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Characterization of shallow groundwater chemistry in the Yogyakarta basin, Central Java

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Abstract. Sufficient water supply can still be a big challenge in developing countries. A large number of households in Yogyakarta still relay on private dug wells to meet their daily demand. But water from shallow aquifers is prone to pollution from sewage systems, industry and agriculture. To assess the water quality in the basin of Yogyakarta, this study determines the chemical characteristics of the shallow groundwater in anthropogenically influenced and uninfluenced areas in and around the city of Yogyakarta. Therefore, a combination of on-site and laboratory analysis is used to distinguish areas of different water types. The observations give a major ion distribution for the whole research area and show significant anomalies in nitrate and phosphate concentrations especially in the city. Furthermore, high DOC values point out that the aquifer is widely polluted. There is a need for a better groundwater protection and remediation strategy to facilitate future use of those groundwaters.

1. Introduction

The special province of Yogyakarta (Daerah Istimeva Yogyakarta) is located at the south coast in the centre of Java Island, Indonesia. The province and its capital Kota Yogyakarta experienced a high variety of influences from different cultures during its past [1]. Water supply is mainly obtained from an aquifer close to the surface which is therefore prone to pollution. From 1984 to 2013, a groundwater table decline of about three meters was observed [2]. Only 30 % of the population is connected to the city's water supply network which loses about 40 % of its capacity underground [3]. A majority of inhabitants meet their water demand by private dug wells. A small number of households is connected to a sewerage system. High coli bacteria concentrations suggest a high leakage rate from sewage in the city area. The adjusted annual groundwater recharge is about 45.10^6 m^3/a [3]. The groundwater chemistry in these private dug wells is at the focus of this study. In the context of a master thesis within the German-Indonesian GetIn-CICERO cooperation between RWTH Aachen University (Germany) and Universitas Gadjah Mada (Indonesia), a campaign of on-site parameter measurements and laboratory analyses was carried out to assess groundwater quality in the Yogyakarta groundwater basin. We measured on-site parameters from dug wells including the water temperature, electrical conductivity (EC), pH and groundwater level. In each location, water samples were taken and analysed for alkalinity, concentration of the major ions and carbon concentrations. These results are used to outline the types of groundwater present in the aquifer and identify possible sources of pollution. This paper aims to deliver a characterisation of the chemical state of the shallow groundwater in Yogyakarta and to identify possible threats to its groundwater quality.

2. Research Area

The research area is located in the Special Province Yogyakarta. The province is divided into five districts (or "regencies"): Kulon Progo, Bantul, Gunungkidul, Sleman and Kota Yogyakarta. The research area covers Sleman, Kota Yogyakarta and parts of Bantul. It follows the borders of the Yogyakarta groundwater basin. DI Yogyakarta has a population of approximately 3.8 million.

Sleman Regency is located in the northern area of DI Yogyakarta from the city centre (Kota Yogyakarta) up to the slope of Merapi volcano. Sleman Regency has a population density of 2122 inhab. km^{-2}. Kota Yogyakarta is the province capital and has the highest population density in the province by 13290 inhab. km^{-2}. Bantul Regency is located in the south and has a population density of 2009 inhab. km^{-2} [4]. The exact location and outline of the research area is displayed in figure 1. The outline of the groundwater basin is shown in red. Also displayed are the districts, and their subdistricts as well as rivers and observation points. In the northern area of Yogyakarta at the slope of Merapi, farming is a very important land use due to the fertile soil properties of the volcanic products. The precipitation in Yogyakarta averages to 2012 mm/a with 119 days of rain per year. The climate is driven by the alternation of rainy and dry seasons [5].

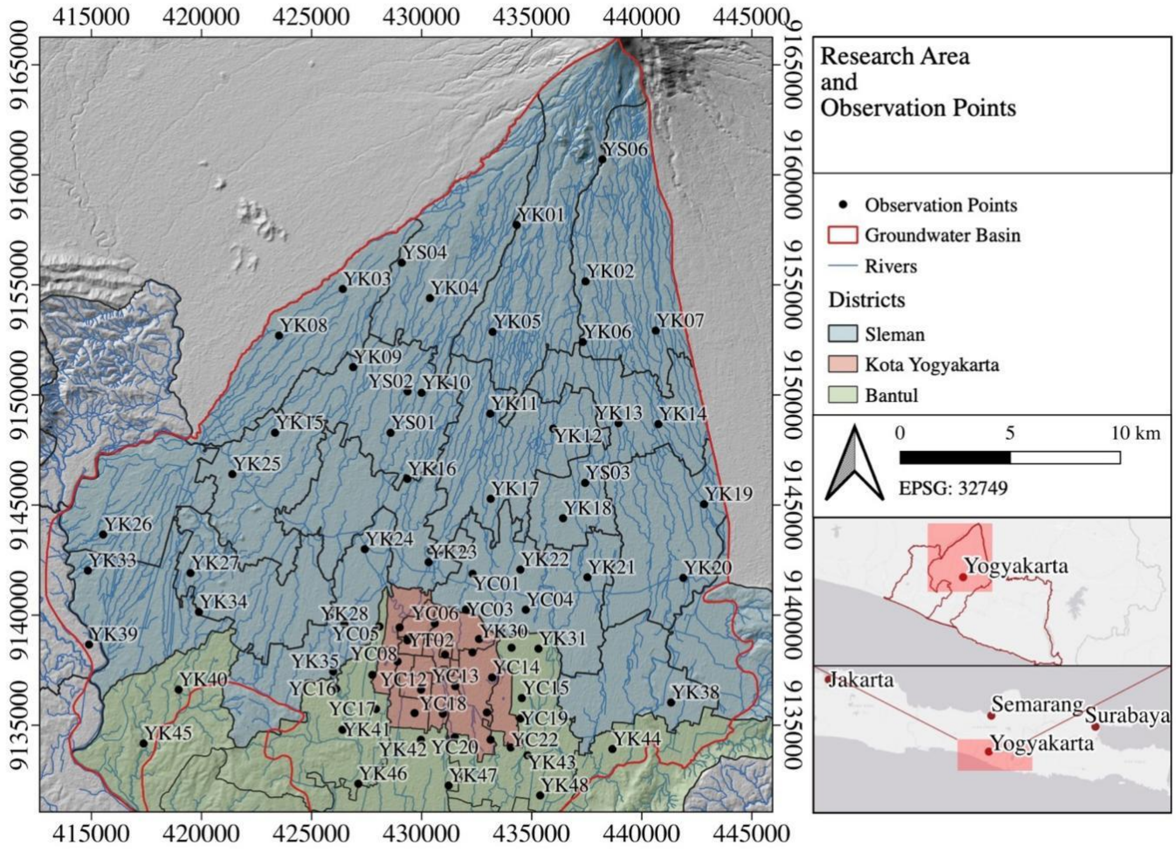

Figure 1. Overview of the research area and location of observation points categorised in the central districts Sleman (north), Kota Yogyakarta (centre) and Bantul (south). EPSG (European Petroleum Service Group Geodesy) is one of the largest geodetic parameter datasets widely used for coordinate reference system identification and is used for the coordinates of the main map and also in figure 5.

IOP Conf. Series: Earth and Environmental Science **851** (2021) 012015 doi:10.1088/1755-1315/851/1/012015

3. Hydrogeological Setting

The dominating hydrogeological system in the research area is the Yogyakarta groundwater basin. The basin is constituted by an upper aquifer (Yogyakarta formation) and a lower aquifer (Sleman formation). Their substratum is formed by the Old Merapi volcano in the north and the Sentolo formation in the south. The Yogyakarta Graben is located underneath the central part of Yogyakarta. This Graben system is filled with Young Merapi deposits which form the upper and lower aquifers of the Yogyakarta groundwater basin. Both formations can be subdivided into several Quaternary layers of gravel, sand, and clayey sand. These layers are partially interrupted by low permeable, more clayey layers [6]. This leads to locally changing head differences between the upper and lower aquifers [7].

4. Methodology

On the basis of former studies in this area, a sampling grid was set up including 78 locations. The grid was designed to get an overall impression of the chemistry in the whole research area. A focus was also to gain detailed information about groundwater uninfluenced from anthropogenic activities in the north as well as to get a higher resolution in the densely populated city area of Kota Yogyakarta. Most samples were taken from private dug wells of local households and few from springs.

At each sampling location, a water sample was taken from the dug wells for further laboratory analysis. Furthermore, on-site parameters as water temperature, EC, pH and groundwater level were measured. The water samples were analysed on alkalinity by manual titration. Total organic carbon (TOC), total inorganic carbon (TIC), their dissolved species (DOC, DIC) and total bound nitrogen (TNb) were measured in the GETIN CICERO laboratory at Universitas Gadjah Mada, Yogyakarta, by elemental analyzers. An additional set of samples was sent to RWTH Aachen University in Germany for major ion analysis by ion chromatography.

4.1. Groundwater Sampling

A majority of groundwater samples was taken from private dug wells since there was no sufficient network of groundwater observation wells available to cover the whole research area. Sampling dug wells in private households requires a minimal invasive sampling method. To still obtain water samples which represents the actual groundwater chemistry, without setting up a pumping installation, the sample was taken one meter below groundwater surface. For this purpose, a steel cage for sampling bottles was designed as shown in figure 2. The sampler was attached to a rope and positioned right above the water surface. For sampling, it was then dropped quickly one meter below surface to be filled in that depth and pulled up after it filled completely with water. Samples were not taken deeper, because the depth of most of the wells was unknow and the well sump was to be avoided. Bottles were taken off the cage, sealed and new bottles were placed for each sampling point.

Figure 2. Bottle cage with additional weight designed to sample water from a certain depth in a private dug well. The cage suits a sample bottle with a volume of 1 L.

IOP Conf. Series: Earth and Environmental Science **851** (2021) 012015 doi:10.1088/1755-1315/851/1/012015

4.2. On-site Parameters
Parameters like pH, EC and water temperature underlay changes with time after sampling [8]. These parameters were thus measured on each sample right after sampling. On-site measurements were carried out with HI98195 and HI9811-5 probes of the company HANNA instruments which were calibrated daily. Additional to chemical parameters, the groundwater level in each dug well was measured with a water level probe.

4.3. Laboratory Analyses
Alkalinity was obtained in the laboratory by manual titration after German norm DIN 38409-7 using methyl orange and hydrochloric acid. The dissolved species were measured on samples filtered at the lab using a filter size of 0.45 µm. Former studies have shown that DOC concentrations in unpolluted aquifers are within the range of 0.1 – 4 mg/L as C. Where concentrations in shallow aquifers are highly dependent on soil properties which influence organic carbon intake [9]. Inorganic carbon concentrations are compared with the results of the alkalinity measurements. Total bound nitrogen (TNb) represents the sum of nitrite, nitrogen (NO_2-N, NO_3-N), ammoniacal nitrogen (NH_4-N) as well as organic bound nitrogen [10]. Main artificial sources of nitrogen in groundwater are sewage and fertilizers [11]. Therefore, TNb is a good indicator for anthropogenically influenced groundwater chemistry.

5. Results
The observed groundwater temperature ranges between 20.8°C and 28.7°C with a mean of 27.2°C. The groundwater temperature is increasing from north towards the city area in the south as elevation decreases, and thus atmospheric temperature increases. Groundwater elevation is decreasing from north to south, following also the elevation decrease. An overview is given in figure 3 and 4.

Minimum, maximum, mean and standard deviation of pH and electrical conductivity in µS/cm are given in table 1 for each district. The largest range of pH values was observed in Sleman with a significantly higher maximum pH value than in the other districts. The same was observed by the electrical conductivities. Remarkable is that in Sleman the minimum observed electrical conductivity was significantly lower than in any other district.

Table 1. Overview of on-site measurements categorized into district.

	pH [-]			**EC [µS/cm]**		
	Sleman	Yogyakarta	Bantul	Sleman	Yogyakarta	Bantul
Min	5.9	6.1	6.0	93	394	311
Max	7.9	7.1	6.9	881	737	873
Mean	6.6	6.4	6.4	336	516	512
Std. Deviation	0.4	0.3	0.2	143	92	155

Table 2. Overview of TNb and DOC measurements in [mg/L] categorized by district.

	TNb [mg/L]			**DOC [mg/L]**		
	Sleman	Yogyakarta	Bantul	Sleman	Yogyakarta	Bantul
Min	< 0.1	0.6	< 0.9	0.9	1.2	1.5
Max	24.1	40.9	40.9	7.4	3.5	6.5
Mean	4.8	17.9	9.8	2.0	2.0	2.7
Std. Deviation	6.7	9.9	10.7	1.2	0.6	1.3

Out of the measurements of TOC, TIC, DOC, DIC and TNb, table 2 gives an overview of TNb and DOC concentrations in mg/L. These are the more significant parameters measured.

Figure 3 and 4 display samples from the city area and from the main recharge area in the north of the city. Groundwater level is used here but correlates with elevation very significantly (R^2 = 0.9997). In the city area data are clustered as the change in groundwater level is low. The trend in temperature is as discussed before. The trend in electrical conductivity is representative to emphasise the anthropogenic influence on the groundwater chemistry that evolves with an increasing population density, and maybe also an increasing trend of water-rock interactions. One outlier is not taken into account, since the observed electrical conductivity is rather high for this elevation.

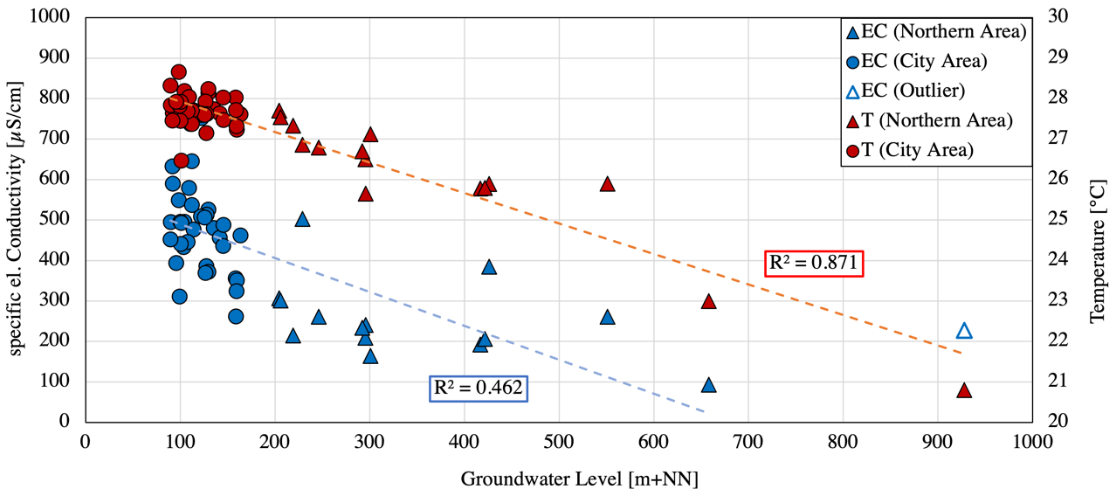

Figure 3. This diagram shows the spatial trend of specific electrical conductivity and temperature of the water samples. The groundwater elevation is highest in the north and decreases southwards to the city area.

Figure 4 displays nitrate concentrations and groundwater level. Samples of the northern area range between no detected nitrate and 57.5 mg/L. The majority of measured nitrate concentrations in the north are below 20 mg/L. The city area shows a high spread of nitrate concentration up to 176 mg/L. This shows very clearly the groundwater pollution in the city area.

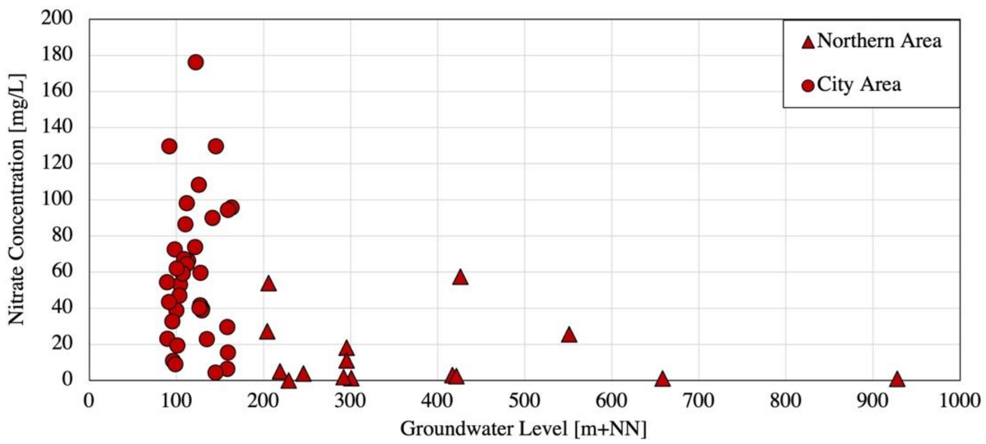

Figure 4. This diagram shows the difference in nitrate concentration measured in the low populated area in the north (high groundwater level) and the city area (low groundwater level).

In figure 5 the concentrations of the major ions measured on groundwater samples are displayed. Cations are shown in a spectrum of red to yellow and anions in blue to green. The presented concentrations are given in mmol(eq)-%. The ion proportion varies clearly within the research area. Characteristic concentrations can be observed in different regions. Bicarbonate is in most springs and wells the dominating anion in western and northern Sleman district. To the south east and in Kota

Yogyakarta the percentage of other anions, especially nitrate, increases and nitrate is higher in concentrations. The most represented cation is Ca^{2+} followed by Na^{+} in the whole research area.

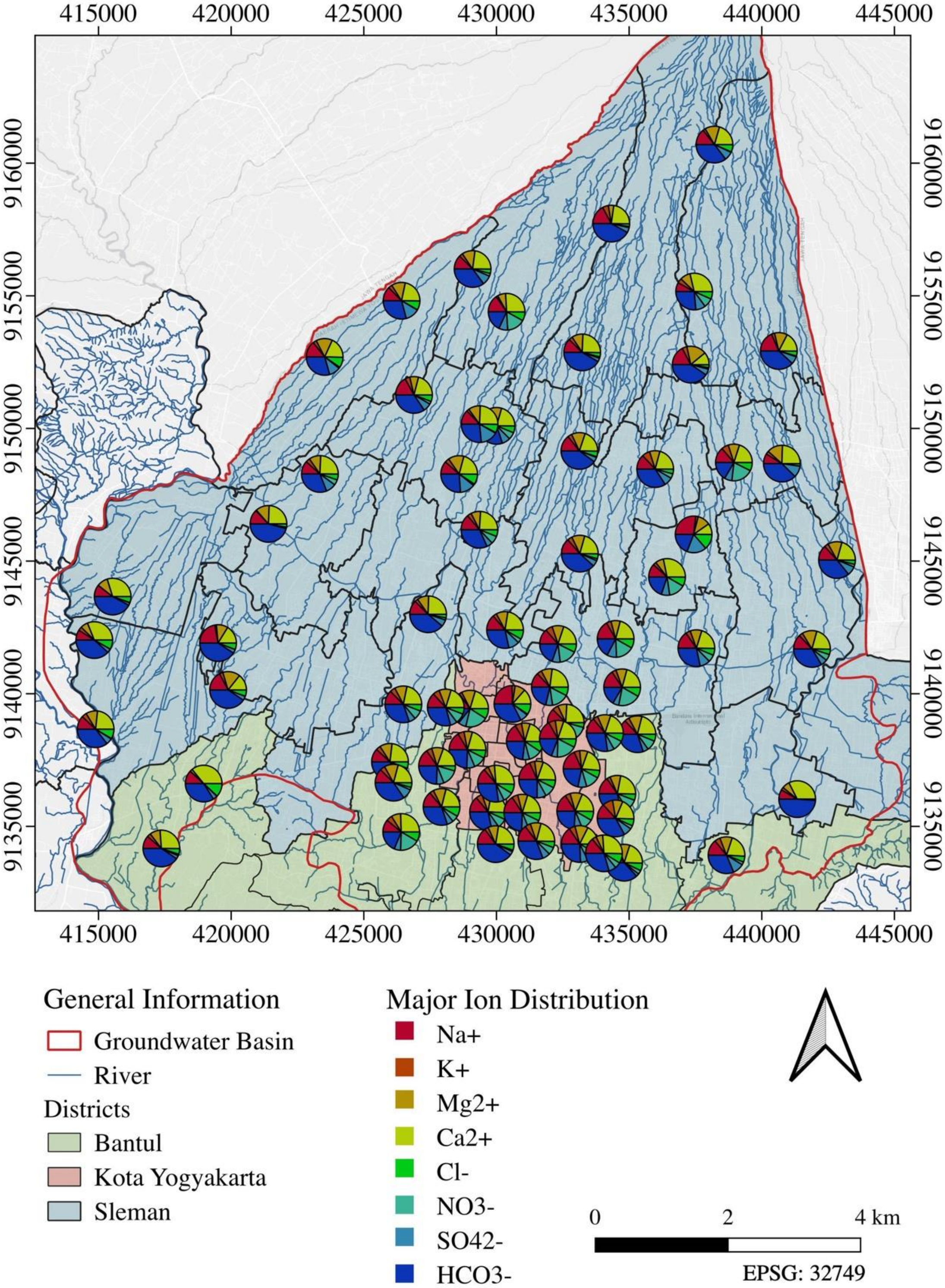

Figure 5. Overview of the main occurring cations and anions in mmol(eq)-% and their spatial distribution in the research area.

6. Discussion

Naturally, each groundwater system has its characteristic, unique water chemistry. It is dependent on several factors such as abundant minerals, soil-water interaction and anthropogenic influence [12]. To describe the water chemistry and distinguish different water types, different diagrams are introduced in the following.

6.1. Water type identification

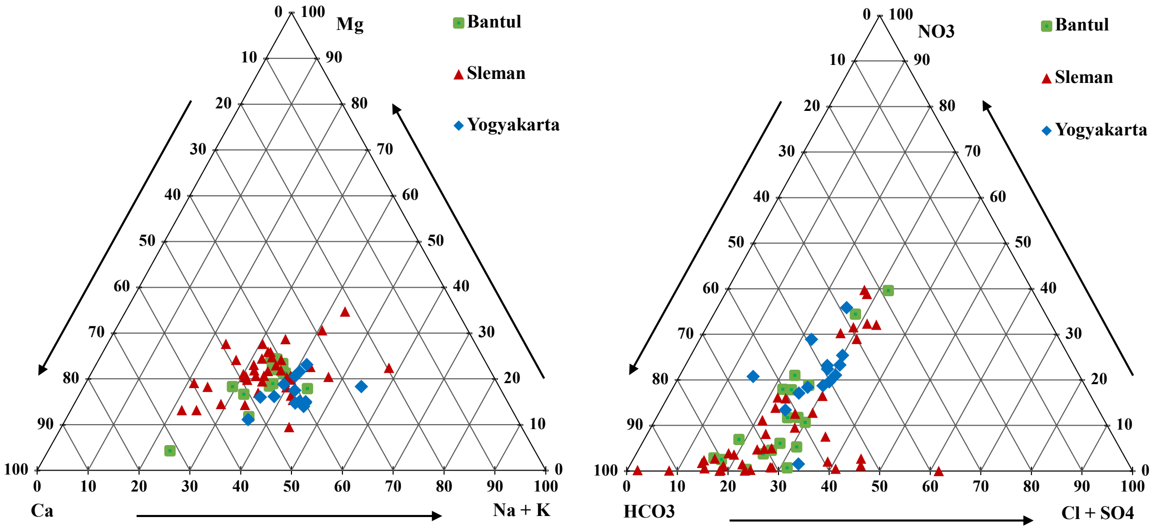

Figure 6. Ternary diagrams of observed cations (left) and anions (right) in mmol(eq)-%.

Figure 6 shows two ternary diagrams displaying each cation (left) and anion (right) distribution in mmol(eq)-%. The cation diagram visualises a similar share for Ca^{2+} and $Na^{+} + K^{+}$ while most water samples show low Mg^{2+} percentages. The right diagram makes clear, that HCO_3^- is the dominating anion for parts of the districts Sleman and Bantul. Most samples of Yogyakarta and some of Sleman and Bantul show higher NO_3^- percentages. It also shows that Cl- and SO4 do not increase with NO_3^-.

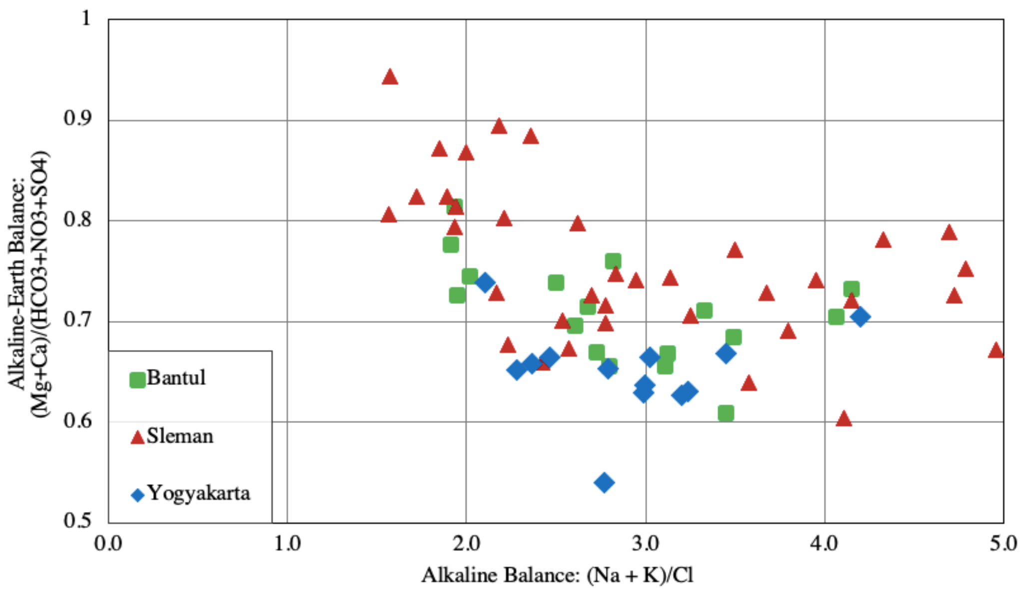

Figure 7. Comparison of the alkaline-earth balance and the alkaline balance. Compartments of all regions show alkalines balanced with bicarbonate.

As indicated before, the water samples show an excess of alkaline elements that are not balanced by chloride. Figure 7 displays the proportion of the alkaline and the earth alkaline balance. Few extreme values with very low chloride concentration lay outside the scale. A part of the water samples including mostly samples from district Sleman show an inverse proportionality. For these samples it can be assumed that the alkalines are balanced by bicarbonate. A majority of water samples can be categorized using Furtak and Langguth as alkaline-earth with higher alkaline mainly bicarbonate [13].

6.2. Identification of possible pollution

In areas of human settlement within a developing society, groundwater pollution is a common issue. There are two different types of sources for groundwater pollution: point sources and non-point sources. Point sources only affect a certain area and can be caused for e.g., by industry, leaking sewage systems or geological anomalies. Non-point sources are not limited to an area and are characterized by a diffusive discharge of pollutant. A typical non-point source is agriculture [14].

Samples from the city area, but also a few samples from north Sleman show over all high nitrate concentrations (Figure 4). To identify possible sources, the nitrate concentrations are compared with the alkaline-earth balance as shown in figure 8. It is obvious that mostly samples from Yogyakarta, but also Bantul and few from Sleman build a coherence of bicarbonate and nitrate. The samples collected in Yogyakarta show a significant correlation with a good coefficient of determination. This correlation may be explained by denitrification and ammonification processes where organic matter is oxidized. Most likely, nitrate is discharged into the saturated zone by sewage and septic tanks [15]. There is a cluster of very low nitrate concentrations in Sleman samples representing water which is rather uninfluenced by human activities.

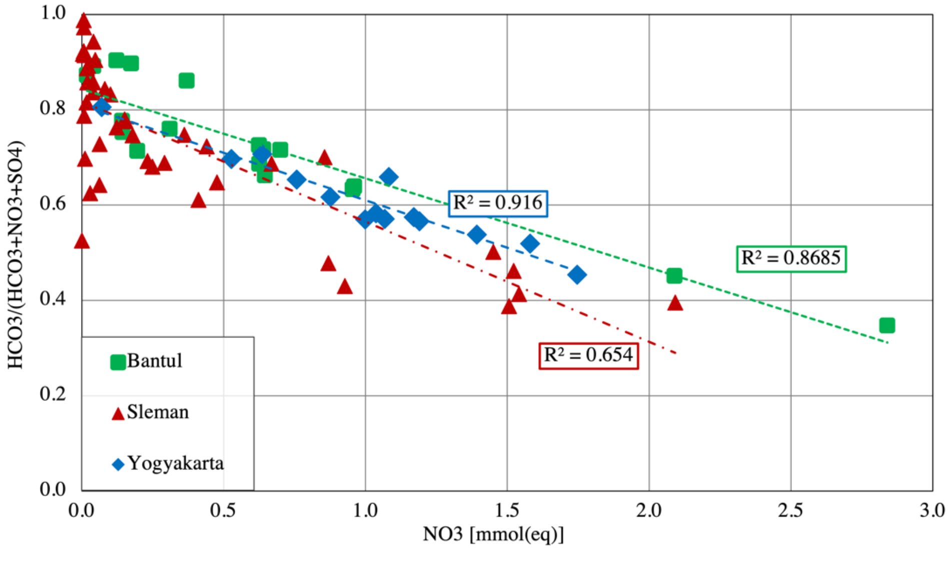

Figure 8. Coherence of bicarbonate and nitrate concentration in the city area and uninfluenced water in parts of Sleman.

In the southern area of Yogyakarta, high phosphate concentrations were observed ranging from 1 mg/L to 4.45 mg/L. High phosphate concentrations often yield from the discharge of washing agent into the groundwater. It is not only used in private households but also in dying processes. A common substance is sodium tripolyphosphate ($Na_5P_3O_{10}$) [15].

7. Conclusion

Sufficient water supply is strongly dependent on water chemistry conditions especially in developing countries. A large number of households in the special region of Yogyakarta still relay on shallow, untreated groundwater from private dug wells. The groundwater chemistry in the Yogyakarta groundwater basin is different throughout the region. Some areas in northern Sleman still show characteristics of uninfluenced groundwater in a good chemical condition. The southern area of Sleman, Kota Yogyakarta and Bantul are more influenced by human activities and very prone to pollution. Especially the city area shows pollution by nitrate and phosphate. These substances are most likely to advance into the groundwater by insufficient sewage water management. Some wells show high DOC concentrations. It was beyond this study to analyse for specific organic contaminants, but such DOC values should be further investigated. To increase groundwater quality for the citizens of Yogyakarta, it would need an intervention and modernisation of a sewage water strategy.

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