Heavy Metal (As and Hg) contamination of shallow groundwater in the coastal areas of Pati and Rembang, Central Java, Indonesia

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Abstract. The current study aims to assess the contamination level of heavy metal in the shallow aquifer of groundwater in Pati and Rembang coastal areas. The analysis result indicated that arsenic and mercury were detected in the groundwater in the range 0.004 µg L⁻¹ and 0.115-0.310 µg L⁻¹, respectively. Referred to the standard of the heavy metals contents in the consumption water by WHO and Indonesian Water Quality Standard for Ground Water (IWQS), groundwater of coastal areas in Pati and Rembang Regions were polluted by arsenic and mercury. The result has confirmed the existence of arsenic and mercury pollution of some shallow groundwater flow in the coastal areas of Pati and Rembang.

I. Introduction

Indonesia has 12,827 villages located in coastal areas, the villages take clean water from various sources, including bottled water (1,106 villages), rain-fed water (1,002 villages), springs (2,761 villages), wells (4,703 villages), rivers/ponds (374 villages), and Municipal Waterworks (1,330). These springs and wells are sourced from groundwater, so there are still 7,464 (58.1%) coastal villages in Indonesia that rely on groundwater as a source of drinking water. The first problem is how shallow groundwater conditions in the north coast of Java, is it still good or has it been contaminated by heavy metals or other pollutants due to agricultural or industrial activities in the upstream area? The study conducted by Research and Development Center Central Java Province in 2004 shows that in 12 regencies/cities on the north coast of Central Java already contains heavy metals (Hg, Cd, Co, Pb, Cr, Ni, Zn, and As) in the water, sediment and soft tissue shells, heavy metal content these have largely exceeded the threshold quality standard limits set by the Decree of Minister of Environment No. 51 of 2004 [1]. Heavy metals have contaminated Semarang as part of North Java coastal land and water. The anthropogenic heavy metals have found in the western part of Semarang land and coastal water [2]. Furthermore, some heavy metals have also found in sediments such as Pb, Cu, and Cr. The preceding research showed that the Semarang coastal area has been contaminated by heavy metals on the sediment and water. The heavy metals there is expected originate from outside as well as inside of Semarang coastal water. The coastal
area of Semarang has been bounded by some big rivers such as West Banjir Kanal, Babon, Semarang, Banger and East Banjir Kanal. Whereas the heavy metals which originate from inside coastal water are expected originate from corrosion of metal of buildings and ships [3].

Several studies have shown that several sources of clean water have been contaminated with metal especially arsenic and mercury. Arsenic and mercury are heavy metals that highly toxic [4]. The presence of groundwater in coastal areas is an essential source of clean water, so it is necessary to study the presence of arsenic and mercury in groundwater in coastal areas. Studies on arsenic and mercury contamination in groundwater in the coastal areas of Pati and Rembang are still very little or not widely known, so it is necessary to study the presence of heavy metals in groundwater in the Pati and Rembang areas.

2. Methodology

2.1. The groundwater sample collection

Samplings of shallow groundwater were conducted on Pati and Rembang coastal land area. The sampling points followed the shallow groundwater flow from south to north areas. Figure 1 shows the sampling points from 6 different shallow wells across those cities (Pati: PJA 1, PJA 6 and PJA 8; Rembang: PJA 3, PJA 4 and PJA 5). The samples were collected in 5 liters bottles that were labeled according to the locations, and sealed firmly.

The temperature, salinity and pH were measured at the time of samples collection using hand refractor meter salinometer, pH meter, and a centigrade thermometer (Horiba Co. Ltd., Japan).

![Figure 1. The sampling areas at the north part of Pati and Rembang coastal shallow groundwaters.](image)

2.2. Heavy metal analysis

All the water samples were brought to the laboratory for heavy metal analysis (Arsenic and Mercury). The methods used for the analysis of Arsenic and Mercury followed the Standard Method for the Examination of Water and Waste Water [8] using Inductively Coupled Plasma-Mass Spectrometry (ICP-MS). The data obtained were compared with the clean water quality standard released by WHO and the Indonesian Water Quality Standard for Ground Water (IWQS).

3. Results and Discussions
The Pati and Rembang coastal areas regencies administratively belong to Central Java Province. Those cities were selected because of their character for the main fisheries and agriculture coastal activities that suspected to decrease the quality of water resources. The results of this study show several physicochemical parameters in shallow groundwater aquifers in the Pati and Rembang Coastal areas (Tables 1).

Table 1. Physico-chemical properties of water samples of shallow groundwater in the Pati and Rembang coastal areas.

| Sampling Site No | Colour  | Odor     | Taste  | pH  | Salinity | Temp |
|-----------------|---------|----------|--------|-----|----------|------|
| PJA 1           | Brownish| Offensive| Tasteless| 7   | 0        | 29   |
| PJA 6           | Colourless| Odorless| Tasteless| 7   | 0        | 28   |
| PJA 8           | Colourless| Odorless| Tasteless| 7   | 0        | 28   |
| PJA 3           | Colourless| Offensive| Tasteless| 7   | 0        | 29   |
| PJA 4           | Brownish| Offensive| Salty | 7   | 5        | 29   |
| PJA 5           | Colourless| Offensive| Tasteless| 7   | 0        | 29   |

Study results show that there are small variations between several physicochemical parameters (pH, salinity and temperature). The odor, taste and color were detected in water samples from several locations that do not comply the standard for drinking water. The water from PJA 1, PJA4, and PJA 5 have brownish color, and/ strong/offensive odor, and/salty. The PJA 1 is relatively far from the coastline with the characteristic swamp sediments. While, the PJA 3, PJA 4 and PJA 5 located in coastal area as fisherman village.

The measured water temperature in situ varies slightly between 28-29 °C with an average of 28.667 °C. This is the most common of tropical areas water temperature. This water temperature variety is the possibility to be affected by the sunlight intensity as the temperature range from 28.5-29.5°C on a relatively hot day afternoon. Some workers reported that the water temperature of the tropical climate was little affected by seasonal variations of temperature [9] [10]. The range of Salinity was varied from 0 to 5.0‰ with a mean of 0.833±0.04‰. The highest desirable level for pH (7.0) is within the range of 6.5-8.0 values for drinking purposes [11].

Table 2. Range, frequency of occurrence and mean ± standard deviation of Heavy Metal (Arsenic and Mercury) residue (mg L⁻¹) from shallow groundwater Pati and Rembang coastal areas.

| Number/ sample code | Contaminant | Methods | Remarks |
|---------------------|-------------|---------|---------|
| 1/ PJA 1            | 0.175       | ICP     | PJA 1, PJA 6 and PJA 8 are taken from Pati |
| 2/ PJA 6            | 0.229       | ICP     | PJA 8 are taken from PJA 3, PJA 4 and PJA 5 are taken from Rembang |
| 3/ PJA 8            | 0.115 0.004 | ICP     | PJA 8 are taken from Pati |
| 4/ PJA 3            | 0.310       | ICP     | PJA 3, PJA 4 and PJA 5 are taken from Rembang |
| 5/ PJA 4            | 0.229       | ICP     | PJA 5 are taken from Rembang |
| 6/ PJA 5            | 0.255       | ICP     | PJA 5 are taken from Rembang |
| Range               | 0.115 – 0.310| ICP     | PJA 1, PJA 6 and PJA 8 are taken from Pati |
| Means ± SD          | 0.21883 ± 0.06712 | ICP     | PJA 3, PJA 4 and PJA 5 are taken from Rembang |
|                     | 0.00066 ± 0.00163 | ICP     | PJA 3, PJA 4 and PJA 5 are taken from Rembang |

*bd : below detected*
To analyze the presence of heavy metals in groundwater more clearly, the results of the analysis of the locations in Pati and Rembang are separated. The graph can illustrate the results of Arsenic and Mercury analysis for Pati and Rembang in Figure 2.

![Graph showing Arsenic and Mercury concentrations in Pati and Rembang](image)

Figure 2. Concentration Arsenic and Mercury in groundwater in Pati and Rembang.

Naturally, the arsenic can be found in soil, air, sediments, and plants. Arsenic dissolved in water in the form of organic and inorganic compounds [5]. Some studies in America and Europe show that the content of arsenic in water naturally in unpolluted conditions is below 0.01 ppm [12]. High levels of arsenic in water typically up to 8.5 ppm are found in locations where there is geothermal activity. Arsenic levels in the study sites were found to range from 0.115 – 0.310 ppm far above the value of 0.01 ppm while the study area was not a geothermal area, indicating that the shallow groundwater had been polluted [6]. Based on the location of the research area, it is an agricultural city and a small part of industrial, so it can be interpreted that the primary source of arsenic pollutants comes from agricultural and industrial activities. The results of the arsenic analysis indicate that the arsenic content in groundwater in Rembang is higher than in Pati. Land use patterns in both areas are similar to agricultural and fishery activities. Pati is more agricultural and aquaculture, while Rembang is more forested and industrial than Pati. It can be concluded that the content of arsenic in groundwater is due to agricultural and industrial activities.

The results of mercury analysis from 6 groundwater sample locations in Rembang and Pati show that only one location in PJA 8 Pati area containing mercury can be detected. Mercury is considered a dangerous metal because as an ion or in the form of certain compounds, it is easily absorbed into the body. In the body, mercury can inhibit the function of various enzymes and can even cause cell damage [7]. The presence of heavy metal Hg in the environment can occur through volcanic activity, rock weathering, and as a result of human activity. However, mercury pollution in sea waters is caused more by human factors than natural factors. The majority of mercury in the environment comes from anthropogenic activities, such as mining, burning fossil fuels, paper processing plants, smelter emissions, etc. In the environment, mercury contained in wastes in public waters is converted by the activity of microorganisms into components of methyl mercury (organic compounds) by microorganisms. The location of PJA 8 is in the Tayu Pati area, where the location around it is a residential and aquaculture area. The presence of mercury in groundwater in shallow wells in residential areas is likely to occur from human activities that carelessly dispose of mercury-containing waste so that it is eventually infiltrated into shallow groundwater flow.

4. Conclusions
Groundwater in the coastal areas of Pati and Rembang regions have contaminated arsenic at levels far above the quality standard, which likely come from the waste of agricultural and industrial activities.
Whereas, the groundwater at one location in Rembang regency indicated contaminated with mercury that predicted from the industrial waste.

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References
[1] Suyanto A, Kusmiyati S, Retnaningsih C. Jurnal Pangan dan Gizi Vol 01 No 02 Tahun 2010 Pp 33-38
[2] Suryono CA J Kelaut Trop 2016;19(1):37–42
[3] Suryono CA, Rochaddi B, Sabdono A, Susanti BT. 2007 Ind J Mar Sci 12 (4):227–32
[4] Kim M-J, Nriagu J, Haack S. Environ Pollut 2002 120(2): 379–90
[5] Gong Z, Lu X, Watt C, Wen B, He B, Mumford J, et al. Anal Chim Acta 2006;555(1):181–7
[6] Garcia-Sanchez A, Moyano A, Mayorga P. Environ Geol 2005;47(6):847–54
[7] Chabukdhara, M, Gupta, SK, Kotecha, Y & Nema, AK, 2017 Chemosphere, 179:167–178
[8] Federation WE 2005 Association APH Am Public Heal Assoc Washington, DC, USA
[9] Efe SI, Ogban FE, Horsfall MJ, Akporhonor EE. 2005 J Appl Sci Environ Manag 9 (1):191–5
[10] Ravindra, K, A Meenakshi, M Rani and A Kaushik. 2003 J Environ Monit 1 5: 419–426
[11] World Health Organization 2004 Guidelines for drinking-water quality Vol 1 World Health Organization;
[12] Welch AH, Westjohn DB, Helsel DR, Wanty RB. Ground Water 2000;38(4):589–604