The Effect of Anthropogenic Activity on the Distribution of Phosphate and Nitrate Content in Shallow Groundwater in Kartasura Subdistrict

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Abstract. The Kartasura Subdistrict is an area with high levels of human activity, which can affect the surrounding environment. One of the impacts of this activity is a change in the quality of groundwater in the surrounding environment. This study aimed to analyze the effect of human activities on the levels of phosphate and nitrate in shallow groundwater used for sanitation in the Kartasura Subdistrict. Groundwater samples were collected from 12 villages across the Kartasura Subdistrict. The methods used to test the phosphate levels were based on SNI 06–6989.31–2005, while the nitrate levels were tested according to the QI/LKA/65 (Screening Spectrophotometer) standard. The results of the tests for nitrate and phosphate were analyzed further according to the Government Regulation No. 82 of 2001 on Water Quality Management and Water Pollution Control. The results of the laboratory tests for nitrate levels showed that the highest nitrate content was found in Pabelan Village, with a value of 26.9 mg/l. This high nitrate content is due to the proximity of the sample location to paddy fields and residential areas, which generate agricultural and household waste that can affect groundwater quality. The highest phosphate levels were observed in Gumpang Village, with a value of 1.328 mg/l, as the samples were taken near industrial and residential areas, causing groundwater to be polluted by industrial and household waste.

Keywords: anthropogenic activity · sanitation activity · phosphate · nitrate · groundwater

1   Introduction

Population development and the needs it entails are inseparable elements from the growing built-up areas and community activities in several areas, such as the case in Kartasura Subdistrict. The increase in the number of residents goes closely with the increase in population activity and the impact it has on the environment. Built-up land is any area created, arranged, and maintained by humans to fulfill human needs to arbitrate the environment as a whole with results that affect the environment. Built-up land includes industrial buildings, residential buildings, roads, or other facilities that have experienced pavement on land (Bartuska & Young, 1994).

Kartasura District is one of the subdistricts in the Sukoharjo Regency. Kartasura Subdistrict is a place for urban development in Sukoharjo Regency. Kartasura is a satellite city for Surakarta as this subdistrict is traversed by provincial roads, Surabaya - Solo - Yogyakarta and Solo - Semarang. The impact of this strategic location is the development of centers of economic activity such as trade, services, and industry, so the unused land is declining. The height of the Kartasura area is grouped in the flat topography (Regional Government, 2018). The low topography of the Kartasura subdistrict makes it accessible for anthropogenic activities to be carried out.

One of the population activities in the Kartasura Subdistrict is the establishment of industrial areas. Besides, resident activities also take place in residential areas. Population activities may cause or affect the environment. One of the influences that can be observed is changes in the quality of groundwater in the Kartasura environment. The groundwater quality can be a result of the density and activities of the local community. The population in Kartasura Subdistrict in 2021 was recorded at 109,724 people. The population density in Kartasura reaches 5,273 people/km^2. Makamhaji Village has the highest density of 10,500 people/km^2, followed by Gumpang Village with a total of 8,255 people/km^2, then Kartasura Village totaling 7,301 people/km^2. Meanwhile, the lowest density is in Ngemplak Village with a total of 1,538 people/km^2. The population density in Makamhaji, Gumpang, and Kartasura is due to the high anthropogenic activity, in which these villages are the centers of economic activity. On the contrary, the lowest density is in Ngemplak Village because it has mainly agricultural land. The low population density does not imply that the groundwater is free of contamination, but it is possible because the results of agricultural activities also affect the surrounding groundwater. Currently, pollution draws more attention to the management of water resources in urban areas, following increasing water problems (Purnama & Cahyadi, 2019).

Water is a basic need that has a significant role in life. There are several types of groundwater sources, namely springs, shallow wells, and borehole wells. The water type that is often consumed by humans is shallow groundwater. It is water in the soil layer with a depth of approximately 15 m below the ground surface. Groundwater is commonly used for household purposes. Groundwater supply can be obtained in various ways. Drinking water is acquired in various ways, both from groundwater and other sources (Widiyanto et al., 2018). Groundwater essentially has adequate quality, but it is not uncommon for it to be polluted. Changes in groundwater quality that comprise non-natural processes are those of changes in groundwater quality brought about by various incidences related to the hydrological system by community activities such as population growth, changes in land use, industry, and others (Anna, 2001). Shallow groundwater located in densely populated areas will be vulnerable to contamination. Human behavior in the accidental disposal of organic and inorganic waste and solid waste and the lack of domestic waste management harms by increasing pollution and reducing water quality (Susanti & Miardini, 2017).

Pollution in shallow groundwater can be prompted by soil conditions in the environment of the contaminated area due to waste or as a result of human activities. Pollution of shallow groundwater commences with the process of absorption of pollutant sources which are discharged directly into the ground, as they seep through the pores to the aquifer layer. The process of absorbing pollutant sources takes a shorter time into the

aquifer layer during the rainy season. The speed of infiltration into the aquifer layer is precipitated by land biophysical factors, for instance, the type of land use (Srivastav et al., 2019). The infiltration is also influenced by the density of vegetation, slope, and soil type. Contaminated groundwater with pollutants will spread in the direction of the groundwater flow, thereby contaminating the shallow groundwater around residential areas (Chang et al., 2008). Increased population growth will have an impact on land conversion into built-up land, especially residential ones. The demand for residential land is increasing followed by the activities of the population upon it, making the need for clean water a vital need for the population also escalating. Results of anthropogenic activities found in the Kartasura Subdistrict influence groundwater conditions. Waste generated from industrial activities and household activities is also a trigger for water pollution in Kartasura Subdistrict. Detergents from human activities have active ingredients or are known as surfactants, which active ingredients can result in worsening water quality. Additionally, water pollution also results from agricultural activities (Sitmuroang, 2017). Polluted groundwater by a toxin will harm human life. This polluted water source by a substance with a value greater than the quality standards will cause health problems and even mortality (Priyana, 2016).

Based on the various results of anthropogenic activities that affect groundwater quality in the Kartasura Subdistrict, the study aimed to analyze the effect of anthropogenic activities on phosphate and nitrate content in shallow groundwater used for sanitation purposes in the Kartasura Subdistrict. It is because the results of human activities in the Kartasura area may lead to contamination of the shallow groundwater which is still actively consumed. Contaminated shallow groundwater used for daily sanitation purposes can bring a negative impact on human beings and the environment.

Phosphates and nitrates are chemical parameters that can indicate pollution in water because these chemicals are closely related to humans i.e. from domestic waste used for daily needs, and the content of fertilizers for agricultural activities comes from industrial waste (Patricia et al., 2018). These chemicals will flow and seep into the ground, thus disrupting the quality of groundwater. Measuring phosphate and nitrate content, important nutrients are carried out because these two parameters become a reference for the fertility level of the water (Arizuna et al., 2014). Phosphate is a substance that has a role in the growth of phytoplankton and is an indicator of water quality and soil fertility (Harnita Harni, Syafriadiman, 2017). The impact of phosphate content in shallow groundwater consumed by humans is digestive problems. Apart from the phosphate content, water quality can also be determined by nitrate content. Nitrate is more easily absorbed by plants so it has a direct influence on the level of water productivity. Agricultural areas in Kartasura Subdistrict are also one of the reasons for water. The nitrate content in shallow groundwater used by the community is the cause of goiter in humans (Ismail, 2011). The main sources of nitrate and phosphate are naturally derived from the waters through the processes of decomposition, weathering, plant decomposition, the remains of dead organisms, and landfill waste (domestic, industrial, agricultural, husbandry farm, and feed residues) which will be disintegrated by bacteria into nutrients (Patty, 2015).
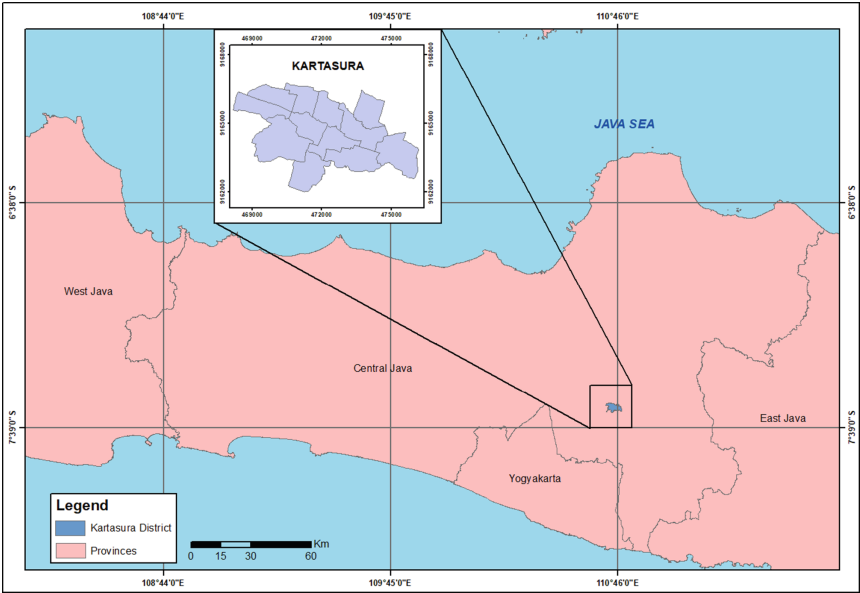
Fig. 1. Map of the study area

Mapping using geographic information system technology is important in this research. The geographic information system plays a role in processing and displaying the visualization of the shallow groundwater distribution which becomes the sampling point. Besides processing the distribution of shallow groundwater sample points, geographic information system technology also plays in visualizing land use in Kartasura Subdistrict.

2 Methods

2.1 Study Area

Kartasura is one of the subdistricts with the smallest area in Sukoharjo Regency, Central Java. The map display of the research location is presented in Fig. 1. It is known as the golden triangle or the meeting point of three routes, namely Solo, Yogyakarta, and Semarang. Kartasura Subdistrict is directly adjacent to Karanganyar Regency to the north, Surakarta City to the east, Gatak Subdistrict to the south, and Boyolali Regency to the west. In 2021, it is recorded that Kartasura Subdistrict covers 2.166 Ha. This area is the smallest subdistrict in Sukoharjo Regency. There are 12 villages mapped, namely Ngemplak Village, Gumpang Village, Makamhaji Village, Pabelan Village, Ngadirejo Village, Kartasura Village, Pucangan Village, Kertonatan Village, Wirogunan Village, Ngabeyan Village, Singopuran Village, and Gonilan Village. Based on the economic perspective, Kartasura is an independent city as it has business and residential areas (Statistics Indonesia of Sukoharjo, 2022). The area of every village is very diverse, in which the widest area is Pucangan Village totaling 335 Ha. This is inversely proportional

Table 1. The area of Kartasura Subdistrict (Statistics Indonesia of Kartasura, 2022)

No	District	Area (Ha)
1	Ngemplak	185
2	Gumpang	206
3	Makamhaji	239
4	Pabelan	234
5	Ngadirejo	140
6	Kartasura	136
7	Pucangan	335
8	Kertonatan	146
9	Wirogunan	144
10	Ngabeyan	131
11	Singopuran	134
12	Gonilan	136
	Total	2,166

to Ngabeyan Village, the smallest area, 131 Ha. The distance from Sukoharjo Regency to Jakarta, the capital of Indonesia, is approximately 550 km. The area of each village in the Kartasura Subdistrict is displayed in Table 1.

2.2 Data

The data used in this study were primary and secondary. Primary data were obtained from the results of surveys conducted in the field and followed by conducting laboratory examinations. The survey was conducted by sampling shallow groundwater data from each village in Kartasura Subdistrict. Laboratory tests were carried out to investigate the results of the water quality samples. The coordinate point data for sampling are listed in Table 2.

Secondary data were obtained from related agencies whose data were obtained indirectly. The required secondary data are administrative data and land use data of Kartasura Subdistrict in 2022. The obtained data were then processed using geographic information system technology, in this case, ArcGIS Software. The required secondary data can be seen in Table 3. The results of secondary data collection were used to make maps related to the research.

2.3 Research Parameters

The research was conducted to test the water quality of shallow groundwater samples in the Kartasura Subdistrict using two parameters, consisting of phosphate and nitrate. The test method for the phosphate parameter refers to SNI 06–6989.31–2005, while the test for the nitrate parameter refers to QI/LKA/65 (Screening Spectrophotometer). The test

Table 2. Sample point coordinates

X	Y	Village
475,089	9,164,062	Makamhaji
473,301	9,164,852	Pabelan
472,055	9,165,701	Singopuran
471,851	9,163,316	Ngemplak
468,893	9,165,712	Kertonatan
472,838	9,163,836	Ngadirejo
471,083	9,163,418	Pucangan
471,146	9,165,034	Kartasura
470,121	9,166,113	Wirogunan
471,463	9,165,688	Ngabeyan
473,746	9,163,810	Gumpang
473,956	9,165,630	Gonilan

Table 3. Research data

Data	Source
Administrative Data of Kartasura Subdistrict	Geospatial Information Agency
Land Use Data of Kartasura Subdistrict	Geospatial Information Agency

results for the parameters of nitrate and phosphate used the reference of Government Regulation No. 82 of 2001 on Water Quality Management and Water Pollution Control. The chemical parameters in the quality standards for the parameters in this study are shown in Table 4.

Table 4. Chemical parameters in quality standards according to Government Regulation No. 82 of 2001

No	Parameter	Unit	Quality Standard
1	Phosphate	mg/L	0.2
2	Nitrate	mg/L	10

Fig. 2. Documentation of Shallow Groundwater Sampling Locations in Wirogunan Village

Fig. 3. Documentation of Shallow Groundwater Sampling Locations in Gonilan Village

3 Results and Discussion

3.1 Field Survey

Sampling of shallow groundwater was carried out in 12 villages across Kartasura Subdistrict. The communities in Kartasura Subdistrict still consume shallow groundwater for their daily needs. The sampling was conducted randomly and only one point was taken from every village. The water sampling process should be sterile without any contamination. Sampling should not be taken after rain as it will affect the content contained in groundwater. Shallow groundwater sampling in Wirogunan Village is shown in Fig. 2, samples in Gonilan Village are shown in Fig. 3, Pabelan Village's samples are shown in Fig. 4, and Singopuran Village's samples are in Fig. 5. Distribution Shallow groundwater sample points are depicted on the map in Fig. 6. The physical conditions at each sampling location are different. Some villages showed clear and odorless water. On the contrary, other villages had colored and odored water, therefore it can be inferred that the groundwater has been polluted. This will negatively impact health if it persists as a consumption source.

3.2 Land Use

Land use impacts water quality, and the influence of land use can be either positive or negative. Commonly, the impact obtained as a result of activities from land use is negative. Effects arising include changes in the amount of sediment and the concentration of nutrients, salts, metals, and agrochemicals (Maria & Lestiana, 2014). Land use characterized by community activities, including settlements, agriculture, and industry has contributed to organic matter that influences water quality. Agricultural activities play a vital role in increasing nitrogen uptake into water bodies resulting from several factors, comprising the use of compost, manure, sewage sludge of plants, and soil aeration. The

Fig. 4. Documentation of Shallow Groundwater Sampling Locations in Pabelan Village

Fig. 5. Documentation of Shallow Groundwater Sampling Locations in Singopuran Village
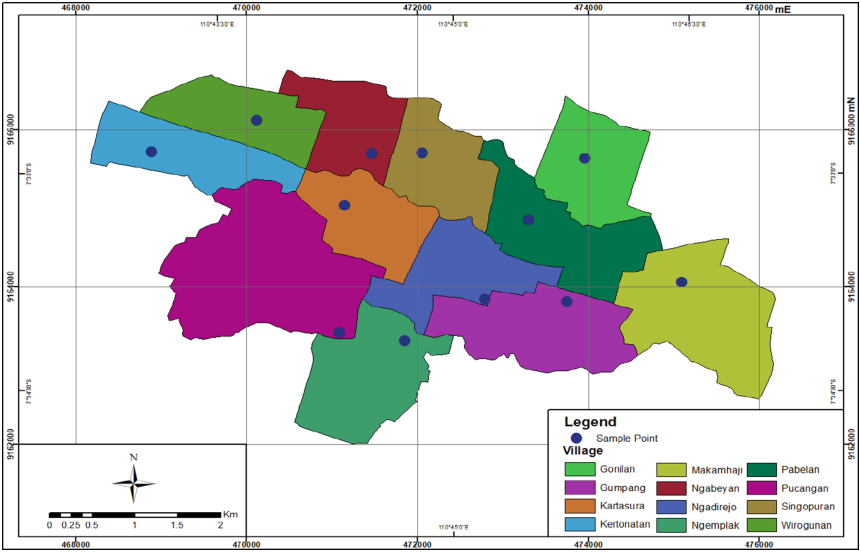

Fig. 6. Map of the distribution of sample points of Kartasura Subdistrict

settlement and industry activities also affect the quality and content of water. Water pollution can be brought about by livestock activities, mainly sourced from waste produced by livestock, namely urine, feces, leftover feed, and water leftover from cleaning livestock and cages (Kiersch, 2000).

Kartasura Subdistrict has several land uses, such as paddy fields, yards, and so on. The most extensive area in Kartasura Subdistrict is the yard, followed by paddy fields, and others. The percentage of yard land use is 72%, paddy fields 21%, and 7% for other purposes. The largest yard area is in Pucangan Village with 207 Ha, while the smallest
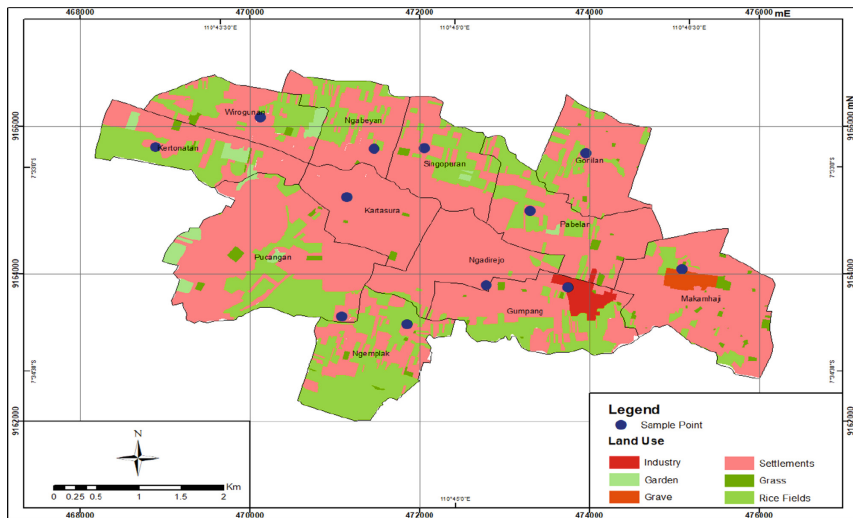
Fig. 7. Map of land use of Kartasura Subdistrict

yard lands with an area of 71 Ha are in Gumpang Village and Ngabeyan Village. Yard land has the most extensive area since Kartasura Subdistrict is experiencing vast growth so it is directly proportional to the growth in housing development. Ngemplak Village has the largest paddy field area of 114 Ha, while Ngadirejo Village and Kartasura Village have the narrowest paddy fields with an area of less than 1 Ha. A land use map is provided in Fig. 7.

3.3 Phosphate

Laboratory tests last for several days. Laboratory test results show that shallow groundwater analysis results at several points are not suitable for sanitation or consumption. The parameters used are phosphate and nitrate. Phosphate has a great function for living things. Phosphate serves to support the formation and strengthening of bones and teeth, helps carry out nerve functions and muscle contractions, and is a raw material for particular important structures in body cells. Phosphate is a chemical substance that contains the mineral phosphorus; when it penetrates the intestine through food, phosphorus will be absorbed and mixed with oxygen to form phosphate. The content in the human body should not be less or more than the applicable standards or regulations because it may affect the body or its function. Phosphate and nitrate support organisms in their growth and development, especially phytoplankton. Changes in levels that occur will certainly affect the life of the ecosystem in the water. The results of laboratory tests for phosphate content in shallow groundwater can be referred to in Table 5.

The function of phosphate within plants can accelerate the growth of seedling roots, speed up and strengthen the growth of seedlings into mature ones, accelerate the flowering and ripening of fruits and seeds, and increase grain production (Sutedjo, 2010). Phosphate in water comes from the results of decomposition, rock weathering, and

Table 5. Result of shallow groundwater laboratory tests for phosphate parameters

Sample Area	Phosphate (PO4)
Makam Haji	0.1917
Pabelan	0.5447
Singopuran	0.2335
Ngemplak	1.078
Kertonatan	0.0735
Ngadirejo	0.4878
Pucangan	0.65
Kartasura	0.5191
Wirogunan	0.1347
Ngabeyan	0.1376
Gumpang	1.328
Gonilan	0.9179

waste from activities on land, while Effendi explains that the anthropogenic source of phosphate comes from detergents (Hutagalung, 1997).

Based on Government Regulation No. 82 of 2001 on Water Quality Management and Control of Water Pollution, it is understood that there are four villages with phosphate content below the threshold, namely Makamhaji Village, Kertonatan Village, Wirogunan Village, and Ngabeyan Village. This is because the physical conditions at the sampling location are well maintained and it is far from human results, such as bathrooms or domestic waste disposal sites, thus it is consumable for regular purposes. Meanwhile, other villages show phosphate content above the quality standard because it is influenced by the results of anthropogenic activities, including domestic waste, industrial waste, and agricultural waste. Gumpang Village has the highest phosphate content because the samples were taken close to industrial and residential areas, therefore the groundwater has been polluted by those activities. This can also be seen in the appearance of colored and odored groundwater. The results of industrial and domestic waste affect the quality of groundwater, especially if the processing of waste products from these industries does not go through proper processing. Processing of industrial waste that violates the applicable standards and is carried out continuously will result in the absorption of the content by the soil and affect the quality of groundwater around the sampling point.

Wastewater has an indirect influence on the quality of groundwater. Wastewater with a low dirty level will be neutralized by the soil layer. However, if it is far from the capacity of the soil, the waste will result in a polluted groundwater (Tejokusumo, 2007). This is modified by the distance between the wells and the type and condition of the well, the category of contamination, rainfall, and many more.

3.4   Nitrate

Nitrogen in water can come from human activities, including producing waste in form of industrial wastewater, animal waste, vehicle emissions, and agricultural waste, all of which can serve in the formation of nitrates (Bahri, 2016). Nitrate content can be raised by an increase in different human activities around the river. Nitrate is a compound that derives from the waste of agricultural fertilizer. These compounds can contaminate shallow groundwater sources. High nitrate content will cause several health problems, such as goiter, cancer, and other health problems. Nitrate consumed and penetrating the human body will be reduced to nitrite, which contains carcinogenic properties. An effort that should be done to avoid nitrates is to use water from the springs and maintain environmental sanitation. The results of laboratory tests for phosphate content in shallow groundwater can be seen in Table 6.

Based on the results of laboratory tests using nitrate parameters carried out at 12 points across the Kartasura Subdistrict, it is found that the highest nitrate content was in Pabelan Village. The value of the nitrate content found in Pabelan Village was 26.9 mg/l where this value exceeded the threshold according to Government Regulation No. 82 of 2001 concerning Water Quality Management and Water Pollution Control, stating the quality standard for nitrate levels for drinking and daily use is 10 mg/l. The effect of the high nitrate content in Pabelan Village is due to the proximity of the sampling location to paddy fields and settlements where both lands have anthropogenic activity results which can affect groundwater quality. This corresponds with Hu J's statement (Hu, 2018) in (Miriam et al., 2021), fertilizers and pesticides with nitrogen content used for agricultural activities will affect the surrounding ecosystem if they are carried by the flow and absorbed by the soil, hence reducing water quality. The groundwater samples were shallow, the wells were not covered, thus susceptible to contamination. The area of

Table 6.   Result of shallow groundwater laboratory tests for nitrate parameters

Sample Area	Nitrate (NO3-N)
Makam Haji	0.1633
Pabelan	26.95
Singopuran	7.774
Ngemplak	2.488
Kertonatan	0.4484
Ngadirejo	2.626
Pucangan	5.916
Kartasura	5.187
Wirogunan	1.409
Ngabeyan	0.2484
Gumpang	7.026
Gonilan	1.969

the paddy fields makes the use of fertilizer higher so that the fertilizer will be absorbed by the soil and affect the groundwater around the paddy fields. Shallow groundwater samples at 11 other village points had a nitrate content value of less than 10 mg/l. The lowest nitrate content was in Makamhaji Village with a value of 0.1633 mg/l. The low value of nitrate in Makamhaji Village is due to a minimum anthropogenic activity that directly affects nitrate levels and it is located near the cemetery. Judging from the existing land use map, when compared to Kartasura Village with paddy fields, the value of nitrate content is higher than Makamhaji Village due to land conversion from previously paddy fields to built-up land, so the remaining agricultural activities are still reserved in soil. It is also added by activities that produce domestic waste so it leads to groundwater contamination.

4   Conclusions

Based on the results of laboratory examinations, it was found that the phosphate levels in eight villages were above the predetermined quality standards. Shallow groundwater in Gumpang Village had the highest phosphate content, namely 1,328 mg/l. It is because the sampling location is close to industrial activities and resident activities that produce industrial waste and domestic waste. Additionally, the characteristics of groundwater were also inadequate because it displayed a cloudy color and emitted odors, therefor groundwater is unfit for daily use as it may harm health. The highest level of nitrate parameter was found in Pabelan Village with a value of 26.9 mg/l. This occurs due to agricultural activities in the vicinity of the location and the covered wells so they are prone to contamination from the environment and other activities. The closer the sampling location is to the results of anthropogenic activity, the higher the phosphate and nitrate levels in shallow groundwater in the Kartasura Subdistrict. The impact prompted by these two parameters can result in serious illness among communities. This indicates that it is necessary to properly and optimally manage domestic, agricultural, and industrial waste so as not to affect the quality level of shallow groundwater, which is still actively consumed for daily needs.

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