and Significance Test

The approximately 880 000 people that are supplied with municipal drinking water in the Gothenburg region, are supplied with water from 12 different water works. The municipally owned water supplies range from simpler filtration and sedimentation treatment to advanced membrane filtration.

This analysis aimed to investigate the relationships between socio-economic indicators and VASS-data at the block level. We started by excluding specific columns from both datasets that are irrelevant or non-informative for the analysis. To avoid perfect multicollinearity, categories that sum to one (e.g., Male/Female, Employed/Unemployed, or place of birth groups) were reduced by removing at least one category per group, ensuring statistical independence and preventing redundancy in the analysis. To also avoid multicollinearity between socio-economic parameters, we tested the correlation between different socio-demographic variables before including them in our model. Highly collinear indicators were therefore excluded or merged.

After merging the socio-economic and VASS datasets based on the block identifier, we converted the necessary columns to numeric types to ensure the accuracy of our statistical calculations. We then calculated the Spearman correlation coefficients for each pair of socio-economic and VASS columns, excluding missing data. The results were compiled into a correlation matrix, which was subsequently visualized as a heatmap. This heatmap provided a clear and concise visual representation of the strength and direction of the correlations, allowing us to easily identify significant relationships between different socio-economic factors and VASS metrics. This analysis is valuable for understanding the interplay between socio-economic conditions and service support metrics.

We then calculated the p-values for the Spearman correlation coefficients between each pair of socio-economic and VASS columns, which were compiled into a p-value matrix. P-values indicate the statistical significance of the correlation coefficients, helping to determine whether the observed correlations are likely due to chance. By focusing on p-values, we ensure that the identified relationships are robust and reliable. In this analysis, p-values were computed for each pair. We visualized this matrix as a heatmap, highlighting the significance of the correlations and aiding in the identification of statistically significant relationships. This approach helps to understand which socio-economic factors have meaningful associations with VASS metrics.

Inspection of extreme cases

To assess whether differences in water system performance were concentrated among municipalities at the tails of the socio-economic distribution, we compared VASS indicators between the three municipalities with the highest and lowest proportions of low-income residents. We selected three municipalities per group as a balance between representing the tails of the distribution and avoiding results that are overly sensitive to any single municipality. Low-income share was selected as the stratification variable because it is the primary socio-economic indicator. For each group, we extracted all VASS performance metrics related to water quality monitoring, customer complaints, and pipe infrastructure failures. We calculated groupwise mean values and quantified absolute and relative differences for each indicator. To test whether the distributions differed between the poorest and wealthiest municipalities, we used the Mann–Whitney U test, which does not assume normality and is appropriate for small sample sizes (Mann and Whitney, 1947). We additionally computed Cohen's d to quantify the magnitude of differences between the municipal groups (Cohen, 1988; Sawilowsky, 2009), providing an effect-size measure that is independent of sample size.

4. Results

4.1. *Socio-demographic differences between self-supplied and municipal users*

We estimate that nearly 880 000 people are supplied with municipal drinking water in the Gothenburg region, and approximately 176 000 people are private well users. Table 5 summarizes the socio-demographic characteristics of populations connected to the municipal drinking-water supply (MDWS) and those relying on private wells. Statistically significant differences were observed across all examined variables ($p < 0.001$, Pearson's χ^2 tests), indicating that the two populations differ systematically in their socio-economic composition. However, because the population size is large, statistical significance was expected even for modest differences. Effect-size estimates (Cramér's V) therefore provide important additional context and show that associations across variables range from very small to small ($V = 0.008–0.071$).

Income distributions differ significantly between the two groups ($\chi^2(3) = 578.4$, $p < 0.001$, $V = 0.036$). Self-supplied households are slightly more concentrated in the higher income brackets, although the effect size indicates that this difference is modest in magnitude. Educational attainment also differs significantly ($\chi^2(3) = 2744.2$, $p < 0.001$, $V = 0.071$). Municipally connected populations include more individuals with tertiary education, whereas self-supplied areas have relatively more high-school graduates; this variable shows the strongest effect size among those examined. Employment rates are higher among self-supplied residents ($\chi^2(1) = 885.8$, $p < 0.001$, $V = 0.028$), consistent with their income distribution, although again the effect size is small.

Age distributions show clear contrasts ($\chi^2(6) = 2405.1$, $p < 0.001$, $V = 0.048$). Self-supplied populations are on average slightly older and include higher proportions of young children, adolescents, and elderly residents, groups generally more vulnerable to risks associated with untreated drinking water. Country of origin shows the strongest disparity after education ($\chi^2(3) = 3676.0$, $p < 0.001$, $V = 0.060$). Self-supplied households are predominantly Swedish-born, whereas connected populations are more heterogeneous and include a higher share of residents born outside the EU. Gender differences are minor but statistically significant ($\chi^2(1) = 64.4$, $p < 0.001$), with an extremely small effect size ($V = 0.008$) and a slightly higher proportion of men in self-supplied households.

Overall, the results reveal two socio-economic profiles that differ consistently, although generally modestly, in magnitude. Self-supplied households are somewhat more affluent, more often native-born, and slightly older, while municipally connected populations are younger, more diverse, and have higher shares of tertiary education. These differences, although small in effect size, remain relevant for understanding potential disparities in exposure and vulnerability related to drinking-water quality, particularly for age groups and populations with higher reliance on untreated water.

Table 5
Socio-economic characteristics of municipally connected and self-supplied populations, including χ^2 statistics, p-values, and Cramér's V for each variable.

	Category	Connected Population	Self-supply	χ^2(df), p-value, Cramér's V
Income	Low	22.6% (87 680)	18.5% (12 148)	$\chi^2(3) = 578.4$ $p < 0.001$ $V = 0.036$
	MediumLow	22.7% (87 940)	23.1% (15 150)	
	MediumHigh	26.2% (101 257)	27.8% (18 226)	
	High	28.5% (110 305)	30.6% (20 057)	
Age	Average age	39.67	40.01	$\chi^2(6) = 2405.1$ $p < 0.001$ $V = 0.048$
	0 – 6	8.27% (72805)	8.91% (14919)	
	7 – 15	10.61% (93450)	12.16% (20340)	
	16 – 19	4.26% (37490)	4.79% (8019)	
	20 – 24	6.03% (53114)	4.87% (8152)	
	25 – 44	30.09% (264935)	25.12% (42025)	
	45 - 64	23.76% (209159)	26.22% (43867)	
	over 65	16.98% (149509)	17.91% (29954)	
Education	Pre-highschool	9.20% (43711)	10.05% (8646)	$\chi^2(3) = 2744.2$ $p < 0.001$ $V = 0.071$
	Highschool	35.41% (168271)	43.67% (37562)	
	3 years after highschool	17.31% (82281)	16.30% (14018)	
	4 years after highschool	35.72% (169767)	27.89% (23991)	
Employment	Employed	79.75% (420448)	83.03% (78085)	$\chi^2(1) = 885.8$ $p < 0.001$ $V = 0.028$
	Unemployed	20.25% (106760)	16.97% (15959)	
Country of Origin	Sweden	77.79% (684932)	83.84% (140254)	$\chi^2(3) = 3676.0$ $p < 0.001$ $V = 0.060$
	Nordics without Sweden	1.77% (15564)	1.85% (3100)	
	EU without Nordics	3.60% (31712)	3.26% (5458)	
	Rest of the World	16.84% (148254)	11.04% (18466)	
Gender	Female	49.98% (437781)	48.90% (81146)	$\chi^2(1) = 64.4$ $p < 0.001$ $V = 0.008$
	Male	50.02% (438140)	51.10% (84781)	

4.2. *Assessing socio-economic disparities among municipal water users*

4.2.1. *Assessment of correlation patterns*

To evaluate redundancy among the socio-economic indicators, we first examined their pairwise associations using Spearman correlation coefficients. In Fig. 2, the multicollinearity assessment showed that several socio-economic variables were strongly correlated, particularly those representing related demographic or socioeconomic dimensions (for example, unemployment with low income, and non-EU born with low income). To avoid redundancy in subsequent analyses, we retained only four indicators that were conceptually distinct and exhibited lower pairwise correlations: low income, low education, women, and vulnerable age (population aged 0–6 and ≥65 years). These variables provided a non-collinear set of socio-economic characteristics for further comparison with VASS performance indicators.

Significant associations between socio-economic characteristics and VASS indicators were limited in magnitude and scattered across variables (see Fig. 3). Low income showed the largest number of statistically significant correlations, including positive associations with pipe breaks in both the network and service lines ($\rho = 0.22$–0.27, $p < 0.001$) and with several water quality indicators, such as unsatisfactory chemical test results ($\rho = 0.25$, $p < 0.001$) and microbial tests with comments ($\rho = 0.15$, $p < 0.001$). Low income was also negatively correlated with most of the connection and annual fees ($\rho = –0.28$ to $–0.31$, $p < 0.001$).

Low education showed few significant correlations; the strongest were positive but small associations with pipe breaks in the network ($\rho = 0.11$, $p < 0.05$) and chemical tests with comments ($\rho = 0.09$, $p < 0.05$), and a negative correlation with microbial tests unsatisfactory ($\rho = –0.17$, $p < 0.001$).

Female share exhibited only weak and sparse associations, most of which were small in magnitude ($|\rho| < 0.10$), with a few reaching significance for connection fees and water and wastewater fees ($p < 0.05$). The vulnerable-age indicator showed the strongest overall pattern, with positive correlations with water and wastewater fees and annual fees ($\rho = 0.23$–0.39, $p < 0.001$) and a large negative correlation with unsatisfactory microbial tests ($\rho = –0.36$, $p < 0.001$).

Several additional correlations were statistically significant but small in size, particularly for odor-related and comment-based test outcomes.

4.2.2. *Comparison of extreme municipal income groups*

While the regional correlation analysis mainly showed weak and indicator-specific associations, the extreme-case comparison between the three poorest and three wealthiest municipalities revealed substantial and statistically meaningful differences across several key indicators.

For the extreme-case comparison, municipalities were ranked by the share of low-income residents and the three with the lowest shares ("wealthiest three") were compared with the three with the highest shares ("poorest three"). Fig. 4 provides an overview of all VASS indicators and their effect size. Tariff structures differed systematically between these groups. The poorest municipalities had lower water and wastewater and annual fees (e.g. wastewater fee: 21.1 vs 30.7 SEK m^{-3}, Cohen's $d = -2.43$; annual fee type B: 63.0 vs 83.6 kSEK, $d = -2.91$; $p < 0.001$ for both), whereas the connection fee for a single-family house (type A) was higher (297.6 vs 247.0 kSEK, $d = 1.28$, $p < 0.001$). Fees for a multi-family connection (type B) were lower in the poorest group ($d = -0.69$, $p < 0.001$).

Network reliability indicators showed large differences. Pipe breaks per person were roughly twice as frequent in the poorest municipalities, both in the main network (7.4×10^{-4} vs 3.3×10^{-4}, $d = 2.79$, $p < 0.001$) and in service lines (1.8×10^{-4} vs 6.5×10^{-5}, $d = 4.19$, $p < 0.001$). Interestingly, pressure and quality complaints were substantially more common in the wealthiest municipalities. This is consistent with previous research that finds that higher-income neighbourhoods tend to register more service requests/complaints than lower-income ones (Feigenbaum and Hall, 2015). This pattern may therefore reflect differences in reporting behaviour rather than differences in actual service conditions, which would bias complaint-based indicators as a proxy for service quality. Differences in water quality monitoring and outcomes were more mixed: the poorest municipalities showed higher rates of chemical and microbial tests with comments (e.g. microbial tests with comments: 0.0308 vs 0.0049 per person, $d = 2.08$, $p < 0.001$), slightly higher shares of unsatisfactory chemical tests ($d \approx 0.21$, $p < 0.001$).

Overall, comparing the municipalities with the lowest and highest shares of low-income residents revealed clear and statistically significant disparities in microbial and chemical test results with noted issues and in pipe-break frequency, while patterns in monitoring intensity and other water quality outcomes were less consistent.

5. Discussion

5.1. *Pivate wells vs. Public provision*

In this study, we aimed at identifying socio-economic disparities in

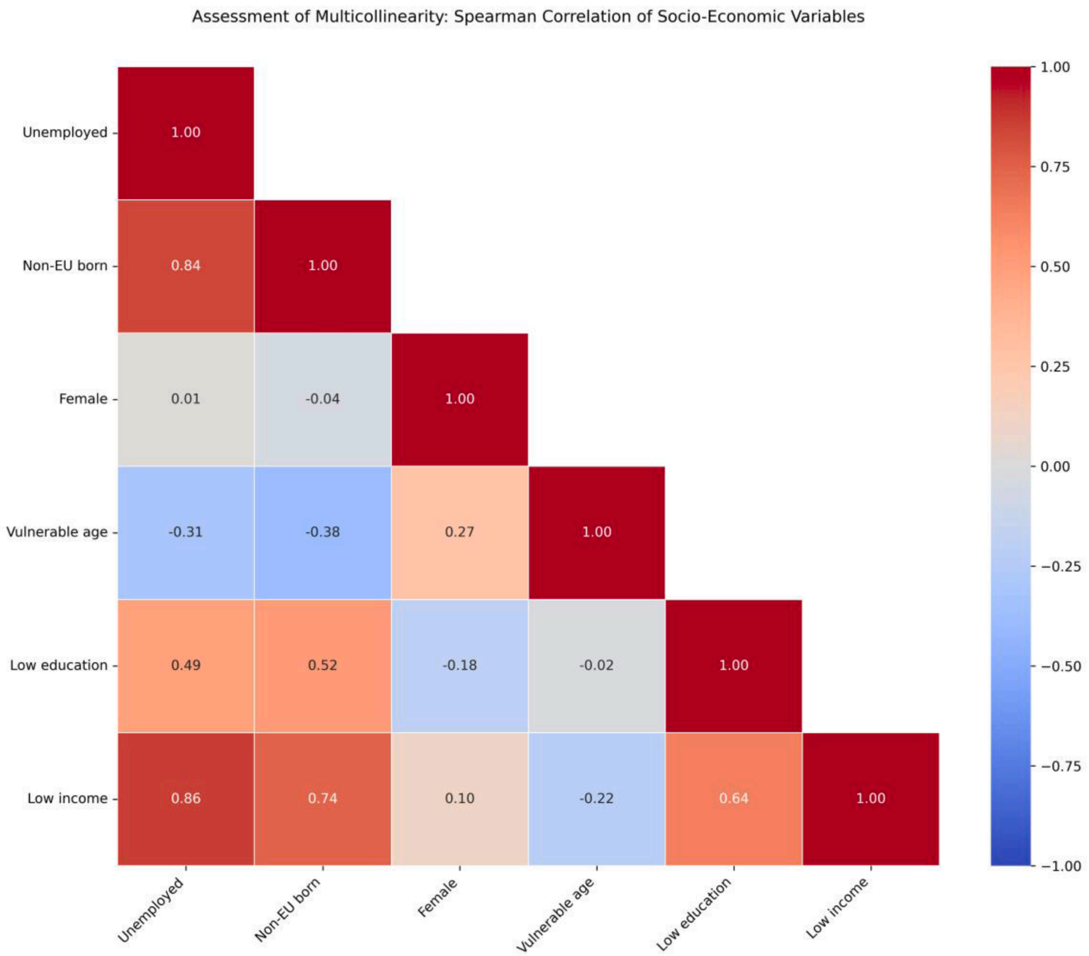

Fig. 2. Spearman correlation matrix for six socio-economic indicators: unemployment, non EU-born population, proportion of women, vulnerable age (0–6 and ≥65 years), low education, and low income. Values represent pairwise Spearman's ρ coefficients, shown only for the lower triangle.

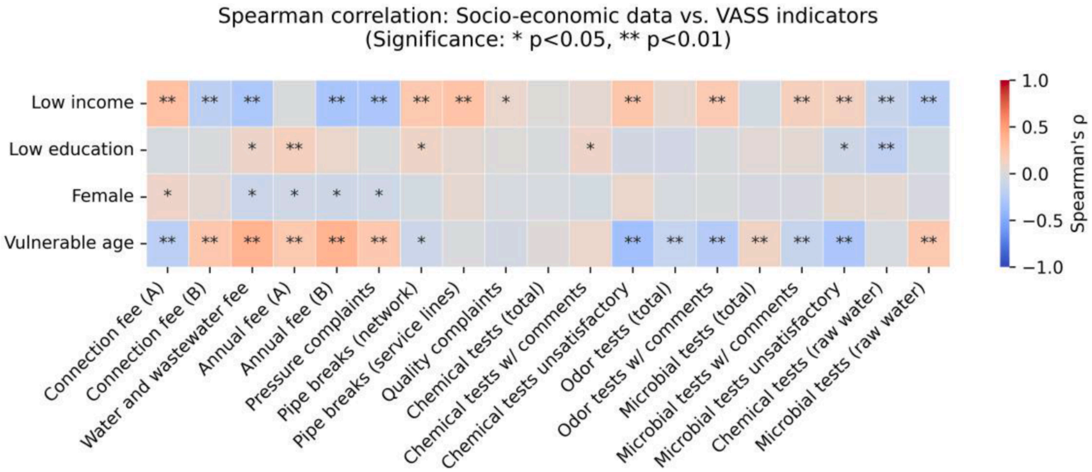

Fig. 3. Spearman rank correlations between socio-economic characteristics and VASS indicators across the case study municipalities. Cells show correlation coefficients (colour scale), with asterisks marking statistically significant associations (* $p < 0.05$; ** $p < 0.01$). Socio-economic variables include low income, low education, proportion of females, and vulnerable age groups. VASS indicators are grouped into connection and annual fees, network performance (pressure complaints and pipe breaks), and drinking water quality monitoring outcomes. For fee variables, (A) refers to single-family houses and (B) to multi-family houses.

the supply of drinking water in Sweden by using the Gothenburg region as a case area. The results showed that consumption of untreated drinking water by private well owners is slightly more common for economically advantaged and Swedish born populations. This income pattern is consistent with a recent finding from the United States where households reliant on private wells and septic systems are, on average, more likely to be higher income (Hernandez and Pierce, 2023). At the same time, it contrasts with a large body of drinking-water inequity

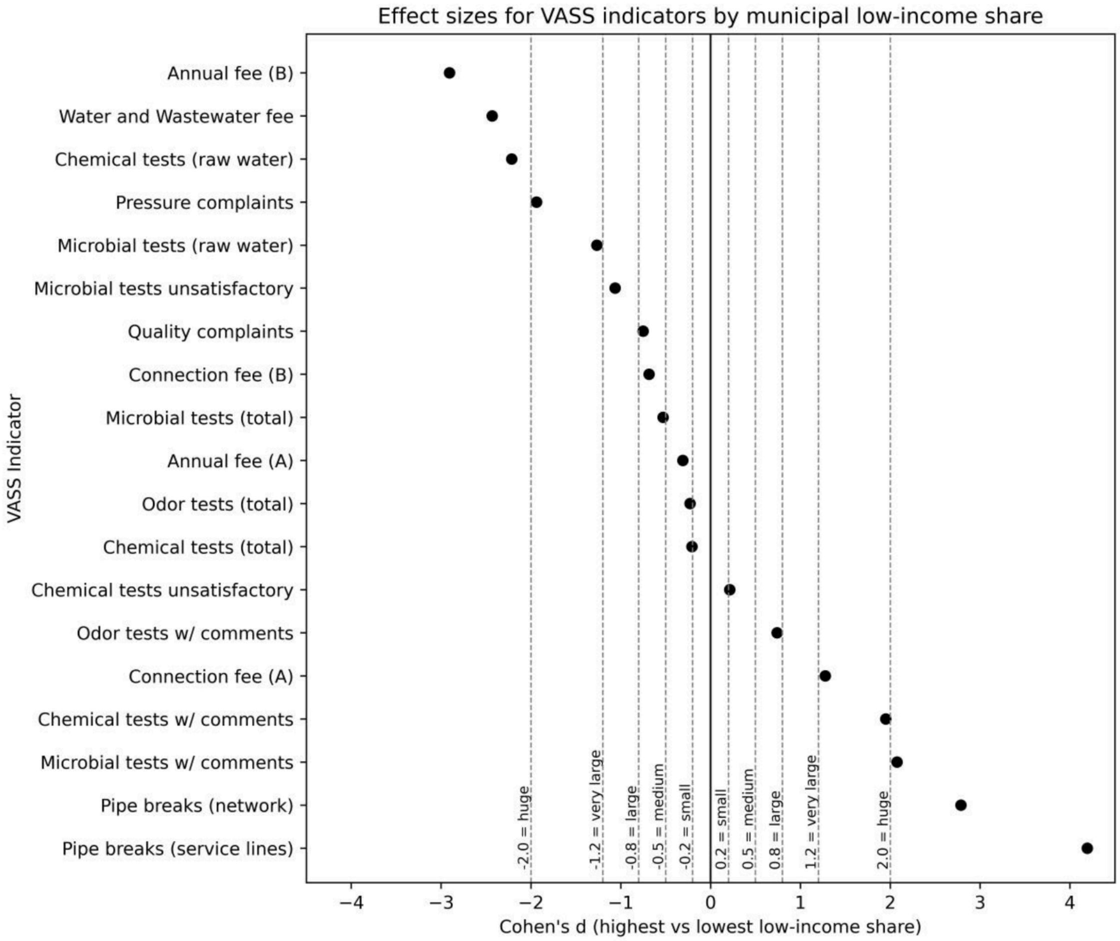

Fig. 4. Cohen's d effect sizes for differences in VASS indicators between the three municipalities with the highest and the three with the lowest shares of low-income residents. Effect sizes quantify the magnitude of difference relative to pooled variability, where positive values indicate higher indicator levels in higher-low-income municipalities. Vertical dashed lines represent interpretive benchmarks for small ($|d| \approx 0.2$), medium ($|d| \approx 0.5$), large ($|d| \approx 0.8$), very large ($|d| \approx 1.2$), and huge ($|d| \geq 2.0$) effects.

research that documents higher contamination burdens and worse water quality outcomes in lower-income and minority communities, including in areas relying on domestic wells and small systems.

A potential explanation for why higher-income households more often rely on private wells is that rural and peri-urban areas around Gothenburg tend to attract more socio-economically advantaged residents. This pattern reflects long-standing Swedish housing ideals in which the owned detached house outside the city has been promoted as a desirable and good living environment, from the *egnahem* movement (a Swedish movement promoting owner-occupied detached houses) and its emphasis on the virtuous rural home (Edling, 1996) to later preferences for the suburban villa as a symbol of autonomy and a good family life (Almqvist, 2004). Moreover, housing policy and market developments have reinforced this socio-spatial pattern by consistently associating detached, peri-urban homeownership with more affluent groups (Grundström and Molina, 2016). Living outside the city is therefore often a lifestyle choice rather than a financial necessity. Given that natural water quality is generally perceived as good in Sweden, the absence of a municipal drinking water connection is usually not a decisive factor when choosing where to live. This combination of socio-economic sorting and cultural preferences helps explain why private wells are more common among higher-income households in Western Sweden.

5.2. *Differences in municipally delivered drinking water*

The absence of clear regional socio-economic gradients in municipally delivered drinking water suggests that, at a broad scale, the extended Gothenburg region provides relatively uniform service levels, at least when assessed through standard performance indicators. This contrasts with findings from other countries, where socio-economic disparities often manifest in drinking water quality or infrastructure reliability. One explanation may be the structure of the Swedish water sector itself, where utilities operate under similar regulatory frameworks and cost-recovery principles, potentially moderating large-scale socio-economic differentiation. Thus, while regionwide patterns appear equitable based on available VASS indicators, the correlation results alone do not rule out the presence of more localized or structural disparities. A limitation is that the socio-economic indicators come from the latest small-area dataset that was openly available to us at the time of analysis (reference year 2018), so recent demographic and socio-economic change may have shifted some area-level estimates.

The pronounced differences observed between the wealthiest and poorest municipalities indicate that socio-economic disparities in municipal drinking water services do exist but become visible only when examining the most contrasting cases. The markedly higher frequency of pipe breaks in poorer municipalities points toward differences in infrastructure condition or investment capacity, consistent with the idea that utilities serving less affluent populations may face structural constraints in maintaining network reliability. The variation in tariff structures supports this view, as lower annual fees and water/wastewater fees per m^3 in poorer municipalities may reduce costs for consumers but also restrict the financial capacity needed for sustained infrastructure renewal. Together, these findings suggest that inequalities in municipal service delivery are not evenly distributed across the region but are instead concentrated in specific municipalities where socio-economic conditions and utility characteristics intersect to shape infrastructure performance.

5.3. Analysis as a decision tool to improve self-supply or connect to MDWS

The results of this study can be employed by local authorities to prioritise municipal drinking water improvement strategies. The framework used to prioritise areas for future connections draws on several indicators, including economic assessments, the age and condition of existing infrastructure, the performance of on-site sewer systems, and recorded drinking water violations. However, decisions on new connections often do not include environmental justice considerations (Schwetschenau et al., 2022). Adding the considerations of environmental justice adds to an equal society and provides a decision tool that helps identify which areas are most in need of connection to the municipal system.

The results of this analysis can also be used to support decisions concerning public subsidies on, e.g., monitoring of drinking water quality. Currently, the recommendation in the study area is for a private well to be monitored every three years. This could cost the homeowner around SEK 2000 (corresponding to 190 USD) per testing. To support more frequent monitoring for vulnerable groups, SGU proposes a subsidy to provide free monitoring for families with small children (Lång et al., 2022). Deciding whether this kind of support should be universal or targeted is ultimately a policy decision that involves value judgments and distributional trade-offs between public health protection and equity. The results of this study can contribute to that idea by indicating vulnerable areas and users who could benefit the most from the proposed subsidy. In addition, other forms of support measures could be developed to target vulnerable groups, e.g., free water testing for people over the age of 65.

5.4. Exploring environmental justice in high income countries

In high-income countries, where water and sanitation services are typically widespread, equity concerns often show up less as complete lack of infrastructure and more as differences in service quality, affordability, and the distribution of remaining risks and responsibilities (Brown et al., 2023). In our case, this shows up as differences in who remains on self-supply versus municipal provision, and how service and monitoring indicators vary across socio-economic contexts. Integrating environmental justice into drinking-water planning is therefore not only normative but also practical. The tracking of connection, self-supply, affordability, and service indicators can act as an early-warning signal for distributional problems before they become entrenched through infrastructure decisions. This is particularly relevant given projections of substantial increases in water and wastewater tariffs in Sweden over the coming decades (de Fine Licht, 2023), which may widen affordability gaps and shift burdens unevenly across households.

6. Conclusions

This study examined socio-economic differences in drinking water access and service conditions across the extended Gothenburg region, combining water performance indicators with the spatial distribution of private wells. At the regional scale, correlations between socio-economic characteristics and drinking water indicators were generally weak, suggesting relatively uniform service provision across utilities.

However, when comparing municipalities with the highest and lowest shares of low-income residents, clear disparities emerged: poorer municipalities experienced substantially higher pipe-break frequencies and showed more microbial and chemical test results with noted issues, indicating that inequalities in service conditions may be localized rather than regionwide.

In contrast, private well use followed the opposite pattern, with untreated groundwater consumption slightly more common in socio-economically advantaged communities. This reflects settlement patterns and cultural housing preferences but national monitoring data show that private wells frequently fail to meet drinking-water standards, highlighting a relevant exposure pathway in rural areas. By combining detailed municipal supply areas with high-resolution socio-economic data, this study provides a more precise assessment of who receives which type of water service.

As water and wastewater rates in Sweden are expected to rise substantially in coming decades, integrating environmental justice perspectives into infrastructure planning can offer early insight into where affordability pressures or service disparities may emerge.

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CRediT authorship contribution statement

Nadine Gärtner: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Andreas Lindhe:** Writing – review & editing, Project administration, Funding acquisition, Data curation.

Declaration of competing interest

The authors declare no competing interests.

Data availability

The data that has been used is confidential.

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