Effect of Population Density Level on Fecal Coliform Concentration in Shallow Groundwater in Kartasura Sub-district, Sukoharjo

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Abstract. Pollution of groundwater in urban areas can be prompted by high population density, excessive waste production, high levels of development, and social activities of the communities. This study aimed to analyze the spatial distribution of fecal coliform and the effect of population density on the level of shallow groundwater contamination by fecal coliform in the Kartasura Sub-district. This study used the field survey method. The survey was conducted to obtain primary data, including groundwater sample data and coordinates of dug wells. Meanwhile, the fecal coliform content in groundwater samples was determined through laboratory tests. The results showed that 66.67% or 8 of 12 groundwater samples in the Kartasura Sub-district did not meet the fecal coliform quality standards in water, with the highest content of 920 MPN/100 mL in Ngadirejo Village. On the contrary, the lowest, with a value of 4.5 MPN/100 mL was located in Gumpang Village. Groundwater samples located in settlements have a higher probability of fecal coliform content than those of industrial areas, rice fields, and cemeteries. The result of the correlation coefficient attained 0.143, indicating that the level of population density does not affect groundwater contamination by fecal coliform in Kartasura Sub-district. This research is necessary given the lack of public knowledge regarding groundwater sanitation. This research provides public knowledge regarding groundwater sanitation through spatial modeling in research areas where groundwater is contaminated with fecal coliform.

Keywords: Fecal Coliform · Population Density · Social Activity

1 Introduction

Water is the most vital component in life. Every living creature in this world needs clean water to fulfill needs; for drinking water, cooking, sanitation, agriculture, and industrial needs. However, only some areas have the access to clean water in proportion to their need for clean water. This signifies that many areas lack clean water. The unavailability of clean water can be the result of several reasons, such as excessive use of water,

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drought, and water pollution by contaminants. Water pollutant materials may derive from industrial activities or household waste. Pollution by industrial activities is triggered by the negligence of businessmen in managing the production waste (Anna et al., 2019). Contaminated water, indeed, can result in health problems due to its toxic chemical content.

Groundwater pollution is when the water already contains contaminants. This contamination is a problem often found in urban areas. This occurs due to the proximity of this phenomenon to the level of population density. The higher the population density, the more waste will be generated (Widiyanti, 2019). Apart from the population density, this type of pollution in urban areas can be precipitated by excess production of household and industrial waste, high levels of development, social activity, and excessive use of groundwater neglecting groundwater balance. Groundwater pollution by waste can occur when waste discharged through sewers or septic tanks seeps through gaps and enters the groundwater layer (Priyana, 2016). Gradually, the waste continues to grow and pollutes the soil layer which initially functions as a filtering tool. On the other hand, waste from public facilities contributes to groundwater pollution in urban areas (Cholil, 1996).

There are three types of groundwater pollutants, one of which is biology. This is characterized by the penetration of bacteria in groundwater, for instance, coliform bacteria. Groundwater contamination by fecal coliform can be modified by the proximity of the septic tank to the sewer with dug wells (Sapulete, 2010). This phenomenon is often observed in densely populated areas, resulting from the lack of space for the construction of latrines that follow the predetermined standards. As per the Indonesian National Standard (known as SNI) 03-2916 of 1992 on Specifications of Dug Wells for Clean Water Sources, the ideal interval between a latrine and a water source is 11 m at minimum (SNI, 1992). The poor public awareness of septic tank construction that complies with established standards will have a serious impact on the existing groundwater quality. To this day, there are many latrines proximate to dug wells, such as those in Kartasura Sub-district.

Kartasura Sub-district is one of the Sub-districts in Sukoharjo Regency adjacent to the west of Boyolali Regency, to the north of Karanganyar Regency, to the south of Gatak Sub-district, Sukoharjo Regency, and the east of Surakarta City. The area is directly affected by the urban sprawl phenomenon that occurs on the outskirts of Surakarta City. This situation ensues effects on the increasing population. This is shown by data from the Statistics Indonesia (referred to as BPS) of Sukoharjo Regency in 2022 that the population density in Kartasura Sub-district was the highest compared to other sub-districts, with a population density totaling 6,007 people/km^2 in 2021 (Statistics Indonesia of Sukoharjo Regency, 2021).

In addition to the relatively high population density, most people still consume groundwater from dug wells to fulfill their clean water needs as it is considered to have better quality compared to surface water (Alamsyah & Kurniawan, 2016; Widiyanti, 2019). If observed further, groundwater has gone through a filtering process by the subsoil before finally being deposited (Alamsyah & Kurniawan, 2016). Even so, groundwater may be prone to pollution.

Over time, the increase in population density and development activities in Kartasura Sub-district has resulted in a deteriorated quality of existing groundwater. A high level of population density may induce problems for the environment since the population will continue to grow. Conversely, land availability will continue to decrease. These conditions will encourage people to create densely populated areas where groundwater will be susceptible to fecal coliform contamination.

Escherichia coli (E. coli) is a type of coliform bacteria that lives in animal and human feces (Pranoto et al., 2014; Yohannes et al., 2019). E. coli bacteria indicate that the water has been contaminated with human and animal feces (Sunarti, 2015; Dangiran & Dharmawan, 2020). E. coli bacteria live in open natural soil, so that soil becomes a good growth medium (Sutiknowati, 2016). Water that contains E. coli bacteria when consumed will entail health problems, one of which is diarrhea (Kosasih et al., 2009; Hardjono & Cholil, 2019; Dangiran & Dharmawan, 2020). Based on data from the Sukoharjo Regency Health Profile in 2020, diarrhea cases in Kartasura Sub-district were 3.90%, or approximately 4,303 people out of 110,548, which 1,318 of them were children under 5 years of age (Sukoharjo Regency Health Profile, 2021). Currently, diarrhea ranks second as the cause of children under-five mortality in Indonesia (Muchlis et al., 2017). Despite of its serious impact on health, unfortunately, these bacteria are indestructible using cooling or freezing, therefore special measures are needed such as irradiating with Ultraviolet (UV) light, administering antibiotics, or heating above 100 °C (Sutiknowati, 2016). In short, fecal coliform causes groundwater pollution and it is necessary to investigate its distribution.

One of the steps that can be used to determine the distribution of fecal coliform contamination is spatial modeling and in-depth analysis related to the magnitude of fecal coliform contamination in shallow groundwater in the Kartasura Sub-district. Furthermore, spatial modeling should use a Geographic Information System (GIS) to map areas where groundwater is polluted. GIS serves as processing spatial data and displaying it in map form to obtain spatial information related to shallow groundwater contamination by fecal coliform. In this study, the spatial modeling is shown in the fecal coliform distribution map in Kartasura Sub-district. This research is necessary due to the lack of public knowledge regarding groundwater sanitation. This research provides public knowledge regarding groundwater sanitation through spatial modeling in research areas where groundwater is contaminated. This study aimed to 1) analyze the spatial distribution of fecal coliform in shallow groundwater in Kartasura Sub-district; 2) analyze the influence of population density on the level of shallow groundwater contamination by fecal coliform in Kartasura District.

2 Methods

2.1 Study Area and Data

This research is located in Kartasura Sub-district, Sukoharjo Regency, Central Java Province, Indonesia (Fig. 1). Kartasura Sub-district is directly adjacent to three different regencies/cities. To the west, it is bordered by Boyolali Regency, to the north by Karanganyar Regency, to the south by Gatak Sub-district, Sukoharjo Regency, and the

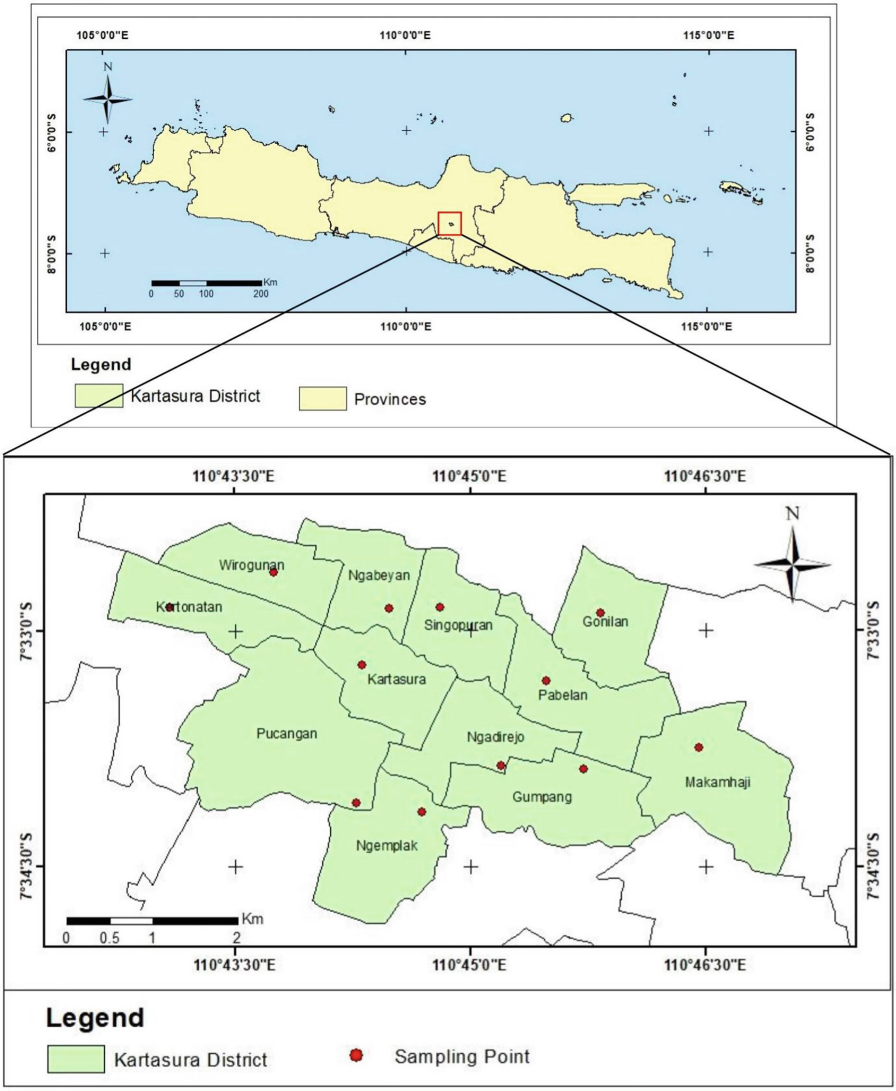

Fig. 1. Map of research locations

east by Surakarta City. Kartasura Sub-district covers around 1,923 ha, which consists of 10 villages and 2 urban villages with the widest area being Pucangan Village.

2.2 Data Processing Technique

The method used in this study is a field survey method, with data sources comprising two types of data; primary data and secondary data. The survey was carried out to collect primary data, including groundwater sample data and coordinates of monitoring wells.

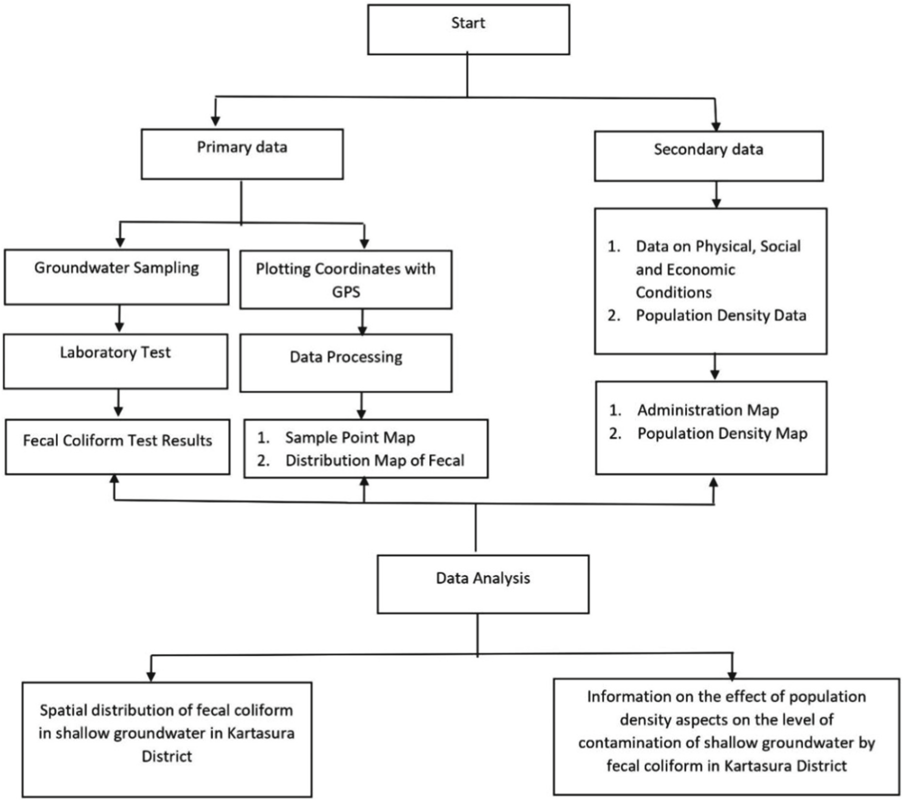

Fig. 2. Research flowchart

Meanwhile, the fecal coliform content in groundwater samples was determined through laboratory testing, using the method used to investigate fecal coliform contamination in water, namely the Most Probable Number (MPN). The secondary data were displayed in administrative boundary shapefile data and land use in the Kartasura Sub-district taken from the Geospatial Agency and population density data obtained from the publication of the Kartasura Sub-district in 2022.

The research phase began with the selection of sample locations. The population in this study consists of active dug wells in Kartasura Sub-district for sanitation and hygiene. Subsequently, a field survey was performed to obtain coordinate data for the location of the dug wells and groundwater samples. The water sampling location was decided using a purposive random sampling method based on land use in Kartasura Sub-district, namely densely populated residential areas, rice fields, cemeteries, and industrial areas. One type of land use is determined as one administrative area (village). The selection method of the distribution pattern was done qualitatively.

The next stage is data processing. The obtained coordinate points that have been obtained through field surveys were further extracted into spatial data so they could be processed using ArcGIS software. Spatial data processing with ArcGIS software generated maps of research locations, fecal coliform concentrations, land use in Kartasura Sub-district, population density in Kartasura Sub-district, and distribution of fecal coliform in Kartasura Sub-district. On the other hand, water samples taken were tested at the Environmental Laboratory of Perum Jasa Tirta 1. After attaining the results from the data processing stage, the next step was to carry out the data analysis stage. The research flowchart can be seen in Fig. 2.

Data presentation in tabular form was processed to display data on fecal coliform test results and population density data. Additionally, data were presented in maps to help observe the study locations of this study. Creating the distribution maps of sample points utilized the Graduated Symbols technique to achieve a map that describes the size of fecal coliform contained in each groundwater sample point. The greater the fecal coliform content, the larger the circle symbol depicted displayed, and vice versa; the smaller the symbol on the map, the smaller the fecal coliform content it represents in groundwater samples. The distribution map of the sample points is shown in Fig. 3. Generating a population density map applied the Graduated Colors Technique to obtain a map that describes the level of population density in the Surakarta Sub-district. The darker color on the map represents that the population density is higher, and vice versa, the lighter the color on the map, the lower the population density is. The map of population density in the Kartasura Sub-district is depicted in Fig. 10. Unlike the two obtained maps, the distribution map of fecal coliform concentrations was created using the Inverse Distance Weighted (IDW) Interpolation technique.

3 Result and Discussion

3.1 Spatial Distribution of Fecal Coliform

The results obtained in this study were groundwater contamination data by fecal coliform which infiltrated every village in Kartasura Sub-district; Gonilan, Pucangan, Pabelan, Singopuran, Ngemplak, Kertonatan, Ngadirejo, Kartasura, Wirogunan, Ngabeyan, Makamhaji, and Gumpang Villages. Based on laboratory tests, the results showed that 66.67% or 8 of 12 samples of groundwater in the Kartasura Sub-district had an inappropriate fecal coliform content and exceeded a predetermined threshold. Based on the Regulation of the Indonesian Minister of Health in Quality Standards No. 32 of 2017, the threshold value for fecal coliform content is 50/100 mL (Indonesia, 2017). The test results of the fecal coliform content are shown in Table 1.

Based on the data in Table 1, the results of the lab test for fecal coliform content found that the fecal coliform concentration in the sample water had varying values, ranging from a minimum of 4.5 MPN/100 mL to a maximum of 920 MPN/100 mL. Differences in fecal coliform content in each sample could be the result of dug well conditions. There are two types of dug wells used as sampling sites, namely open wells and closed wells. An open well is an open dug type as can be found in Singopuran Village, whereas a closed well is that with a cover. The cover on the dug well serves to prevent the penetration of foreign particles and objects that may contaminate well water. The covered well is located in Kartasura Village as indicated by woven bamboo placed as cover so that fallen dry leaves do not enter and contaminate the groundwater.

Table 1. Fecal coliform content

No.	Water Sample	Fecal Coliform (MPN/100 mL)	Minister of Health in Quality Standards No.32 of 2017 (MPN/100 mL)	Description
1	Gonilan	70	50	Unqualified
2	Pucangan	170	50	Unqualified
3	Pabelan	140	50	Unqualified
4	Singopuran	170	50	Unqualified
5	Ngemplak	33	50	Qualified
6	Kertonatan	220	50	Unqualified
7	Ngadirejo	920	50	Unqualified
8	Kartasura	240	50	Unqualified
9	Wirogunan	7.8	50	Qualified
10	Ngabeyan	220	50	Unqualified
11	Makamhaji	34	50	Qualified
12	Gumpang	4.5	50	Qualified

Most of the sampling wells are located next to residents' houses, which signifies that groundwater is used to meet the need for clean water, especially for sanitation activities. The map of the fecal coliform concentration contained in each sample point is provided in Fig. 7.

The level of fecal coliform content at each sample point is influenced by land use, social activity, population density, and the form of the dug well. The dug well in Ngadirejo Village had the highest fecal coliform size, reaching 920 MPN/100 mL. This is due to the open well and is proximate to the poultry shed, causing the manure to infiltrate and contaminate the water. The content of fecal coliform in Ngadirejo Village groundwater was very high, hence the facility should no longer be suitable for use. The groundwater remains active for the sanitation purposes of the owner. The façade of the dug well in Ngadirejo Village is shown in Fig. 3.

In contrast to Ngadirejo Village, the dug well test results of Gumpang Village had the lowest fecal coliform value, namely 4.5 MPN/100 mL. Thus, groundwater in Gumpang Village is safe for hygiene and sanitation purposes as its value is below the applicable threshold. The location of the dug well is in the yard of the resident's house (open land) and far from the latrines. This suggests that the dug wells in Gumpang Village are far from pollutant sources, so the fecal coliform content in samples is low. The groundwater is still consumed by the owner to wash dishes, but the cloudy water prohibits the owner to use it as drinking water. Groundwater used for drinking water should be free from contaminants, such as fecal coliform (Untung, 1996; Hudaya et al., 2010; Setianto & Fahritsani, 2019). The appearance of the Gumpang Village dug well is shown in Fig. 4.

Conversely, dug wells in several villages have a fairly high content of fecal coliform. Ngabeyan Village had a fecal coliform content of 220 MPN/100 mL, Kertonatan Village

Fig. 3. Dug well condiiton in Ngadirejo Village

Fig. 4. Dug well condition in Gumpang Village

had a fecal coliform content of 220 MPN/100 mL, Singopuran Village had a fecal coliform content of 170 MPN/100 mL, and Pucangan Village had a fecal coliform content of 170 MPN/100 mL. This situation occurs due to the location adjacent to the latrines.

It was found that the distance between the latrine and the dug well was less than 10 m. The appearance of the sample associated with a latrine in Pucangan Village is shown in Fig. 5. This demonstrates that the high fecal coliform content in the groundwater samples is because of the close interval to the latrine (pollutant source). The distance between the latrine and the dug well affects the bacterial content of nearby water sources, the closer the latrine is to the dug well, the greater the bacterial content will be (Hudaya et al., 2010; Widiyanto et al., 2015; Yuliansari, 2019; Dangiran & Dharmawan, 2020).

Furthermore, the content of fecal coliform in the groundwater samples of Kartasura Village is rather high. The test results showed that the amount of fecal coliform in the groundwater sample was 240 MPN/100 mL. Kartasura Village is the center of the Kartasura Sub-district, therefore the activity and mobility of the population are high. Resident activities in Kartasura Village include household activities, markets, schools, hospitals, restaurants, and others. It leads to the high fecal coliform contained in groundwater samples. Resident activities can have an impact on existing groundwater contamination. The appearance of dug wells in Kartasura Village is similar to the dug wells in other villages with a cover height of 75 cm to 1 m. The display of the Kartasura Village dug well is shown in Fig. 6.

After the results of the fecal coliform test were obtained, mapping was carried out based on the coordinates that had been extracted into shapefiles. Given Fig. 7, the highest yield fecal coliform concentration map is located in Ngadirejo Village marked with the biggest circle symbol. In practice, the condition of the groundwater samples in Ngadirejo Village was cloudy and smelled fishy. However, the water remained active for sanitation purposes. The pungent odor indicates that the level of water pollution in the area is quite a high (Widiyanto et al., 2015). A similar phenomenon occurred in Gumpang Village where the groundwater was turbid. However, it did not produce a pungent and fishy odor

Fig. 5. Condition of dug wells in Pucangan Village

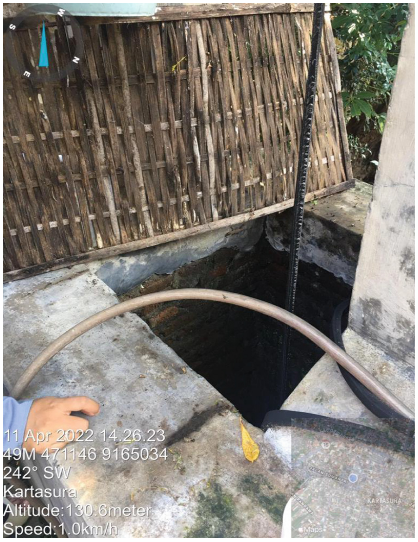

Fig. 6. Dug well condition in Kartasura Village

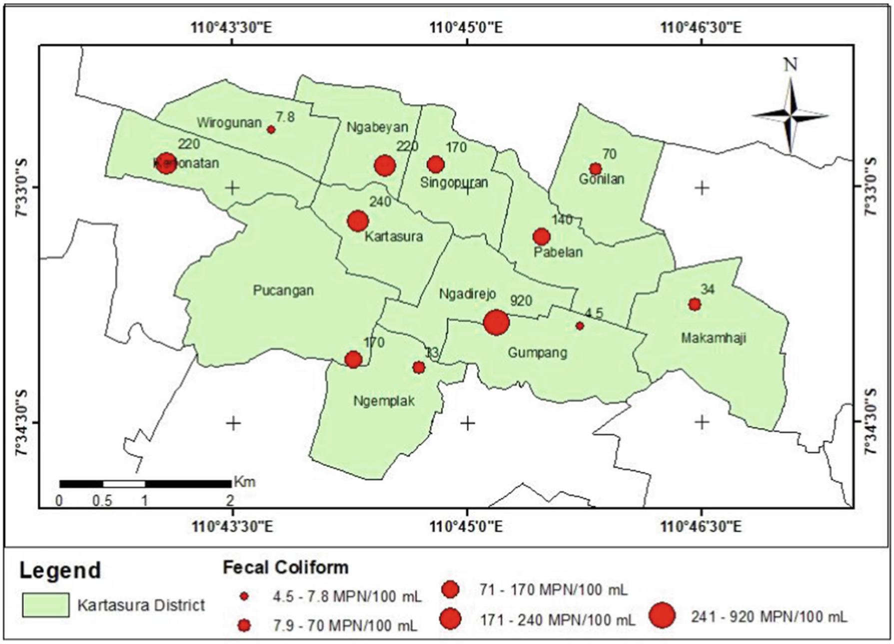

Fig. 7. Map of fecal coliform concentration

as found in Ngadirejo Village. Groundwater samples in Gumpang Village had the highest level of turbidity. The standard unit used to measure water turbidity is the Nephelometric

Turbidity Unit (NTU). According to the test results of the turbidity level in Gumpang Village, it obtained a value of 20.4 NTU. The location is near an industrial area, so this condition is deemed to be the cause of the turbidity of the groundwater sample in Gumpang Village. Turbid watercolor can also be an indication of water pollution (Widiyanto et al., 2015).

3.2 Distribution of Fecal Coliform

Generating a distribution map of fecal coliform utilized the IDW method to find out which areas are included in the red zone and have the highest level of fecal coliform pollution. Figure 8 shows a map of the distribution of fecal coliform in the Kartasura Sub-district.

Figure 8 shows that the fecal coliform distribution map in Kartasura Sub-district is divided into five classifications. The redder the location on the map implies the greater the fecal coliform content in the groundwater sample. The distribution of the fecal coliform red zone includes two villages, namely Ngadirejo Village and Gumpang Village. All groundwater samples used as sampling locations proved positively polluted by fecal coliform, so people should be more selective in finding water for consumption, especially those areas in the red zone. As many as 8 of 12 groundwater or 66.7% samples found that the fecal coliform content exceeded the regulated quality standards, including the villages of Gonilan, Pucangan, Pabelan, Singopuran, Kertonatan, Ngadirejo, Kartasura, and Ngabeyan. This suggests that the groundwater is unfit for consumption and causes

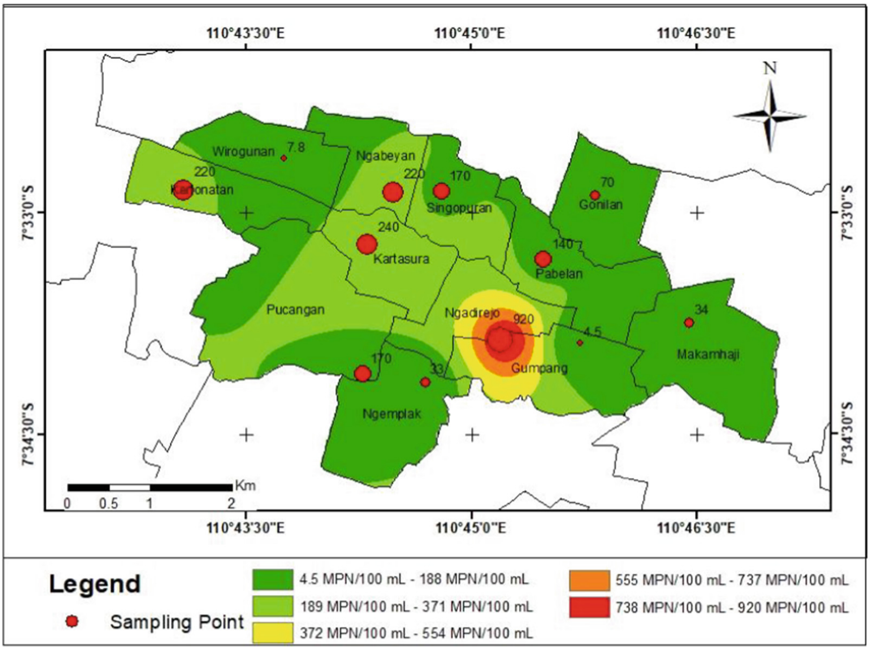

Fig. 8. Fecal coliform distribution map in Kartasura Sub-district

serious health problems. Therefore, special attention should be addressed to those whose groundwater is in the red zone.

Fecal coliform is one of the parameters used to determine the quality of water; if the amount is very high, it indicates that the quality of the water is bad/low. The results of this study are expected to give insight to the people in Kartasura Sub-district about the condition of the groundwater because all of them are actively used for sanitary hygiene purposes. The data can also be used by the local government to improve the supply of clean water.

3.3 Land Use Factor

Good spatial management is the key to controlling environmental pollution. If the land use patterns are dominated by human activities, of course, it will change land characteristics that impact environmental pollution (Dinasia et al., 2022). Humans as living beings need a place to live because the increasing population grows with the changes in land use for residential areas (Affan, 2014). Groundwater contamination may occur due to many factors, apart from dug well conditions, groundwater pollution can be influenced by the physical and social of the surrounding environment. The following is a visualization of the Kartasura Sub-district land use map.

Figure 9 describes that the dominant land use is residential areas, agricultural areas, and industrial areas. Various land use activities such as agriculture, industrial activities, and community social activities affect water quality in Kartasura Sub-district. If

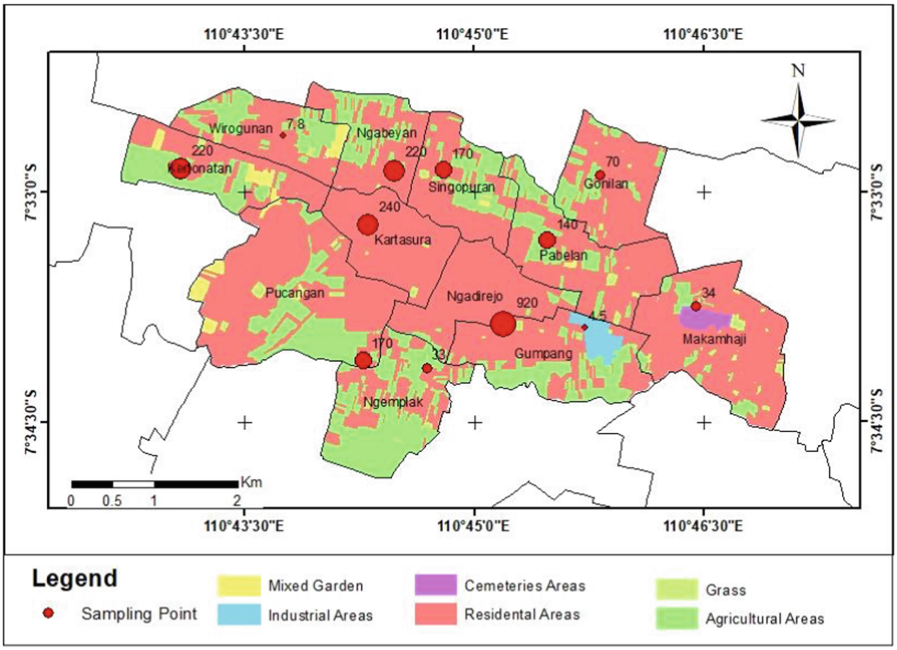

Fig. 9. Map of land use of Kartasura Sub-district

examined further on the Kartasura Sub-district land use, the fecal coliform content was very high. Located in a residential area, the visualization on the map is shown by pink color areas. These areas include Ngadirejo Village, Kartasura Village, Ngabeyan Village, and Kertonatan Village. These sites had fecal coliform test results of more than 200 MPN/100 mL, while groundwater sample points located in areas associated with paddy fields or vegetation had a smaller content of fecal coliforms, such as Singopuran Village, Pucangan Village, Pabelan Village, Gonilan Village, Ngemplak Village, Makamhaji Village, Wirogunan Village, and Gumpang Village with fecal coliform below 200 MPN/100 mL. The lowest bacterial content was found in groundwater samples from Gumpang Village. Groundwater sampling locations were carried out in areas associated with industrial areas. Furthermore, the content of fecal coliform in Makamhaji Village was also relatively low due to the location, in which the sample water was taken in the burial area. In contrast to Ngemplak Village and Wirogunan Village, the groundwater sampling locations were conducted in areas associated with agricultural land. This indicates the reason for the low content of fecal coliform in groundwater samples. In contrast, groundwater samples taken from residential land use patterns suggest that the fecal coliform content was very high, as seen in Ngadirejo Village and Kartasura Village. In essence, the type of land use at the sampling location influences the level of water pollution because the more domestic waste will be found in residential areas than in cemeteries or rice fields. Thus, residential areas influence by increasing groundwater contamination by fecal coliform (Yohannes et al., 2019).

3.4 Population Density Factor

High population density can have a negative impact on the environment. The increasing level of population density in the Kartasura Sub-district affected the increase in domestic waste produced. The higher the level of population density, the more waste will be produced, and subsequently, the greater the contribution to water pollution (Setianto & Fahritsani, 2019; Achmad et al., 2020; Sejati, 2020). Groundwater originating from densely populated settlements contains materials that cause sample water to smell (Widiyanti, 2019). Table 2 is population density data for Kartasura Sub-district.

Based on the data in Table 2, it is found that the population density ranged from 1,538 people/km^2 to 10,500 people/km^2. The level of population density in the Surakarta Sub-district is precipitated by the limited built-up land in Surakarta City, causing a shift in settlement development towards Kartasura Sub-district (Aini et al., 2020). The total population in Kartasura Village is approximately 15,259 people with a population density of 7,301 people/km^2. The high level of population density in Kartasura Village occurs thanks to the capital status of Kartasura Sub-district so trade and service activities are mostly centered in Kartasura Village. Eventually, people will choose to live in urban settlement areas, because of easy access and proximity to vital objects such as markets, financial institutions, health facilities, and economic conditions in more developed urban areas. The high level of population density in Kartasura Village has an impact on groundwater contamination by fecal coliform. The test results showed that the content of fecal coliform in the groundwater sample of Kartasura Village was 240 MPN/100 mL. This value was rather high compared to the other 11 villages. The following is a map of the distribution of population density in the Kartasura Sub-district as presented in Fig. 10.

Table 2. Fecal coliform content and population density (statistics Indonesia of Kartasura Sub-district, 2022)

NO.	Water Sample	Fecal Coliform (MPN/100 mL)	Population Density (Individual/km^2)
1	Ngemplak	33	1,538
2	Gumpang	4.5	8,255
3	Makamhaji	34	10,500
4	Pabelan	140	6,569
5	Ngadirejo	920	5,580
6	Kartasura	240	7,301
7	Pucangan	170	5,044
8	Kertonatan	220	2,029
9	Wirogunan	7.8	3,857
10	Ngabeyan	220	4,852
11	Singopuran	170	5,523
12	Gonilan	70	5,565

Given the population density distribution map of Kartasura Sub-district, Makamhaji Village had the darkest color visualization compared to other areas. This implies that the population density was the highest. In contrast, Ngemplak Village has the brightest color visualization indicating that the population density was the lowest. The highest population density was found in Makamhaji Village with the highest population density of 10,500 people/km^2. The high level of population density in Makamhaji Village occurs due to the very strategic location of Makamhaji Village which is directly adjacent to Surakarta City. Corresponding states also occur in Pabelan Village, with a population density of 6,569 people/km^2, and Gonilan Village, with a population density of 5,565 people/km^2. The three villages are directly adjacent to Surakarta City. Generally, people are more likely to opt for the urban center to live in. Although Makamhaji Village had the highest population density, which is 10,500 people/km^2, the fecal coliform content in the groundwater samples was relatively low, namely 34 MPN/100 mL since the soil samples taken are located in a burial area far from settlements. In the burial site, very little human activity can be observed, so the waste generated is low as well. Moreover, the soil in the burial area contains high organic matter and is supported by many plant roots which allow the soil to filter water better. Therefore, the level of groundwater contamination by fecal coliform in Makamhaji Village was also low, namely 34 MPN/100 mL. Similarly, this situation also occurred in Gumpang Village with a total population density of 8,255 people/km^2, with the lowest level of fecal coliform contained in the groundwater sample, namely 4.5 MPN/100 mL. Gumpang Village is an industrial area, so the population density is high.

The level of population density will affect the level of groundwater pollution because the more people reside there, the more waste will be produced. Therefore, a correlation

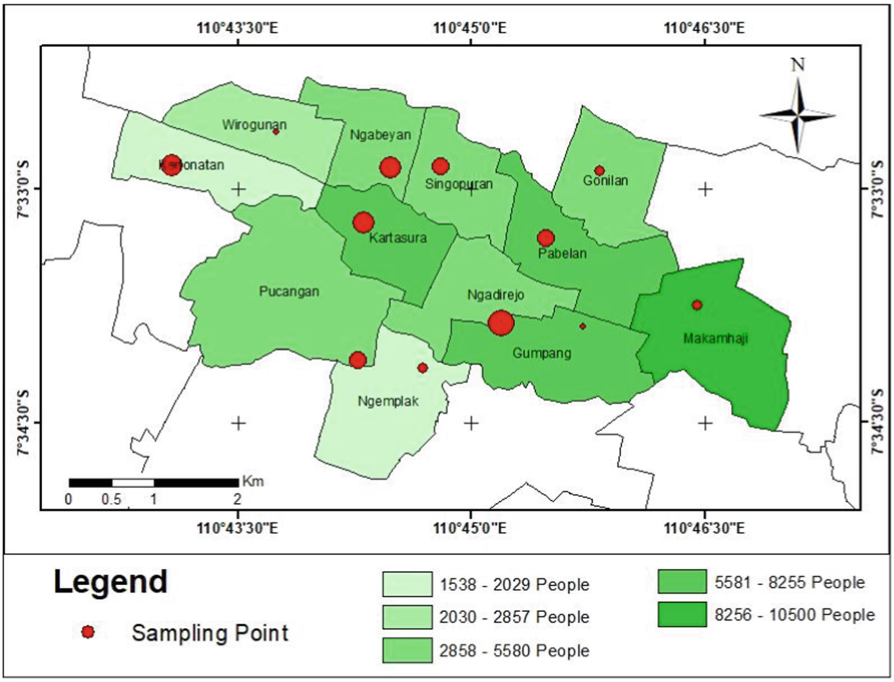

Fig. 10. Map of population density of Kartasura Sub-district

Table 3. Relationship between population density and fecal coliform

		Population Density	Fecal Coliform
Population Density	Pearson Correlation	1	-0.058
	Sig. (2-tailed)		0.857
	N	12	12
Fecal Coliform	Pearson Correlation	-0.058	1
	Sig. (2-tailed)	0.857	
	N	12	12

test was carried out to investigate the effect of population density on the level of groundwater contamination by fecal coliform in the Kartasura Sub-district. Based on the results of a correlation coefficient of 0.143 in Table 3, this suggests that the level of population density does not affect groundwater contamination by fecal coliform in Kartasura Sub-district.

The most influential factor in the groundwater contamination level in Kartasura Sub-district is the dug well condition, such as those found in Ngadirejo Village adjacent to the poultry house. This, indeed, shows a higher level of pollution compared to the well proximate to open land. Furthermore, the pattern of land use modifies the human activities in living surrounding, such as the pattern of land use for settlements. Human activity will be denser so more waste will be generated, in contrast to the pattern of land use for rice fields. One solution that can overcome this pollution issue is to build dug wells far from pollutant sources, or build drilled wells that can later be consumed collectively, considering that drilled wells have better quality than dug wells. Dug wells have a higher level of risk of contamination when compared to drilled wells (Korniasih & Sumarya, 2021).

4 Conclusions

The results show that 66.67% or 8 of the 12 groundwater samples in Kartasura Sub-district did not meet the fecal coliform quality standards in water, with the highest content reaching 920 MPN/100 mL, as found in Ngadirejo Village. Meanwhile, the lowest was discovered in Gumpang Village with results laboratory test of 4.5 MPN/100 mL. The distribution of fecal coliform closer to the red zone indicates that the level of contamination of groundwater by fecal coliform in that area is higher, including Ngadirejo Village and Gumpang Village.

Land use patterns influence the amount of fecal coliform contained in groundwater. Groundwater samples located in residential areas have a higher fecal coliform content than samples in land use designated as industrial areas, rice fields, or cemeteries because community social activities are centered in residential areas. Subsequently, the correlation coefficient results were 0.143, demonstrating that the level of population density has no effect on groundwater contamination by fecal coliform in Kartasura Sub-district.

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