Major Ions for Tracing Leachate Migration within Shallow Groundwater in the Vicinity of Municipal Landfill in Bantar Gebang – Bekasi

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Abstract: *Bantar Gebang landfill located in Bekasi regency is a biggest sanitary landfill in Indonesia which comes up some refusals from local people because of its bad impact on their environment. Major ion contents in leachate and fresh groundwater were investigated during the rainy and dry season to determine contamination by leachate released from Bantar Gebang and Sumur Batu landfill. Leachate contained high concentrations of all major ions that was mainly characterized as a* $NaKHCO_3$ *water type. On the other hand, most fresh groundwater samples were predominated by* $CaMgHCO_3$ *and CaMgCl water type. Concentrations of* K^+, Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, Cl^-, HCO_3^- *and* NO_3^- *in leachate were to be in a maximum factor of 2110; 7; 6; 143; 20; 112; 349 and 20, respectively than its contents in groundwater. Leachate from Bantar Gebang was detected have a higher concentration than those contained in Sumur Batu that was probably due to its mature leachate. An estimated mixture of leachate to fresh water in monitoring wells (5 m and 15 m depth) was in the range of 20 to 34%, related to* Na^+ *and* Cl^- *signatures, while the shallow groundwater located in residents in the vicinity of these landfills exhibited maximum leachate about 2%.*

Keywords: *major ions; shallow groundwater; leachate; Bantar Gebang landfill*

INTRODUCTION

Increasing in industries and population in a city will be accompanied by rapid increases in both the municipal and industrial solid waste [1-2]. The potential environmental impacts from landfills activities are pollution of groundwater and surface water as well as bad odor. The main cause of groundwater pollution is leachate which is defined as the aqueous effluent generated as a consequence of rainwater percolation through wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves [3-4].

Most leachates contain a large amount of organic matter, heavy metals, ammonia, chlorinated organic and inorganic salts dissolved from municipal and commercial solid waste. A combination of physical, chemical and microbiological process transfer pollutants from the waste to the percolating water and it has the possibility to contaminate groundwater [5]. A complex series of biological and chemical reactions occur because of decay and dissolution from buried refuse. In a young landfill, containing a large amount of biodegradable organic matter, a rapid anaerobic fermentation takes place called as acidogenic phase, resulting in a volatile fatty acid. In a mature landfill, the methanogenic phase occurs. This phase, microorganisms develop rapidly in the waste and convert volatile fatty acid to biogas (CO_2 and CH_4). There are many factors affecting the quality of such leachates such as age, precipitation, seasonal weather variation, waste type and composition [5-6].

The risk of groundwater contamination by leachate is much higher if the landfill was built without engineered liner and leachate collection system [7]. The largest landfill waste site in Indonesia is Bantar Gebang landfill which located in Bekasi. This landfill was constructed in 1986 by Jakarta administration and covers to 3 villages (Ciketing Udik, Sumur Batu, and Cikiwul) with a total area of 108 ha area. As much as 6500 tons of waste are offloaded to this landfill every day.

To minimize groundwater pollution, Bantar Gebang landfill has applied sanitary landfill system in which consists of lining system, leachate collection ponds, and leachate water treatment. Some monitoring wells both shallow and deep wells are also made in surrounding of Bantar Gebang landfill to observe the water quality. In the southern part of Bantar Gebang landfill, approximately 2 km away, a rather newer landfill of Sumur Batu is located which is utilized to dump rubbish produced by Bekasi people. This landfill was constructed in 2002 which covered 14.5 ha area and had applied sanitary landfill system too [8-9]. However, the worries of the leachate contamination to groundwater are still experienced by local people.

Local people living surrounding Bantar Gebang landfill frequently complained about the impact of their environment because of that landfill such as bad odor, the possibility of groundwater contamination and reducing local people health. In the case of groundwater, they strongly concern to the effect of leachate plume movement to shallow groundwater because they still utilize it for daily needs. This landfill is surrounded by dense residents (14760 people/km^2) [10], agriculture and industries like garment, plastic and cooking oil. There is a possibility that the waste of those industries is also disposed of directly, without wastewater treatment, to a drainage ditch or Ciketing River which can contribute to groundwater contamination. Hydrologically, natural water moves from water surface system to groundwater system; the water moves from groundwater system to surface water system. Thus, groundwater system can be contaminated by surface water flow, or surface water system can be contaminated by groundwater flow. One of most groundwater problems taking place landfill areas is leachate infiltration flow that could contain harmful contaminants from landfill to its groundwater system [11].

Therefore, the programs such as evaluation, assessment, and recommendation to save sustainability of clean groundwater in surrounding Bantar Gebang landfill are essential to be carried out. An understanding of leachate composition is important although the solid waste production decrease. Even after decommissioning of the landfill, the trash will continue to decompose and probably impact to groundwater contamination.

Some investigations of chemical contents in landfill leachate from Bantar Gebang have been reported. Groundwater quality in Bantar Gabang Sub District had been compared to the Storet System of Environmental Protection Agency (EPA). The study concluded that bad water quality was caused by its environmental condition and recent waste disposal site [12]. Monitoring results carried out by a laboratory in Ministry of Environment and Forestry showed that some local people's wells and river flow through disposal site of Bantar Gebang had been contaminated by *E. Coli*. In Bekasi region, groundwater flow moves from south to north through the landfill site, based on geo electrical measurement with self-potential method [13]. However, groundwater in southeastern part of Bantar Gebang landfill has been contaminated by leachate until hundreds meter from this landfill. The spread of leachate is seemly not influenced by gravitation effect, but it is estimated that process contamination is due to capillary, osmosis or electrokinetic mechanism [14].

From a hydrological point of view, safety analysis of landfill is greatly influenced by shallow groundwater dynamics that take place either locally or regionally. Some parameters that must be well-understood are groundwater origin, direction and rate of groundwater flow, and groundwater characteristics [11,15-16]. This study is focused on shallow groundwater characteristics using the content of major anion-cation and nitrate dissolved in water in the surrounding of Bantar Gebang landfill. Hydrochemistry method can be applied to explain groundwater evolution and water quality such that the uses of groundwater would be more suitable and water treatment method can be determined.

The aquifer in Bekasi groundwater basin is separated in two aquifer systems; those are unconfined and confined aquifer. The unconfined aquifer has the thickness less than 30 m and depth less than 40 m below land surface whereas the thickness of confined aquifer varies to 80 m and the bottom depth 20–160 m below land surface. In this study, the groundwater samples were taken from unconfined aquifer system with the depth around 0–40 m that the term is called as shallow groundwater. The unconfined aquifer and semi unconfined aquifer is underlain soil layer which is composed of sandstone and conglomerates while the thickness of aquifer varies and forms as lenses. Barrier layer which has a characteristic as aquitard and aquiclude consist of clay stone and silt stone. Aquifer system of Bekasi groundwater basin has a declining slope from south to north direction. The geology of the studied area is composed by deposition of sedimentary rocks and tertiary to recent volcanic rocks [17].

The aim of this study is to determine chemical effects of generation and migration of leachate on groundwater by chemical analysis of water from shallow wells and monitoring wells from the landfill.

■ EXPERIMENTAL SECTION

Materials

Materials used in this study were Cl^-, SO_4^{2-}, NO_3^+, Na^+, K^+, Ca^{2+}, Mg^{2+} standard solution, Na_2CO_3, $NaHCO_3$, HCl, HNO_3, H_2SO_4, dipicolinic acid, acetone and micropore filter paper.

Instrumentation

Apparatus used in this study were Ion Chromatography (IC) for anions (833 Basic IC plus Metrohm) which is equipped by Metrosep A Supp 5 (150/4) column and Compact Autosampler Metrohm 863, Ion Chromatography for cations which is equipped by Metrosep C4 (250/4.0) column and Compact Autosampler Metrohm 863, pH meter 691 Metrohm and Global Positioning System.

Sampling Location

Bantar Gebang shallow groundwater samples were collected from resident's wells with the depth of 6 to 20 m. The samples were located in the radius approximately 1–2 km away from Bantar Gebang landfill. Leachates samples were collected from one plant, called as IPAS-3, of five plants in the area of Bantar Gebang landfill and from Sumur Batu landfill. Leachate was sampled from input and output ponds as well as from run off. Sampling periods were scheduled in the dry season and rainy season. A suite of 18 groundwater, 5 leachates, and 2 river samples were collected in this study. Sampling sites are mapped in Fig. 1 with a dot, triangle and star symbols as groundwater, leachate water, and river water samples, respectively.

Each 500 mL liter of water samples were stored in plastic bottles for anion and cation analysis. To analysis cations, it is important to add a few drops of HNO_3 in water samples to prevent a precipitation process of some cations. All water samples were then analyzed at Laboratory of Hydrology, Center for Application of Isotopes and Radiation, National Nuclear Energy Agency (BATAN) which routinely participated in proficiency test [18-19].

Procedure

Analysis of dissolved anions in water

Analysis of major dissolved anions in water was carried out by Ion Chromatography with Metrosep A Supp 5 (150/4) column. This kind of column can separate Cl^-, NO_3^- and SO_4^{2-} elements in different retention time. Those anions were separated in approximately 6, 10 and 15 min for Cl^-, NO_3^- and SO_4^{2-}, respectively. As much as 20 µL filtered samples were injected to IC and elucidate with 3.2 mmol Na_2CO_3, 1 mmol $NaHCO_3$, and 20 mL acetone. Each area of the element was plotted to its area of calibration standard curve such that the element concentration could be determined. Analysis of bicarbonate element was conducted by HCl titration at endpoint pH of 4.5.

Analysis of dissolved cations in water

Analysis of major dissolved cations in water such as Na^+, K^+, Ca^{2+}, and Mg^{2+} was carried out by Ion Chromatography with Metrosep C4 (250/4.0) column. The retention time of each element was approximately 6, 8, 16 and 20 min for Na^+, K^+, Ca^{2+}, and Mg^{2+}, respectively. The eluent used for separation of these elements was 1.7 mmol/L nitric acid, 0.7 mmol/L dipicolinic acid. Each area of the element was plotted to its area of calibration standard curve such that the element concentration in water samples could be determined.

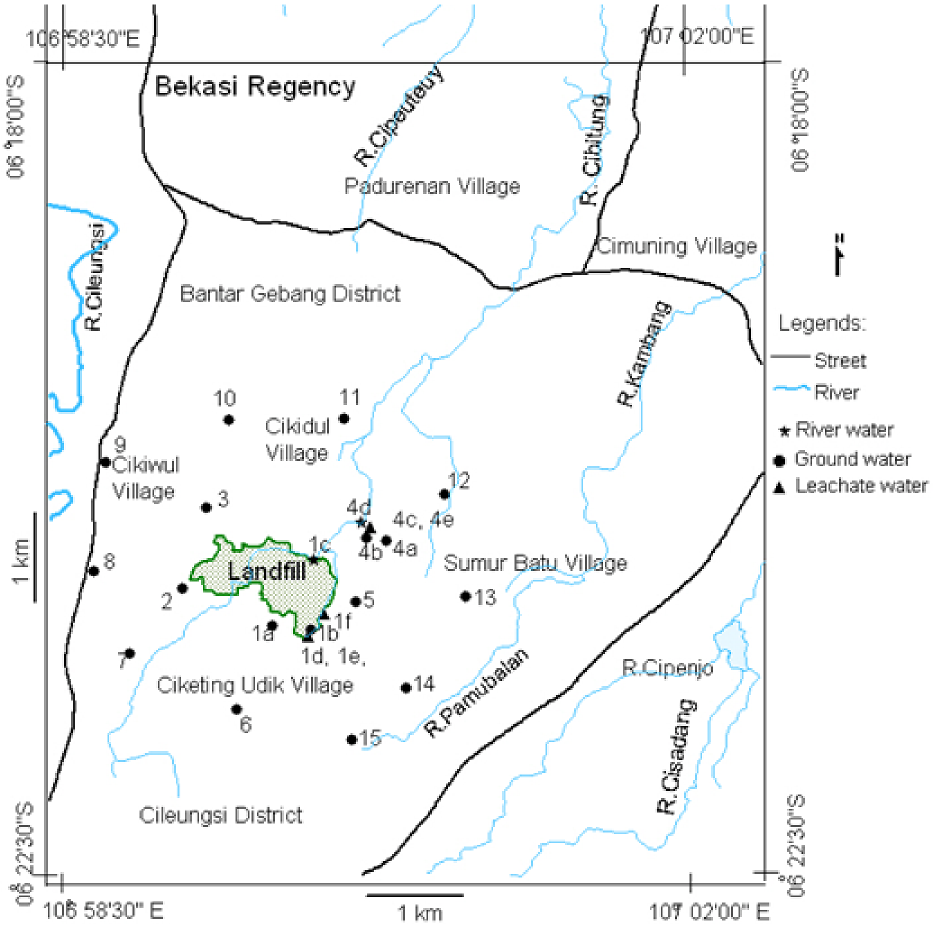

Fig 1. Sampling sites for shallow groundwater, leachate, and river in the surrounding of Bantar Gebang landfill

■ RESULTS AND DISCUSSION

The chemical data are reported in Table 1, 2 and the piper diagram in Fig. 2, 3. Piper diagram provides an overview of the chemical composition of the samples and indicates that there are four distinct groups of samples. These plots include two triangles, one for plotting cations and the other for plotting anions. The cation and anion concentrations are reflected in the diamond-shaped field such that those compositions form a single point, from which is defined the type of waters in the study area.

Leachate collected from Bantar Gebang and Sumur Batu landfill has the different water type to shallow groundwater. It clearly explains that the leachate samples are classified in $NaKHCO_3$ water type; which are quite different to groundwater and river samples. The group groundwater and river samples are spread in $MgCaHCO_3$, CaMgCl and NaCl water types. In sampling period of the

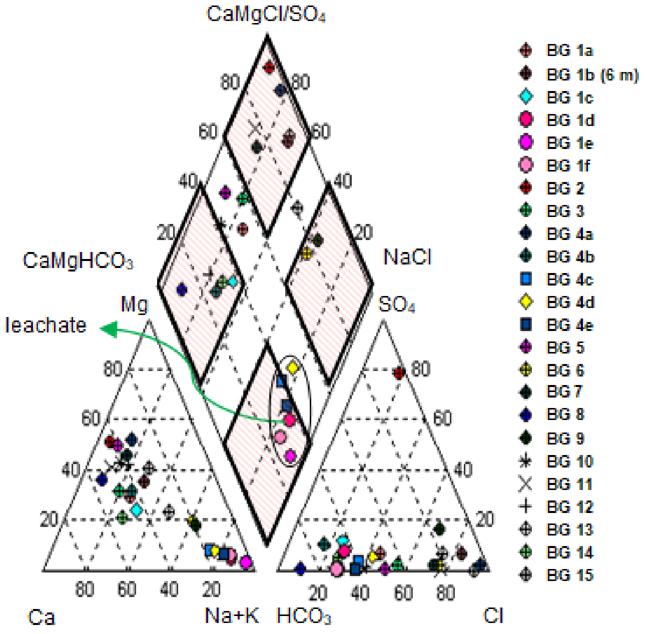

Fig 2. Piper diagram for water samples collected in the rainy season

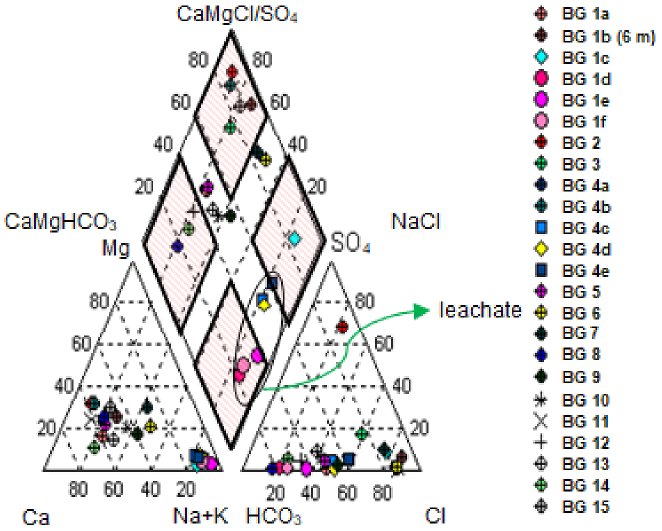

Fig 3. Piper diagram for water samples collected in the dry season

dry season. Leachate samples from Sumur Batu landfill seemly move to NaCl water type compared to those are collected in a rainy season, while leachate samples collected in Bantar Gebang landfill are still in $NaKHCO_3$ water type either during the dry season or rainy season. It seems that evaporation or dilution of more mature or more concentrated leachate from older landfill of Bantar Gebang does not significantly affect the water evolution compared to those of rather newer landfill of Sumur Batu.

Fig. 2 and 3 shows that groundwater samples were mostly predominated by Ca-Mg-Cl during the rainy and dry season. Sulfate concentration was quite lower than chloride in most groundwater samples. The rest was under Ca-Mg-HCO_3 and NaCl water type or mixed with Ca-Mg-Cl. In the rainy season, groundwater samples of BG-6 and BG-9 had NaCl water type. Rainfall is the major source of chloride; rainfall and oxidation of iron sulfide are the main sources of sulfate in native groundwater [20]. From calculation using the Aquachem software, the evolution of the water from Ca-Mg-Cl in dry season moving to NaCl in the rainy season could be caused by dissolution of geogenic Na-Cl from halite mineral, as much as 40.5 mg/L for BG-9 and 45.3 mg/L for BG-6.

In contrast to groundwater, river sample of BG-1C had Ca-Mg-HCO_3 water type during the rainy season, but it has undergone evolution to NaCl water type in the dry season. However, the chemical composition of BG-4d seemly was not influenced by the changes of season. Its water type remains in $NaKHCO_3$ that has the same type of leachate water samples. As seen in Fig. 1, BG-1c was located in the upper stream from leachate drainage whereas BG-4d was in downstream about 5 m distance from Sumur Batu landfill ponds.

Mostly, there is no significant change in the hydrochemical facies of shallow groundwater samples defined during the sampling period of the rainy and dry season. It could indicate that most of the major ions are natural in origin except some monitoring wells at BG-1b (6 m and 15 m depth) and BG-4a,b (5 m and 15 m depth). The reason is groundwater passing through rocks dissolves only small quantities of mineral matters because of the relative insolubility of the rock composition [21]. Some minerals dissolved in Bantar Gebang shallow groundwater are probably composed by halite (NaCl), sylvite (KCl), carbonate ($CaCO_3$), dolomite ($CaMg(CO_3)_2$) and anhydrite ($CaSO_4$) which their contribution to the composition of groundwater can be calculated by Aquachem program. For example, in the rainy season, BG-11 had Ca-Mg-Cl water with dolomite dissolution of 154.2 mg/L then followed by halite of 27.4 mg/L. The site of BG-2 with Mg-Ca-SO_4 water type has dissolved anhydrite mineral as much as 530 mg/L and halite 47.5 mg/L. The site of BG-8 with Ca-Mg-HCO_3 water type has dissolved dolomite as much as 160.3 mg/L and carbonate 41.5 mg/L.

As mentioned above, leachate samples from Bantar Gebang and Sumur Batu landfill were primarily a $NaKHCO_3$ water type which was extremely different from water type of groundwater samples. The major chemical contents of leachate samples were much higher than those of groundwater samples either during the rainy or dry season. The chemical composition of leachate varies from time to time and site to site due to the differences in waste composition, rainfall, moisture content, climatic changes, site hydrology, waste compaction, the interaction of leachate with the environment [6,22].

Total dissolved solids (TDS) values were calculated by Aquachem Program of leachate in input pond of Bantar Gebang landfill and Sumur Batu landfill. The

Table 1. Anion and cation contents from shallow groundwater, leachate, and river collected in the rainy season in surroundings of Bantar Gebang Landfill

Sample ID	Concentration (ppm)							
(sample type-depth)	K^+	Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-	HCO_3^-	NO_3^-
BG-1a	2.12	29.00	11.82	18.57	8.74	41.82	76.77	15.77
BG-1b (monitoring-6 m)	58.54	250.34	156.97	214.94	86.41	827.73	164.41	363.62
BG-1b (monitoring-15 m)	na	na	na	na	na	na	na	na
BG-1c (river)	7.36	26.30	8.63	17.26	12.15	19.43	84.20	2.70
BG-1d (leachate-outlet)	674.82	96.53	33.58	664.29	440.22	1164.40	4612.00	564.28
BG-1e (leachate-inlet)	2000.40	84.51	56.79	1779.23	133.68	3611.06	15602.58	-
BG-1f (leachate-run off)	995.49	133.31	57.83	916.61	34.90	1587.56	7058.31	397.42
BG-2	0.83	114.46	82.62	18.66	374.36	63.30	22.29	98.00
BG-3	0.57	18.70	7.48	8.62	1.58	26.49	34.67	39.22
BG-4a (monitoring-5 m)	4.85	82.00	79.62	43.05	8.26	290.52	17.34	2.26
BG-4b (monitoring-15 m)	0.31	5.26	2.35	3.48	3.63	4.28	329.39	8.29
BG-4c (leachate-outlet)	200.82	65.42	17.45	195.19	32.32	246.02	695.92	-
BG-4d (river)	199.78	52.33	16.72	188.89	47.89	278.68	586.95	42.45
BG-4e (leachate-inlet)	387.11	88.05	29.50	467.98	13.96	575.10	1721.24	145.71
BG-5	1.83	40.81	30.82	11.11	0.97	62.19	104.02	0.19
BG-6	0.52	5.93	3.50	20.70	0.94	27.90	14.86	30.67
BG-7	0.49	10.58	7.74	5.02	1.00	29.26	17.34	79.30
BG-8	1.40	51.85	21.16	9.79	0.87	12.51	175.84	6.81
BG-9	0.84	5.53	3.09	20.35	8.34	25.34	9.91	61.33
BG-10	0.46	15.60	9.61	5.95	0.71	18.59	44.68	62.38
BG-11	0.46	38.81	20.36	10.77	1.07	79.69	39.63	24.65
BG-12	0.32	12.87	8.47	7.11	0.86	10.56	52.01	13.75
BG-13	0.07	7.95	3.88	14.68	3.61	29.05	12.38	16.51
BG-14	0.38	13.48	3.31	7.67	3.45	12.73	56.96	22.71
BG-15	0.71	17.60	14.44	19.41	0.21	71.29	9.91	26.16

measured TDS values in input pond of Bantar Gebang landfill were higher with the maximum level of 7848.8 mg/L than Sumur Batu landfill with the maximum level of 2018.3 mg/L, and each leachate represented the mature and young age part of landfill respectively. Bantar Gebang landfill was actively operated over a period of thirty years whereas Sumur Batu landfill started its operation for fourteen years. Besides that, the capacity for dumping solid waste in Bantar Gebang landfill is much higher that covers 108 ha area compared to Sumur Batu landfill that covers an area of 14.5 ha [8-9]. It means that the age of landfill, kind of waste and rainfall are the most important factor which affects the composition of leachate [6,21]. Leachate quality correlates well with the waste age that is largely due to microbial degradation of both organic and inorganic constituents in the waste experiencing different exposure of acetogenic and methanogenesis phases [24].

As seen from Table 1 and 2, bicarbonate concentration for leachate taken from Bantar Gebang landfill was highest with an average of 10836 mg/L for two sampling periods while chloride, nitrate and sulfate concentration was 2465, 477 and 151 mg/L, respectively. The lower anion concentrations are found in younger Sumur Batu leachate which had an average concentration for bicarbonate, chloride, nitrates, and sulfate about 895, 428, 114 and 39 mg/L, respectively. The two municipal landfills are mainly utilized to dispose of organic solid waste produced from domestic households and market activities, but non-organic materials such as plastics and metals are also disposed to the landfill. The composition of disposed materials in Bantar Gebang landfill is 65% of organic materials and 35% of non-organic materials from an average of 6000 ton/day of total disposal solid [8].

As the organic content of the waste is decomposed, a significant amount of bicarbonate is formed in leachate as a product of the bacterial respiration. Under anaerobic condition, as taken place in leachates, CH_2O (represent organic compound) is converted to acetate, H_2, and CO_2 in methanogenic process. Through acetic fermentation, acetate produces CO_2 and CH_4. In all these reactions, inorganic carbon which is represented by CO_2 will naturally hydrate and dissociate to form bicarbonate [5,25]. The other source of bicarbonate in leachate may be the cap system used in landfill which consists of primarily calcium carbonate, consolidated as limestone, diluted by rainwater [25]. The high chloride and sodium concentration in leachate samples reflect the significant presence of soluble salt in municipal solid waste. The major sources of chlorine are papers and plastics carried out a sorption and complexation process in methanogenesis and acid phase [5,25].

In Bantar Gebang landfill, chloride in leachate could be attributed by a large amount of sewage, septic effluent, agricultural chemicals and animal waste deposited in the site. Source of sulfate in leachate is mainly from the anaerobic oxidation of sulfide, decomposition of organic sulfur, soluble waste, synthetic detergents and dissolved sediments. Many organic compounds contain sulfur as sulfate, sulfonate or sulfide. During anaerobic condition such as wastes, complete utilization or dissimilation results in the release of organically-bound sulfur as sulfate ion [26].

Table 2. Anion and cation contents from shallow groundwater, leachate, and river collected in the dry season in surroundings of Bantar Gebang Landfill

Sample ID	Concentration (ppm)							
	K^+	Ca^{2+}	Mg^{2+}	Na^+	SO_4^{2-}	Cl^-	HCO_3^-	NO_3^-
BG-1a	1.73	34.94	5.92	15.49	0.25	37.15	70.62	4.11
BG-1b-15 m	8.99	328.65	110.12	224.76	94.54	972.33	131.49	369.69
BG-1c	139.00	38.60	3.62	195.00	68.44	453.9	153.41	277.91
BG-1d	1353.44	178.95	70.25	1317.92	126.81	2085.21	13393	635.49
BG-1e	832.00	109.00	35.60	1770.00	41.34	3671.63	10958.04	-
BG-1f	885.00	204.00	56.40	1551.00	127.44	2672.79	13393.16	312.5
BG-2	1.05	70.64	23.86	13.49	172.25	42.67	29.22	69.63
BG-3	0.49	26.62	5.30	9.17	11	27.8	19.48	45.92
BG-4b	4.06	124.28	43.33	28.54	4.95	282.22	75.49	4.42
BG-4c	228.11	50.87	17.09	261.60	37.51	288.29	484.59	8.51
BG-4d	647.19	77.97	34.76	414.00	11.84	1008.71	2922.14	12.01
BG-4e	462.44	86.52	30.99	488.54	73.05	604.09	676.96	112.27
BG-5	1.94	48.13	8.94	17.91	5.18	42.88	82.79	18.55
BG-6	0.38	9.94	3.45	16.93	0.84	29.72	7.31	34.49
BG-7	0.60	20.05	8.12	10.78	3.84	21.33	7.31	67.4
BG-8	2.04	53.55	9.44	13.56	0.88	15.31	126.52	10.59
BG-9	1.31	12.55	2.25	10.20	0.97	14.99	21.92	33.37
BG-10	1.64	6.71	1.89	5.48	1.55	8.07	17.06	14.18
BG-11	0.76	60.04	14.30	15.88	1.43	125.04	29.22	33.94
BG-12	0.61	15.37	3.97	6.77	1.96	11.08	38.96	12.02
BG-13	1.03	22.79	3.61	14.73	6.77	21.03	51.14	6.35
BG-14	0.96	25.38	2.41	9.52	3.88	12.94	68.16	0.03
BG-15	0.97	20.58	7.82	10.42	0.08	46.19	12.18	17.88

The lower sulfate concentration than chloride concentration in leachate is due to the microbial reduction of sulfate to sulfide and as an indication of leachate being in methanogenesis phase [15]. In a natural system, nitrates represent the most oxidized form of nitrogen. The high concentration of nitrates in leachate samples could be originated from domestic or agricultural waste. In addition, the higher concentration of nitrates in leachate is primarily a result of oxidation of ammonium to nitrite. Subsequently, nitrite is oxidized to nitrates by nitrification process which can be quickly assimilated by plants or otherwise reduced again to nitrite and ammonium by denitrification process. The concentration of nitrates in leachate from Bantar Gebang landfill is much lower than that measured in Ibb city landfill within the range of 1000 to 1500 mg/L [23].

Cation concentrations of Na^+, K^+, Ca^{2+}, Mg^{2+} in leachate were significantly higher than those detected in fresh groundwater, similar evidence to anion concentrations, during rainy and dry season sampling. Natrium concentration was the highest among those cations and followed by K^+, $Ca^{+,}$ and Mg^{2+}. The average concentration of Na^+, K^+, Ca^{2+} and Mg^{2+} were respectively as follow 1333, 1123, 134 and 52 mg/L. In the other hand, the concentration of those cations for Sumur Batu landfill was much lower with the average of 353 mg/L for Na^+, 319 mg/L for K^+, 73 mg/L for Ca^{2+} and 24 mg/L for Mg^{2+}. The calcium and magnesium concentration in leachate are lower in methanogenic phase due to higher pH and lower dissolved organic matter content which may form complexes with the cations. The higher sodium and potassium in leachate are from the effects of sorption, complexation and precipitation processes either in acid or methanogenic phase [5]. The possible origin of those cations in leachate is chemical sources in refuse and desorption from clays. If the cations are coming from inorganic compounds in the refuse, anions of chloride and sulfate would perhaps be higher. Desorption from clay may be an important source of those cations because the huge ammonium generated in the leachate could be exchanged with the cations contained in clay which is used for covering the trash [5].

The concentration of Ca^{2+} in leachate from both landfill showed much higher than that of Mg^{2+}. It means that Bantar Gebang and Sumur Batu landfill is a typical Ca-rich landfill. The results of chemical compositions in some leachate samples from many countries show Mg^{2+} concentration is mostly less than 800 mg/L while Ca^{2+} concentration can reach as high as 2500 mg/L [27]. The wide variation of Ca^{2+} and Mg^{2+} may result from the difference in sources of disposed of solid wastes. Mineral calcite and dolomite are found to be oversaturated in most leachate samples [27]. A case study of landfill leachate from India indicates that concentration of Mg^{2+} is much higher than Ca^{2+} [28]. Another co-disposal municipal landfill in Minnesota appeared to have concentrated Mg^{2+} in the range of 1700–4600 mg/L and Ca^{2+} in the range of 500–800 mg/L. This is a typical Mg-rich landfill that rarely has a high concentration of Mg^{2+} in leachate [27].

As landfill applying a sanitary system, Bantar Gebang and Sumur Batu landfill are equipped by monitoring wells to observe leachate movement to the groundwater system. There are 2 wells for each landfill, dug well with the approximate depth of 6 m and bored well over 15 m depth. Both monitoring wells for IPAS-3 in Bantar Gebang Landfill has a much higher concentration of all major anions and cations, reaching up to a hundred times compared to those detected in shallow groundwater surrounding this landfill. But, there is rather different phenomenon occurring to monitoring wells in Sumur Batu landfill. Its chemical concentrations in both monitoring wells do not significantly increase, about 2–4 times higher than shallow groundwater chemical contents. The more mature leachate which produces more concentrated chemical contents in Bantar Gebang is the main cause of the extent of the leachate-groundwater mixture. Relating to the increase of concentration in these wells for most signature anion and cation, it is inferred that diffusion of the leachate plume to this aquifer points has occurred. The migration of leachate from Bantar Gebang landfill within to the aquifer appears to be obvious.

Compared to cation contents in monitoring wells,

K^+ was relatively lower although its sources in leachate were highly concentrated as seen in Table 1 and 2. In contrast to K^+, Ca^{2+} and Mg^{2+} showed high concentrations, typically for leachate signature. Although those cations have a high affinity for ion exchange, K^+ will be most the retarded of the cations in leachate plume whereas Ca^{2+} and Mg^{2+} typically are the dominating base saturation ions. Thus, they will move with the leachate front. Cations of Ca^{2+} and Mg^{2+} are easily affected by pH and concentration of another solute such as dissolved organic. They are also subject to sorption, complexation, and precipitation which may lessen their utility as tracers [15]. By understanding the characteristics of those cations, it is more useful to apply Na^+ and Cl^- to trace leachate movement within its surrounding groundwater. Despite more conservative, Na^+ and Cl^- is less affected by each process above.

In this study, the concentration of Na^+ and Cl^- was used to estimate the percentage of leachate to groundwater and river calculated from two sources, i.e., leachate and global rainwater. General mixing formula between two end member sources was calculated by Aquachem program. The contribution of leachate to monitoring wells and some shallow groundwater points suspected under influencing leachate migration is performed in Fig. 4 and 5 for Bantar Gebang and Sumur Batu landfill, respectively. The points in these figures are an average of Na^+ and Cl^- concentration during the dry and rainy season. End source of leachates is chosen in which has a maximum concentration of Na^+, characterized to leachate samples from inlet ponds.

Monitoring wells with a depth of 5 and 15 m, in Sumur Batu landfill might have been mixed by leachate portion ranging between 32–34% whereas monitoring wells of 6 and 15 m depth in Bantar Gebang landfill seem to be mixed with leachate at a rather lower portion of 20–24%. The point of downstream of Cibitung River (4d site) which is located about 5 m from Sumur Batu landfill has been significantly influenced by leachate as much as 86%. It indicates that the leachate could be disposed of directly to the river. Three points of resident's well water samples suspected to be contaminated by leachate show a little evidence of 2% percent mixing. Seemly, the portion of leachate to those wells calculated by optimizing Na^+ and Cl^- contents performs lower result compared to those calculated by deuterium (^2H) isotope, obtained approximately 13–18%. But, the comparable results are shown by both parameters optimized for monitoring wells, ranging from 18–32% from deuterium calculation [29].

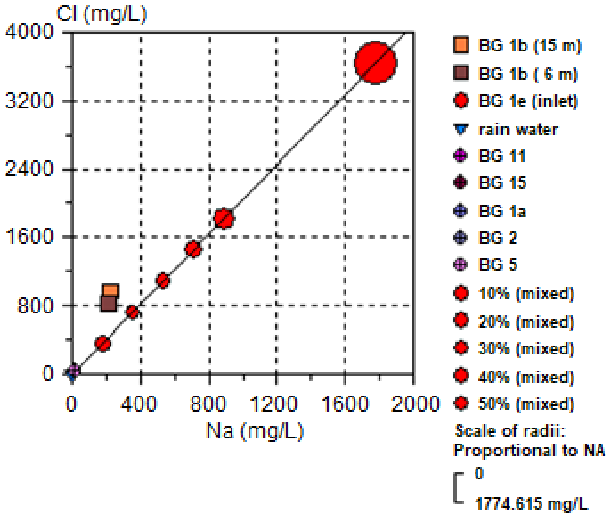

Fig 4. Estimation of leachate contribution to monitoring wells and groundwater in Bantar Gebang landfill related to its leachate mixing line

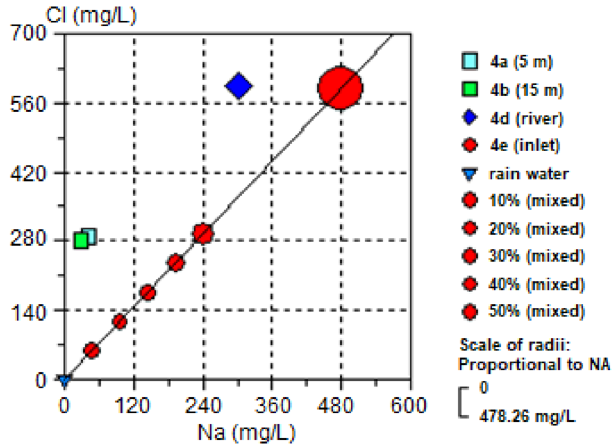

Fig 5. Estimation of leachate contribution to monitoring wells in Sumur Batu landfill related to its leachate mixing line

CONCLUSION

Major cations (K^+, Na^+, Ca^{2+}, and Mg^{2+}) and anion (Cl^-, SO_4^{2-}, HCO_3^- and NO_3^-) concentrations were detected in leachate have a $NaKHCO_3$ water type which is different to groundwater type mostly indicating $CaMgHCO_3$ and CaMgCl either at a rainy or dry season. Concentrations of K^+, Ca^{2+}, Mg^{2+}, Na^+, SO_4^{2-}, Cl^-, HCO_3^- and NO_3^- in leachate were to be in a maximum factor of 2110; 7; 6; 143; 20; 112; 349 and 20, respectively, than their contents in groundwater. The higher concentration of cations and anions in Bantar Gebang leachate rather than those observed in Sumur Batu leachate was perhaps due to its more mature leachate and higher waste capacity such that microbial degradation in both organic and inorganic constituents becomes more extensive. Monitoring wells in both landfills show increasing chemical concentrations compared to those in most groundwater samples. Tracing leachate movement within monitoring wells using more conservative ion of Na^+ and Cl^- indicates a mixture of 20–34% leachate portion. While, the signal from Na^+ and Cl^- observed in resident's wells is approximately 2% leachate portion. From the result of this study, it is suggested that the management of Bantar Gebang landfill should strictly apply sanitary landfill instead of open dumping, as planned earlier by the local government. In addition, due to increases in municipal waste and limitation of the area, it is also suggested to reduce the waste volume by incinerator and use the heat to produce electricity.

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