Monitoring of leachate quality stored in gas ventilation pipes for evaluating the degree of landfill stabilization

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Abstract

Monitoring of leachate quality is the essential measure in aftercare for evaluating landfill stabilization. Generally, the most common way of leachate monitoring is executed at inlet of leachate treatment facility. However, it does not necessarily reflect actual state of the site. Thus, not only the methodology focusing on the discharge for the determination of facility termination but also the methodology that is capable to seize the degree of waste stabilization in landfill must be necessary. In this study, monitoring of leachate quality stored in 68 gas ventilation pipes was conducted and degree of waste stabilization at each location in the landfill was estimated by statistical approach using the results obtained by monitoring. Leachate characteristics varied significantly by each pipe but seemed to reflect the waste condition of nearby location. Correlation among the analyzed items was quite high. Namely, the difference of leachate quality seemed to be categorized by only the level of concentration but not specific characteristics. To confirm this, Euclidean distances of dissimilarity were calculated by multidimensional scaling by using six items of leachate quality and temperature. Two factors (thickness of leachate and concentration of TOC and EC) that distinguish leachate characteristics appeared. To indicate the degree of stabilization by location, spatial distribution of TOC, TN, IC, and Cl were estimated by using ordinary Kriging methodology. As the result, it was estimated that concentration of leachate existing within landfill, especially TN, was higher than completion criteria of leachate, in most part of calculated area.

Keywords: Post-closure care, Monitoring, Leachate quality, Stabilization, Kriging

1 Introduction

In "the Standard for Terminating Post-closure Care of Landfill in Japan" established in 1998 (Japan Ministry of Environment, 1998), quality of leachate obtained by leachate collection system, which can collect representative leachate stored in landfill, is designated as an important index for judging landfill completion. Namely, it is prerequisite for the leachate to satisfy discharge criteria. However, it is not clearly shown which leachate is representative or where the leachate should be obtained. Generally, raw leachate flowing into leachate treatment facility is monitored on a regular basis during active operation phase of landfill, and such monitoring is often carried on into post-closure care phase. Therefore, in the occasion of assessing the termination of post-closure care, the leachate monitored at leachate treatment facility is used for the evaluation in many cases. This methodology for monitoring of leachate seems to be reasonable if quality of the leachate flowing into leachate treatment facility obviously reflects the degree of stabilization of waste in landfill. However, since heterogeneity and inhomogeneity are typical in the ordinary landfill, and occasionally leachate quality may be affected by some other factors such as ground water intrusion, etc., there must be a case in which the leachate obtained at the outlet of main leachate collection pipe or at inlet of leachate treatment facility doesn't reflect actual condition of waste inside of the landfill. The definition of leachate that should be used for judgment of aftercare termination may vary by the concepts regarding landfill stabilization. If the purpose of the standard is the determination for halting the operation of leachate treatment facility only, suitable object for evaluation must be the leachate flowing into treatment facility. But if the purpose is the assessment for essential stabilization of waste, evaluation using only the leachate obtained at the treatment facility seems to be not sufficient. When we consider the latter purpose more significant, we find there is little information regarding which leachate should be monitored or how we monitor them in order to seize the degree of waste stabilization more accurately. Most of previous studies (e.g.: Ehring 1983, Tatsi 2002, El-Fadel 2002, Kulikowska 2008) analyzed leachate collected at a certain point such as leachate pond, outlet of leachate collection system, etc. and discussed relationship between leachate quality and status of waste inside of landfill. Hence, the assumption that leachate quality, which is

averaged by centralizing, reflects status of waste in the landfill is important basis for these studies and spatial variation is not the object for consideration. However, for example, Sormunen (2008) reported that leachate quality in monitoring-wells inside of landfill widely varied by location and they were notably more concentrated than the leachate effluent. This means that spatial variation on the status of waste is large so that these difference has to be identified when considering landfill completion. Hence, what has to be discussed is how the leachate should be monitored in order to know the actual state of waste from the viewpoint of landfill stabilization.

In this study, monitoring of leachate quality stored in 68 gas ventilation pipes was conducted at the landfill where degree of stabilization indicated by leachate quality monitored at leachate treatment facility is completely different from the various evidences identified at the site. First, spatial distribution of leachate was investigated. And next, characteristics of leachate observed at different points were analyzed by statistical approach. Then, we tried to estimate the degree of waste stabilization in terms of leachate quality observed at each location in the landfill by geo-statistical methodology.

2 Material and Methods

2.1 Outline of investigated landfill

Investigated site was a MSW landfill located in Hokkaido, Japan, of which operation was initiated in 1979 and it was closed in 2003. Various kinds of waste were disposed of. Mixed MSW, sewage sludge and C&D waste were the major waste and they were not subjected to any treatment before disposal. Incineration residue had been also disposed of after 1996. But, precise record on the quantity of waste before 1986 did not exist. As for the wastes disposed of after 1986, the mass of them accounted for 80% of total mass of waste in landfill. The percentages of each waste after 1986 were estimated as follows; mixed MSW was 50%, C&D waste was 40%, and sludge was 6%. And at the time of closure, total volume of waste had been 7 million cubic meters. In addition, locations where these wastes were disposed of were not recorded over entire operation period. Due to these shortages of information, it was almost impossible to guess the condition inside of the landfill.

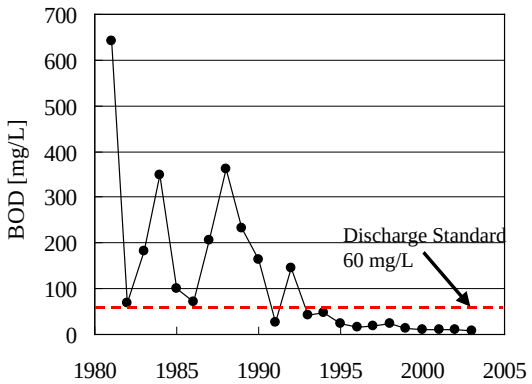

Figure 1: BOD concentration of raw leachate routinely monitored at the leachate treatment facility

Figure 1 indicates BOD concentration of raw leachate monitored routinely at the inlet of leachate treatment facility. Discharge standard of BOD stipulated for MSW landfill site is 60 mg/L. The BOD concentration of this landfill had become lower than discharge standard since 1995. Hence, the leachate of this landfill could be regarded as satisfying the completion standard.

However, at the time of closure, active emission of CH_4 and CO_2 from landfill surface and also the seepage of leachate of relatively high TOC concentration at the landfill surface/slope were identified. These evidences implied that the waste inside of the landfill was still under active degradation phase. Generally, MSW landfill in Japan is constructed as the semi-aerobic landfill, so that installation of leachate collection system and gas ventilation pipes is common practice and they are jointed together to secure substantial airflow. However, in case of this landfill, leachate collection system was not designed and constructed sufficiently, many leachate collection pipes is smashed and segmentalized. Leachate was flowing into the storage pond located at downstream side through main drainage pipe connected to the pond. However, as leachate collection pipes were inadequately installed and most of them were not connected to each other mentioned above, it was not certain how the leachate had flowed within landfill and where the leachate had been generated. A few gas ventilation pipes had been installed but not connected to leachate collection pipes. They were just stood in the waste layer without any plan. Based on these facts, it can be said that this landfill was anaerobic landfill but not semi-aerobic landfill. Owing to these issues, leachate concentration observed at the leachate treatment facility was recognized as not showing the condition of waste inside of landfill. And taking some countermeasures was decided by placing emphasis on actual condition observed at the site. In this countermeasure work, installation of additional leachate collection pipes and gas ventilation pipes, construction of leachate wells and surface drainage ditch, and rearrangement of surface

grading were planned and these works were initiated since 2004.

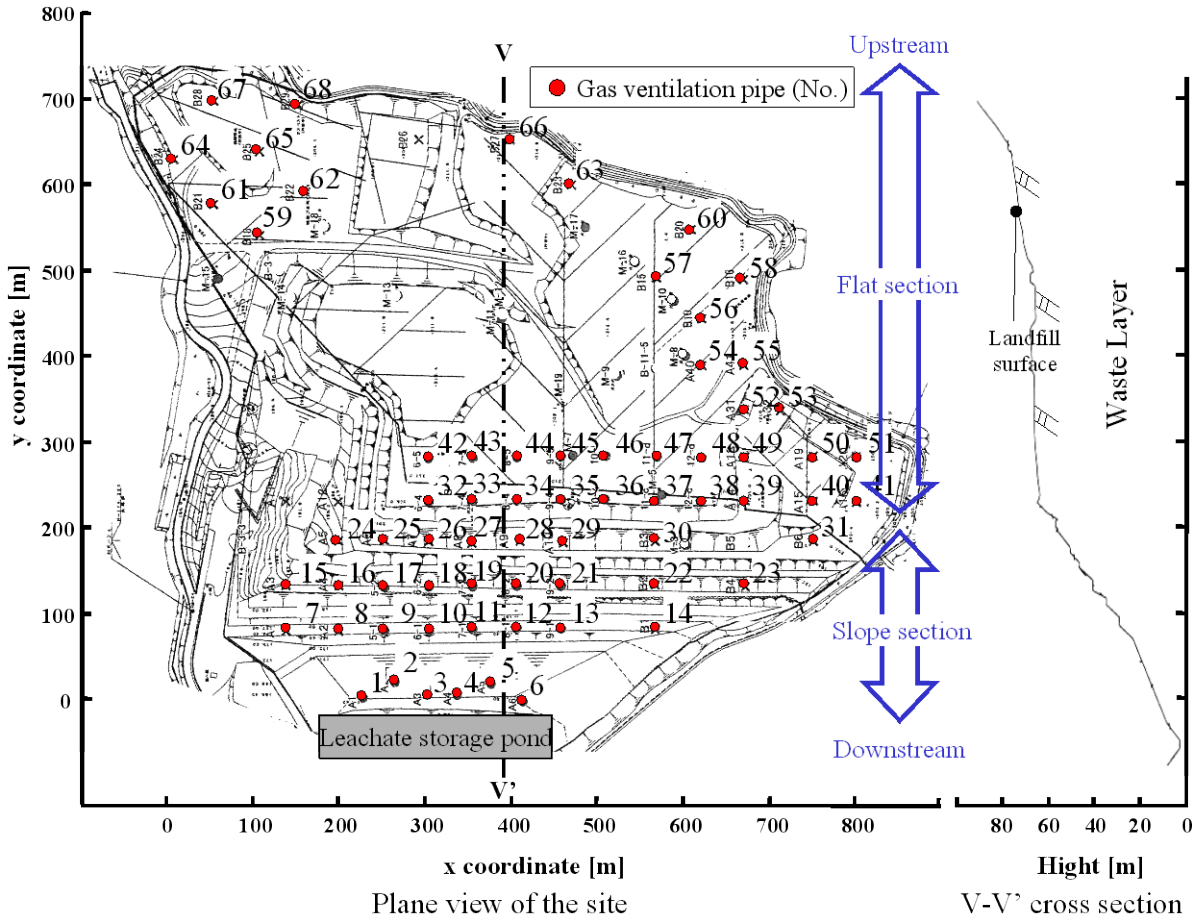

Figure 2: Plane view and V-V' cross section view of the investigated site

Figure 2 indicates plane view and V-V' cross section view of the site. Ground level increases from lower part to upper part in the figure. Slope is located at one thirds of lower part of the figure and there is a leachate storage pond at the foot of the slope. Until the time of investigation, 73 gas ventilation pipes had been installed. The interval of pipes was almost 50m. And 68 pipes, which are indicated as red-points in Figure 2, were selected for investigation in this study. Gas ventilation pipes by the countermeasure work were installed for intending to vent landfill gas and to aerate waste layer. Although gas ventilation pipe is jointed to leachate collection pipe in typical semi-aerobic landfill, these pipes installed in this landfill were simply piled into waste layer and were not connected to any horizontal pipes. Therefore, apart from ordinary gas pipes in semi-aerobic landfill, leachate seeping out from waste layer was stored in the pipes. The structure of the pipe is indicated in Figure 3. The pipe was made of polyvinyl chloride with 20cm diameter and many pores were punched. Average installation depths of pipes were 20m. Detachable cap was equipped at the top of the pipe and landfill gas can be exhausted from the side of the pipe near the top. Rainwater cannot enter the pipe because of the cap.

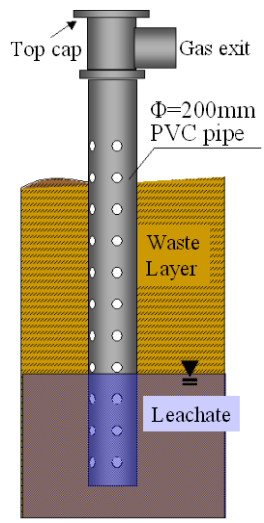

Figure 3: Schematic diagram of gas ventilation pipe installed by countermeasure work

2.2 Sampling of leachate and analysis

Investigation was conducted as follows; for each gas ventilation pipe, at first, depth of leachate surface from the top of the pipe was determined by water level gauge and then leachate stored in the pipes

was obtained by using water-sampling cup. Immediately after the leachate was sampled, pH, EC, and temperature were analyzed. After leachate samples were brought back to the laboratory, TOC, IC, TN, chloride ion, ammonium ion were analyzed. For the analysis of TOC and IC, and TN, TOC-V and TNM-1 of Shimazu Corporation was used, respectively. Chloride ion was determined by Mercury (II) Thiocyanate method and ammonium ion was determined by indophenol spectrophotometric method. Sampling of leachate was conducted six times with three weeks interval.

3 Results and Discussion

3.1 Spatial distribution of leachate quality

As an example, Figure 4 indicates spatial distributions of TOC, TN, IC, and chloride ion obtained at one sampling round. Concentrations of them are shown by the size of circle plotted at the point of gas ventilation pipe from which the leachate is obtained. Coordinate of the circle is consistent with location of pipe indicated in Figure 2. As for TOC, high concentration exceeding 5000 mg/L was observed at the point indicated by astral mark nevertheless it is not plotted because it's size became too large. Results obtained at other round of the sampling showed similar distribution. From Figure 4, it can be found that all items were commonly high at certain points located in the central region of landfill (for example, at x=200-300m, and y=100-200m), and on the contrary, all items tend to be relatively low at the location at where certain item shows low concentration (for example, right side of the landfill). When focusing on the peripheral part of the site, although all items showed low concentration at where leachate concentration was thought to be dilute, there are several particular points at where specific item showed extremely high concentration. For example, at the upper left region, there are several points at where only TOC or Cl was abnormally high. These characteristics were identified only at peripheral region but not central region. The reason why particular points on upper left part of landfill showed different characteristics is considered to be as follows; incineration residue was disposed of at there, and the time when this part was used for disposal was relatively recent. TOC concentration observed at the leachate treatment facility at this time was nearly

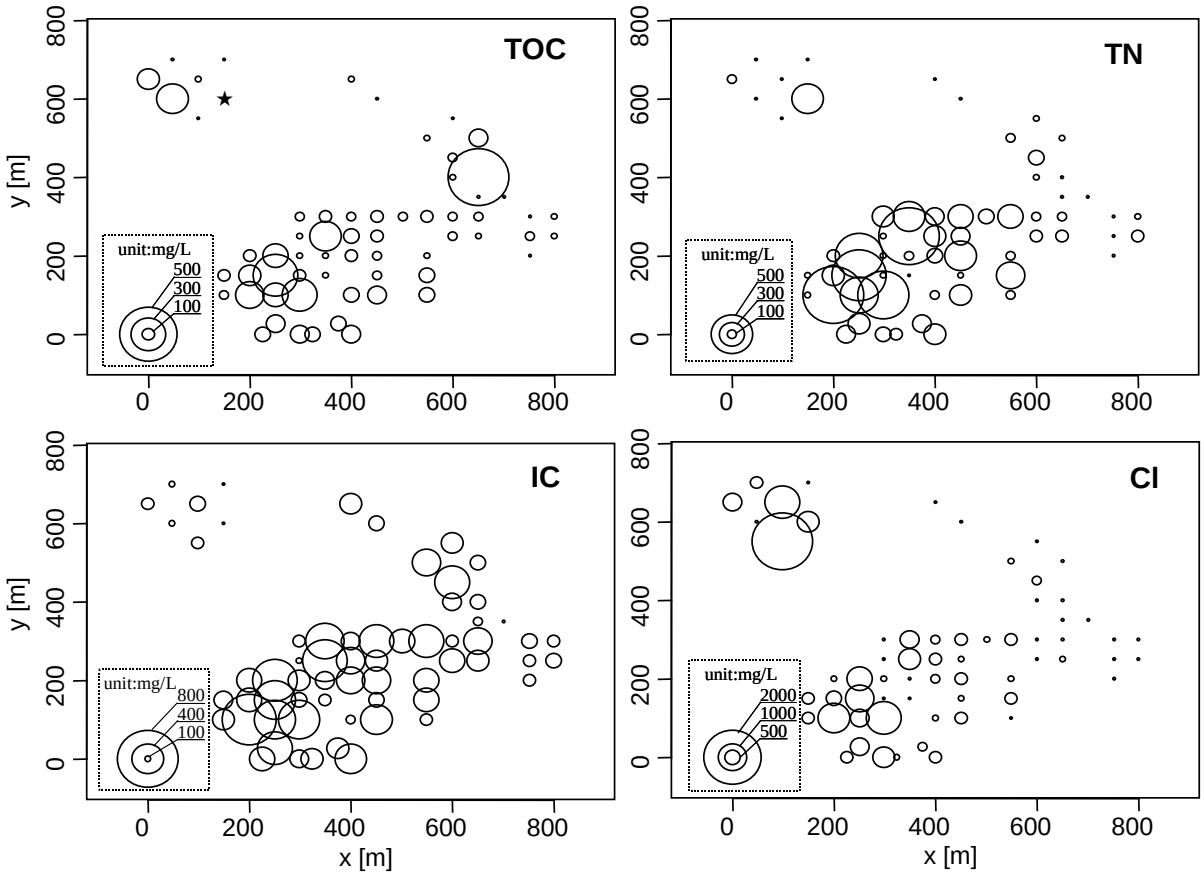

Figure 4: Spatial distribution of TOC, TN and chloride ion at one sampling day. Coordinate of each circle is consistent with location of each pipe indicated in Figure 2.

100mg/L, so its concentration identified at several points in landfill was far high than that of treatment facility. Therefore, even if leachate quality at treatment facility had been satisfying the discharge standard, stabilization of waste in landfill was thought to be doubtful.

To reveal in detail the difference of leachate characteristics identified at each location, dissimilarity was calculated by multidimensional scaling (MDS) method using all observed data of pH, EC, TOC, TN, IC, Cl, and temperature of 4 times. In the MDS, dissimilarity among objects is calculated as the distance by using data that belongs to each object. In this study, the following Euclidean distance was used to calculate the distance.

$$d_{i,j} = \left(\sum_{k=1}^{p} \left(x_{i,k} - x_{j,k} \right)^2 \right)^{0.5}$$

Here, $d_{i,j}$ is Euclidean distance between pipe i and pipe j; $x_{i,k}$ and $x_{j,k}$ are leachate qualities of k observed at pipe i and j respectively; p is the number of leachate quality item. For the calculation of Euclidean distances, each analyzed data was standardized. As for concentration data, they were standardized after logarithmic transformation. Other data was directly standardized. After Euclidean distance among all pipes was calculated, two-dimensional map (Figure 5) was produced based on the distance matrix. For those calculations, R statistical package was employed (Edwards and Oman, 2005).

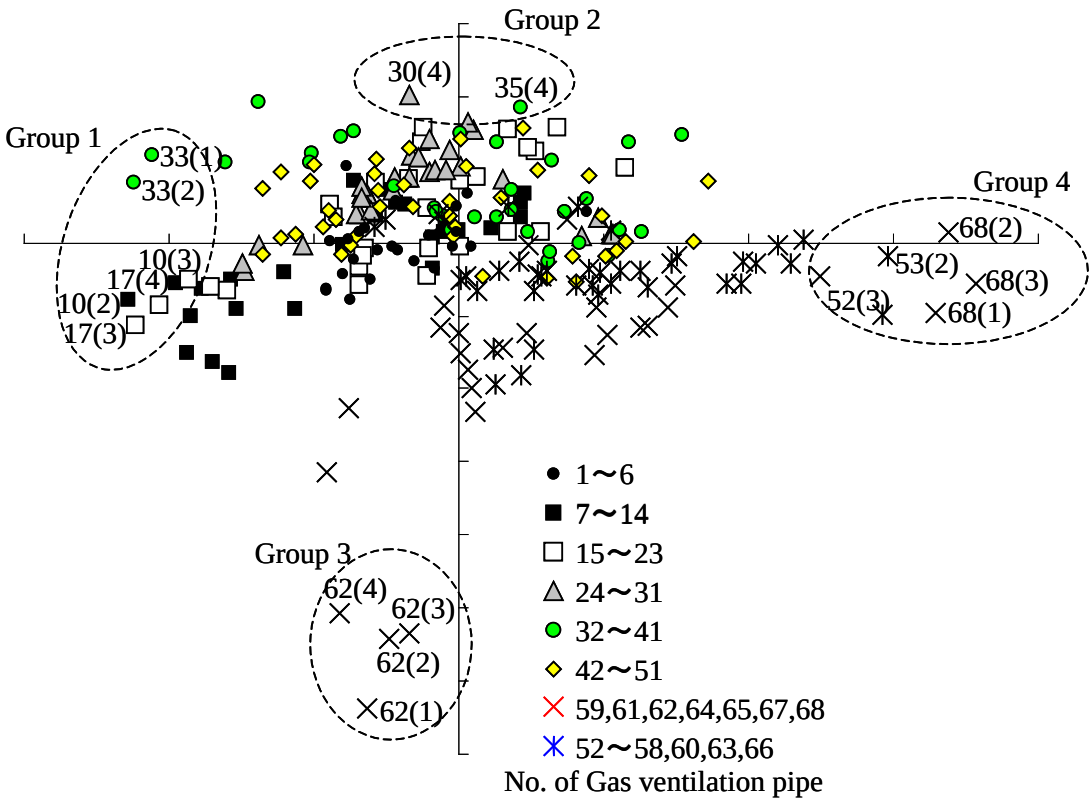

Figure 5: Relative position of leachate quality observed at each gas pipe calculated by MDS. Number indicates pipe No. shown in figure 2, and number in parenthesis indicates round of the sampling. The points allocated near the edge of each axis were categorized into groups in order to identify the meaning of each axis.

Figure 5 indicates relative position of leachate quality observed at each gas pipe calculated by MDS. In this figure, if two points are close, it means that leachate characteristics of these points are similar, and vice versa. In the figure, results obtained at peripheral region were indicated by cross or asterisk mark. As the results, leachates observed at right region of the site have been allocated at right side and those observed at left upper part of the site have been allocated at lower side of the figure. Compared with the leachate obtained at the center region, which were allocated at the upper center part or left upper part, positions of the leachate obtained in peripheral region were far apart from them. Hence, leachate qualities observed at the peripheral region can be regarded as having different characteristics.

In order to identify the meaning of each axis, points allocated near the edge of each axis were grouped as

indicated in Figure 5. As for each group, radar charts with regard to standardized value of each item were drawn in Figure 6. Each axis of radar charts has range from -5 to +5 and zero means average. From the features of these four radar charts, horizontal axis in Figure 5 seems to have a meaning regarding magnitude of concentration. Namely, leachate concentration becomes lower from left to right along with the axis. On the other hand, vertical axis seems to have a meaning of uniqueness of leachate characteristics. Especially, TOC tends to become high and pH tends to become low at points located at lower part of vertical axis.

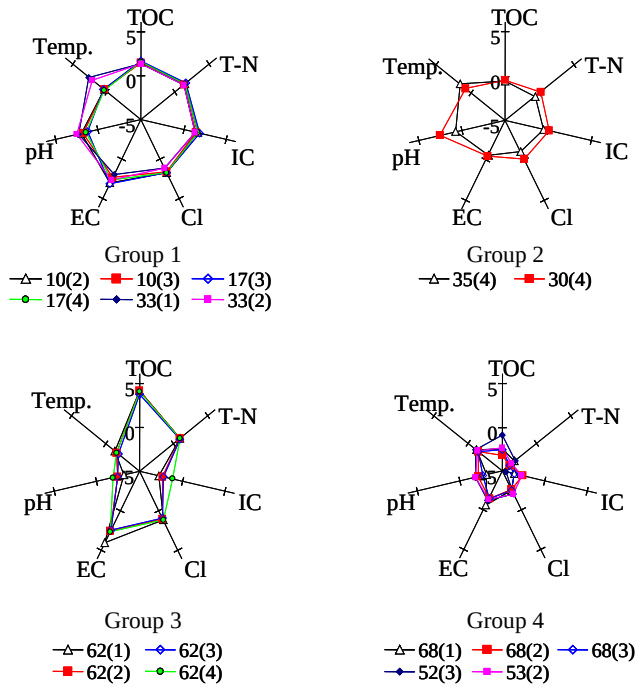

Figure 6: Radar charts with regard to standardized value of each leachate quality item. Number indicates pipe No. belongs to each group, and number in parenthesis indicates round of the sampling.

When excluding data observed in peripheral region, correlation among items of leachate quality is quite high as indicated in Table 1. Prominence of certain item was not identified. That is, all items exhibit high value at where concentration of certain item is high, and vice versa. Hence, difference distinguished in the leachate quality observed in the central region of this site was only the difference on thickness of leachate.

Table 1: Correlation matrix with regard to several leachate quality items (N=184; observation of 4 times at 46 points excluding peripheral region)

	TOC	TN	IC	Cl
TOC	1			
TN	0.758	1		
IC	0.710	0.883	1	
Cl	0.743	0.867	0.863	1

Generally, leachate characteristics must be different if kinds of waste disposed of are different or if degradation process to which landfilled waste had been subjected is different. For instance, soluble salt would diminish early by washout process, BOD must have been high at the early degradation stage, and then, high COD phase would follow. Also, C/N ratio must be high at initial degradation phase and gradually decreases so that the ratio of TOC and T-N must be different in the middle of transformation of waste in landfill. i.e., even if the same waste was disposed of, relative scale of each item in leachate quality must be different when the time period after disposal was different. However, these characteristics were not identified in this site and it could not be explained why only difference on thickness was identified for leachate observed at central region of this landfill, though various waste were coexisting, of which ages after disposal were different.

On the other hand, if the intermixture of leachate was quick, leachate would have similar characteristics and similar concentration. The fact that concentration among adjacent pipes randomly varied means the mix of leachate was slow and insignificant. That is, leachate stored in certain pipe seems to reflect only the quality of leachate existing in limited region close to the pipe. Thus, if leachate concentration was high at certain pipe, it may be showing that adjacent region is in active reaction phase and is not stabilized. This suggests that there is a possibility for enabling estimation regarding the ratio of region in which stabilization progressed or not progressed.

3.2 Fluctuation of leachate quality

In the monitoring executed for confirming landfill stabilization, to seize the continuous decrease trend of leachate quality is significant. In order to achieve this, fluctuation of leachate quality caused by other factors such as rainfall should be eliminated. In Figure 7, fluctuation ranges against average value of each item in leachate quality was indicated in order to discuss fluctuation observed at each gas ventilation pipe. Here, average value of each pipe was calculated by averaging data obtained at four times sampling. Then, fluctuation magnitude was calculated by dividing data obtained at each sampling by average value. Fluctuation of each item is not so large at most pipes. However, at several pipes, whose numbers in horizontal axis were enclosed by circle, concentration fluctuated widely from 0.14 times to 2.8 times against the average value.

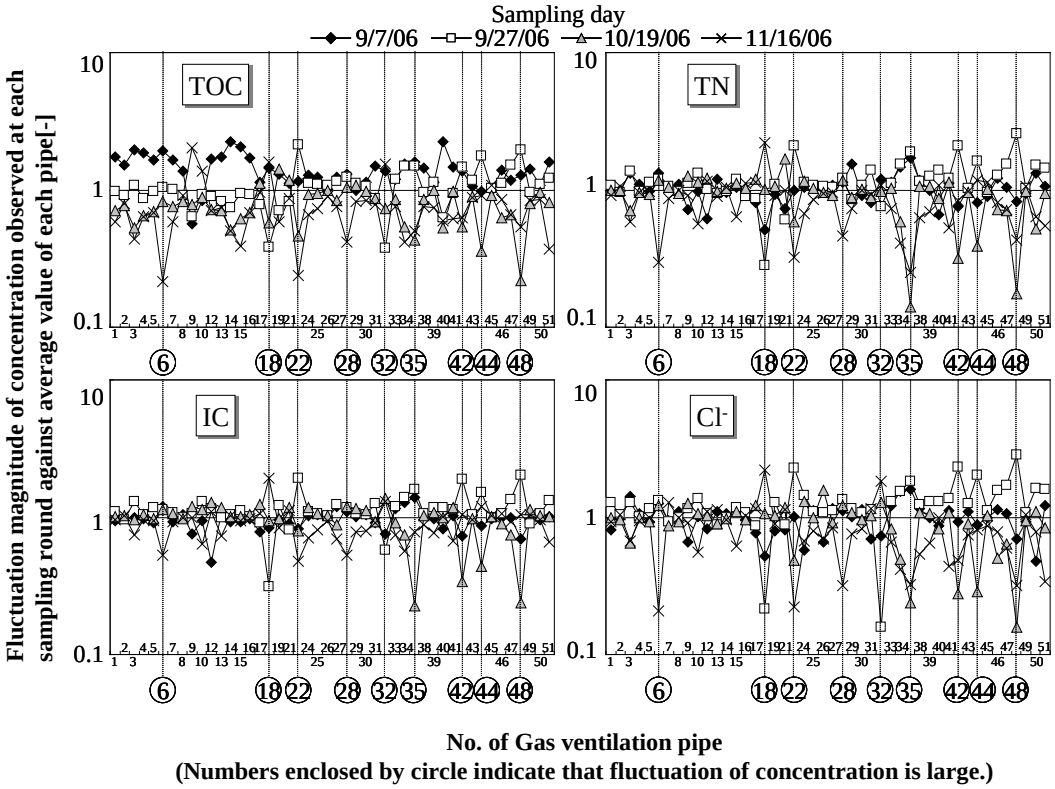

Figure 7: Fluctuation of concentration observed at each sampling round against average value of each pipe. Average value of each pipe was calculated by averaging data obtained at four times sampling. Then, fluctuation magnitude was calculated by dividing data obtained at each sampling by the average value. So, fluctuation magnitude of 1 means the data is the same as the average.

To confirm whether these fluctuations were affected by rainfall, relation between leachate quality and precipitation was examined. To which rainfall before taking leachate these concentrations respond was not clear. So, using cumulative precipitation from one to thirty days, correspondence was checked. As the result, it was found that leachate concentration responds most sensitively to the cumulative precipitation of eight to ten days before leachate sampling. For example, Figure 8 indicates correlation between chloride concentration of point 35, 42, 44, and 48 and cumulative precipitation of eight days. High precipitation during this period makes chloride concentration lower. Other points where wide fluctuation was confirmed also responded to rainfall. These pipes are deemed to be

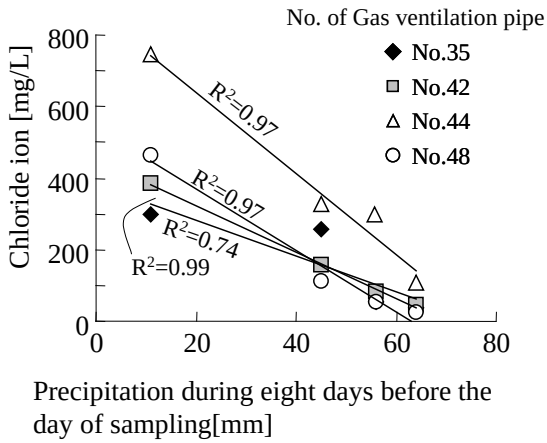

Figure 8: Correlation between chloride concentration and precipitation during eight days before the sampling day

not suitable for monitoring the trend of landfill stabilization.
The reason why only certain pipes responded to rainfall was thought to be as follows; probably the waste/cover soil layer around the pipe was loose and preferential flow was easily formed; consequently, rainwater quickly reached to the depth at where leachate was stored and then it diluted leachate.

3.3 Estimation of the degree of stabilization

Based on above-mentioned discussion, 37 pipes were extracted, which were regarded as not being affected by rainfall and seemed to reflect actual condition of adjacent region. Then, by using their data, spatial distribution of each leachate quality item were estimated by using ordinary Kriging methodology. Kriging is geo-statistical method to estimate values at non-observed points from data observed at other points by using spatial correlation. Up to now, it was used for estimating spatial distribution of contaminants in soil (e.g.: Critto 2003, Komnitsas 2010), that of nutrients in soil (e.g.: Stenger, 2002), etc. As for research on landfill, many studies utilized this approach to estimate whole methane flux from landfill (Spokas 2003, Ishigaki 2005, Awono 2005, Abichou 2006, Wang-Yao 2006). For conducting calculation, Fields package (Nychka, 2005) in R statistical computing environment was used. Target region for estimation was set to 650m x 300m of the landfill at where most of the pipes were located. But the area where the pipe is sparse in the region was ignored in calculation. Hence, total area estimated was about 12ha which is 21% of the landfill. Estimated results on TOC, TN, IC, and Cl are shown in Figure 9.

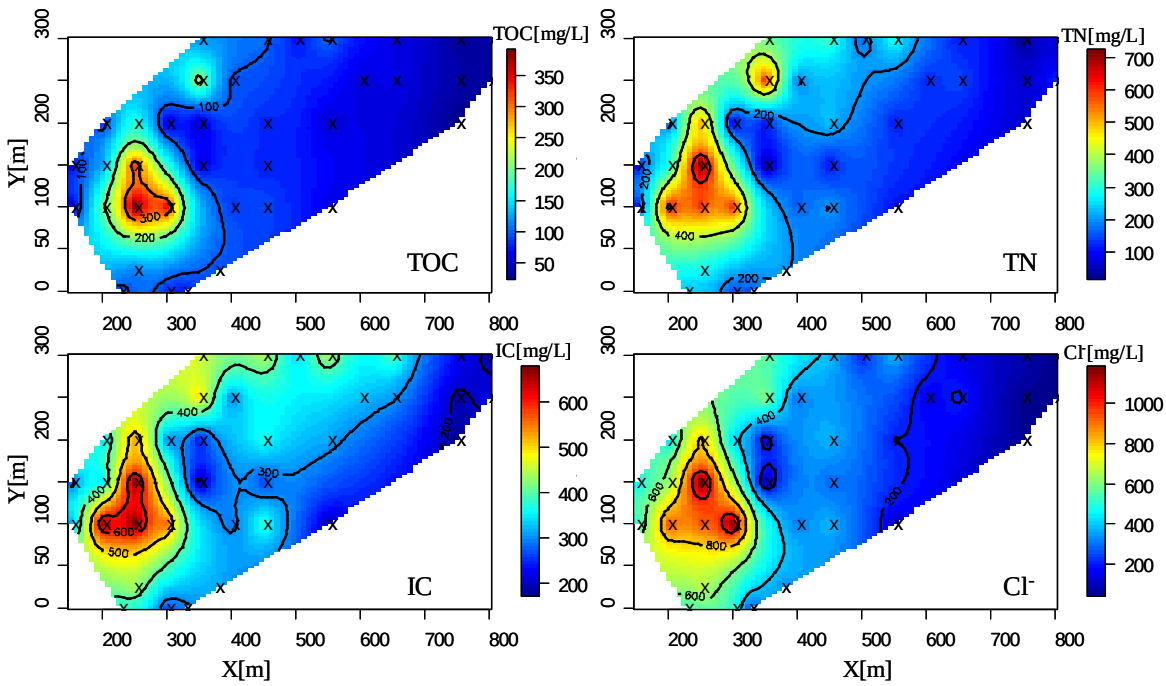

Figure 9: Estimated concentration of TOC, TN, IC, and Cl- at central part of the site.

Concentration of every item became high at left middle part of the region. And they showed common tendency to decrease along with going towards right side. TOC was high at the left middle part. It was about 2% of the calculation area that TOC exceeded 300 mg L^{-1}. Meanwhile, in 64% of the calculated area, TOC was less than 100 mg L^{-1}. The area at where TN was high is the same with that of TOC. But concentration of TN was almost two times higher than TOC. And the ratio of the area at where concentration of TN exceeded 200 mg L^{-1} accounted for 46% of the calculated area. In Japan, one of the completion criteria for terminating post-closure care is that the raw leachate keep satisfying the discharge standard of effluent for at least two consecutive years. The discharge standards on BOD, COD, and TN are 60 mg L^{-1}, 90 mg L^{-1}, and 120 mg L^{-1}, respectively. In this study, TOC was analyzed and it is generally known that TOC value can not be compared carelessly with the standards of BOD or COD. However, Alvarez-Vazquez et al. (2004) reported in their review, in which they summarized many landfill leachate data, that COD value is higher than TOC value in general. Hence, it may be possible to think that COD is

higher than TOC in this landfill also. As indicated in Figure 10, the area in which TOC exceeds 90 mg L^{-1} accounts for 44% of the calculated area. Therefore, it is deemed that the leachate existing in the area of 36% cannot satisfy the discharge standard of COD (90 mg L^{-1}). In addition, with regard to TN, 83% of the calculated area exceeded its discharge standard. From these two aspects, this landfill still needs more time to stabilize and needs to be maintained further. Concentration of chloride ion was almost four times higher than TOC. And it exceeded 300mg L^{-1} in the region of 60%, though there are no standard for chloride ion.

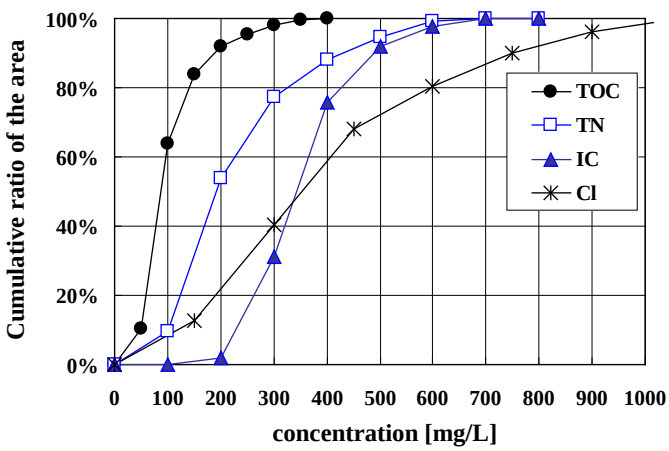

Figure 10: Cumulative percentages of the area occupied by the concentration estimated by Kriging

Only one part of landfill was subjected to the estimation in this study. But it can be said that concentration of leachate stored in landfill is still high in most part compared to completion criteria (i.e. discharge standard). Especially, TN showed the difficulty for satisfying the standard. And besides, certain part had still extremely high concentration. It was not clear why only this part had extremely concentrated leachate. Though the record regarding the age and kinds of waste does not exist, possible speculation is that age of the waste disposed of was not so old or the waste contained much biodegradable fraction.

4 Conclusions

In this study, to discuss the capability of leachate monitoring stored in gas ventilation pipes for evaluation of landfill stabilization, monitoring of leachate quality in 68 gas ventilation pipes was conducted and degree of waste stabilization at each location in the landfill was estimated by statistical approach using the results obtained by monitoring.

The following results were obtained;

Concentration of each leachate quality item varied significantly by each pipe but seemed to reflect the waste condition of nearby location.

Leachate characteristics were different between peripheral part and central part of the site. But correlation among the analyzed items was quite high in the central part of the site. It meant that the difference of leachate quality can be categorized by only the level of concentration but not specific characteristics.

By calculating the Euclidean distances of dissimilarity regarding leachate quality, which was observed at each pipe, two factors (thickness of leachate and concentration of TOC and EC) that distinguish leachate characteristics appeared.

As the result of ordinary Kriging conducted for four leachate items (TOC, TN, IC, and Cl-), spatial distributions of them were estimated and it was found that concentration of leachate existing within landfill, especially TN, was higher than completion criteria of leachate in most part of calculated area. This implied that this landfill still needs more time to stabilize and needs to be maintained. This methodology seems to be effective to draw rough image of landfill stabilization though many monitoring wells or gas ventilation pipes are indispensable.

In this study, only 21% of the investigated site was discussed because installation of gas ventilation pipes was not completed. At present, installation of all pipes which was planned was finished. Hereafter, by conducting same monitoring, discussion with regard to the stabilization of entire site will be possible.

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