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Remote online monitoring of groundwater quality near burial sites for determination of maintenance priority

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ABSTRACT

Many concerns have been voiced concerning the potential for contamination of groundwater in the vicinity of active burial sites for carcasses. The Korean Ministry of Environment has developed a protocol to screen active burial sites based on monitored groundwater data that might lead to the spreading of pathogens and/or chemicals. This methodology is, however, not effective due to the considerable time and cost. In our study, we proposed that electrical conductivity of groundwater can be used as an indicator to continuously monitor groundwater in the vicinity of active burial site and screen for burial sites that are causing contamination. This technique can be adapted for remote monitoring based on interpretation of long-term monitoring data of monitored wells and background concentration in the vicinity of burial sites.

Keywords: Burial sites; Electrical conductivity; Groundwater; Remote monitoring; Sensor; Water quality

1. Introduction

An outbreak of foot-and-mouth disease occurred in South Korea in 2010, causing the culling of hundreds of thousands of pigs in an effort to avert its spread. The outbreak began in November 2010 in pig farms in Andong, Gyeongsangbukdo, and then rapidly spread throughout the country [1]. The burials were conducted to contain the airborne disease threat rather than minimize the subsequent environmental impact, making it possible that the leaching of materials from the decomposing carcasses would contaminate the groundwater.

Starting in the year 2011, the Korean Ministry of the Environment (KMOE) monitored 4,172 burials nationwide and concluded that 417 of these sites (or 9.8% of the total) required reinforcement. The Korea Environment Corporation further reported that 71 of a total of 300 burial sites they monitored demonstrated leakage; these sites were located very close to rivers and streams. To minimize the adverse impacts on the environment, preventive measures were demanded to protect the subsurface environment. In these situations, monitoring of soil and groundwater is of importance, as is early detection of contamination of groundwater before further deterioration.

The environmental monitoring carried out by the Korean government in 2011 showed that the number of

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impacted (defective) burial sites is increasing. As the locations of burial sites become more dispersed, direct monitoring of sites is limited due to cost demand and biosecurity reasons. However, a limited budget for the environmental management of burial sites leads to fewer possible options for the sufficient monitoring of groundwater for potential contamination.

Information management system development is necessary for the integrated management of burial sites. During design and prototype development of the tracking database, the following steps are usually adopted: (1) examination of the data for the monitored groundwater; (2) definition of system function; (3) remote monitoring system design, and (4) design and manufacture of data logger.

Hence, the main objectives of this research were characterization of groundwater near burial sites and the design of an optimal system that allows long-term, real-time remote monitoring.

2. Materials and methods

Currently, groundwater in the vicinity of selected burial sites is monitored once a week for the first six months and once a quarter after that. As a result of direct monitoring of groundwater near burial sites, reports have indicated that many burial pits are defective, generally because they were constructed in limited time.

During monitoring, groundwater is sampled and analyzed for nitrate nitrogen, ammonia nitrogen, chloride, and conductivity level in order to determine whether leakage from the site occurred. According to the guideline provided by KMOE for interpreting monitored groundwater data, three stages for groundwater quality were proposed [2]:

Stage 1: Clear evidence/occurrence of leakage

(1) Ammonia nitrogen concentration is more than 10 mg/L and chloride concentration is more than 100 mg/L.
(2) Active management of burial sites, including relocation and incineration of carcasses, is required.

Stage 2: High probability of leakage

(1) Ammonia nitrogen concentration is more than 2 mg/L and chloride concentration is more than 25 mg/L.
(2) Electrical conductivity (EC) of more than 800 μS/cm.
(3) Active management of burial sites, including relocation and incineration of carcasses, is required.

Stage 3: Low probability of leakage

Stage 4: No leakage

EC is usually measured in μS/cm and is a user-friendly indicator of the number of dissolved ions present in a solution. As most of the dissolved content of natural groundwater is in ionic form, EC can be empirically related to total dissolved solids (TDS). For typical fresh groundwater, dominated by calcium and bicarbonate with subsidiary sodium and chloride, the following approximate relationship applies [3–6]:

$$\mathrm{TDS} = k_e \mathrm{EC} \tag{1}$$

where TDS is expressed in mg/L and EC is the electrical conductivity in microsiemens per centimeter at 25˚C. The correlation factor k_e varies between 0.55 and 0.8.

3. Results and discussion

To monitor groundwater quality in the vicinity of burial sites, we need to select monitoring constituents. Previous research has reported that the characteristics of leachate from the decomposition of carcasses were similar to those of manure from livestock [5]. To assemble remote online monitoring devices, the main aspects that require consideration include what the data is worth; the cost for acquiring the data; and maintenance, endurance, and ease of installation for the devices. To measure groundwater level, pH, and temperatures from remote site, an online meter need to be installed at burial sites to allow the transmission of data from a satellite cable. The devices used for online measurement should be sturdy, as they are operated outside for 24 h a day. In addition, a self-cleaning function for these devices is required.

Various online measurement devices are available; they are different based on target index, maintenance (costs), and prices. Therefore, optimal specifications for the specific task at hand should be decided upon a priori before starting a project. The following table is a guideline for selecting online measurement devices (Table 1).

The optimal index constituent for remote monitoring is based on the scoring for conventional organics that would generally be detected at the burial sites. According to the guideline for selection of remote online monitoring devices, EC was selected.

Table 1
Selection guide for the index-constituent measurement

Index	Water level	Temp.	Conductivity	ORP	Chloride	pH	NH_4-N	NO_3-N	Coliform
Data worth	4	4	4	4	4	3	5	4	5
Cost	4	5	3	3	2	3	1	1	1
Maintenance	4	5	3	3	2	3	1	1	1
Endurance	5	5	3	3	2	3	1	1	1
Ease of installation	5	5	3	3	3	3	1	1	1
Points	22	24	16	16	13	15	13	11	9
Optimum selection	◎	◎	○	○	×	○	×	×	×

Notes: Points: high to low, 5–1.
◎: high for selection: more than 20 points.
○: applicable: more than 15 points.
×: not applicable: less than 15 points.
Full score: 5 constituents multiplied by 5 points = 25 points.

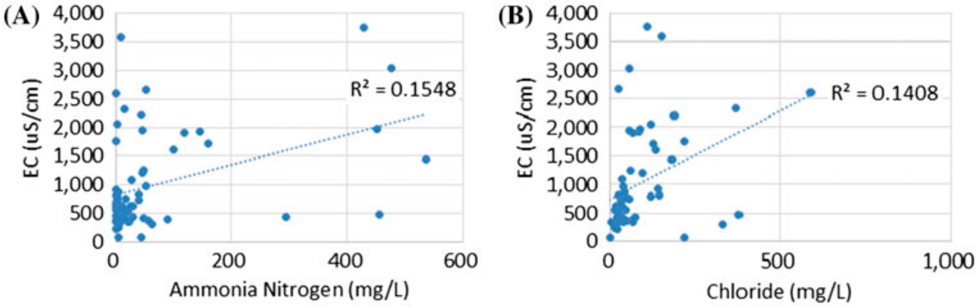

Fig. 1. Correlation analysis results between nutrients and ions of groundwater and EC for monitored data: (A) ammonia nitrogen and EC; (B) chloride and EC.

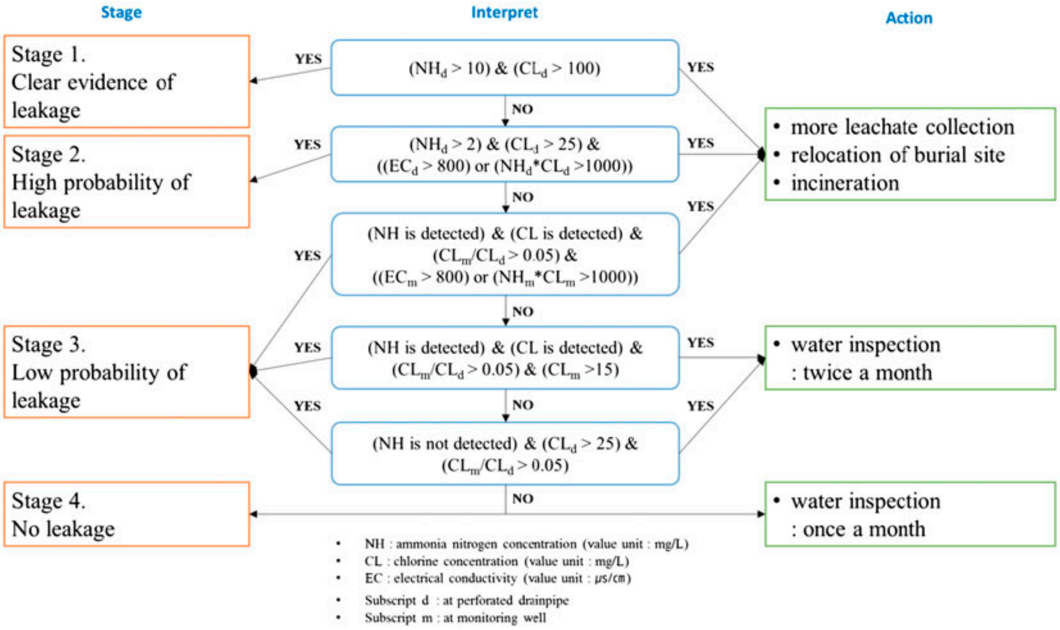

Fig. 2. The guideline for interpreting monitored groundwater data provided by KMOE.

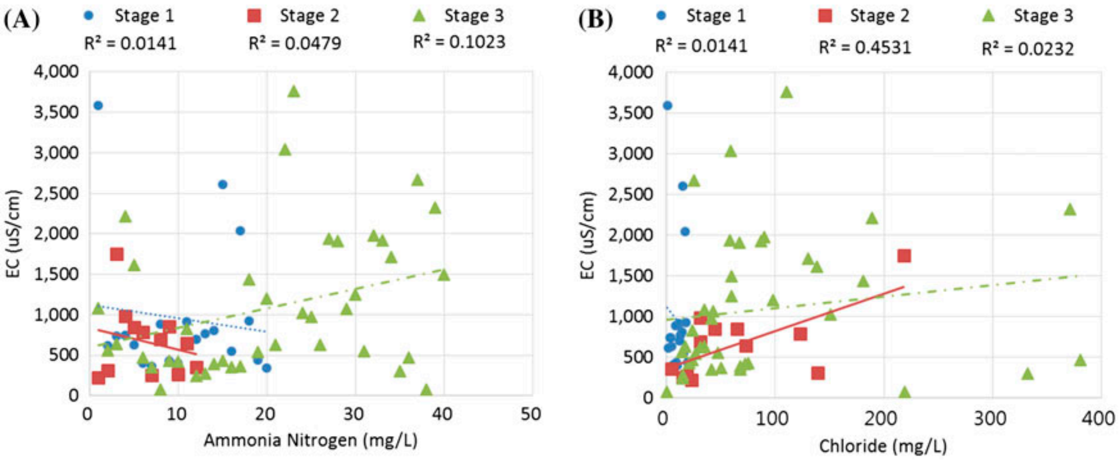

Fig. 3. Groundwater quality data and interrelationship: (A) ammonia nitrogen vs. EC; (B) chloride vs. EC.

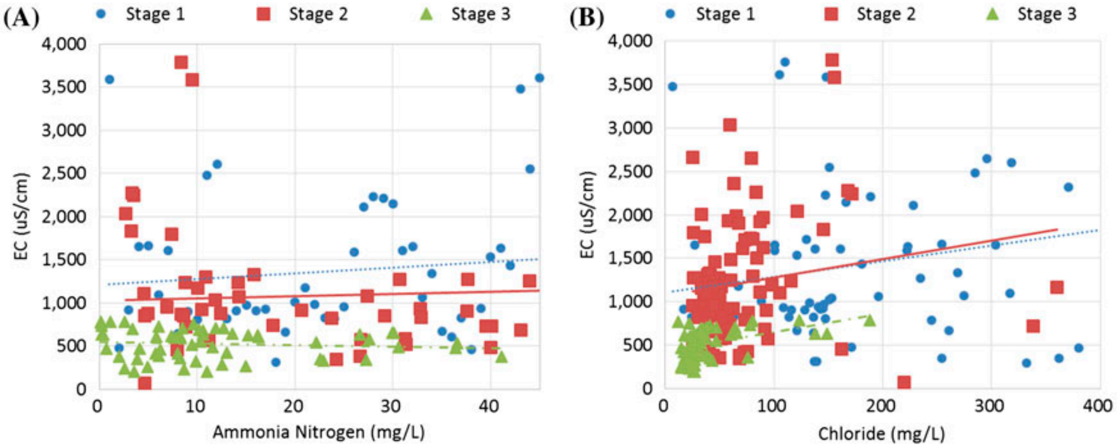

Fig. 4. Groundwater quality data scatter plot and correlation analysis results.

Table 2
Percentile and outliers for groundwater monitoring data

	Ammonia (mg/L)			Chloride (mg/L)			EC (µS/cm)		
	1st	2nd	3rd	1st	2nd	3rd	1st	2nd	3rd
Minimum	0	3	0	7	25	12	300	76	200
First percentile	1	15	5	116	39	23	826	812	377
Median	17	49	10	147	51	29	1,068	1,087	552
Third percentile	61	90	15	254	79	41	2,112	1,502	654
Maximum	644	475	41	590	360	188	3,760	3,790	787
Upper inner fence	151	203	31	461	138	68	−1,103	−222	−39
Lower inner fence	−90	−98	−11	−91	−20	−4	4,041	2,536	1,070

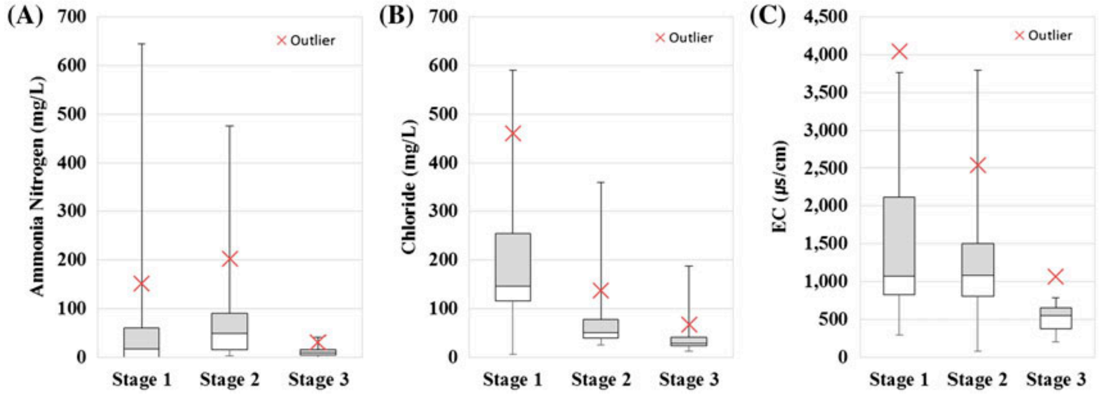

Fig. 5. Box plot and outlier values for (A) ammonia nitrogen; (B) chloride; (C) EC.

For burial sites, ammonia nitrogen and chloride concentration are used for classification, and monitored data are analyzed. Monitoring data were used from 10 burial sites; EC, ammonia, and chloride concentration were analyzed for their relationship. As shown in Fig. 1, EC had a tendency to increase with increases in ammonia and chloride concentration. However, regression coefficients were less than 0.2, signifying weak linear relationships between variables. Variation of EC is a result of various geological and chemical reactions between contaminants and soils.

To clarify characteristics of monitored data, data were reexamined for their correlation with grouped data. Each data point in Fig. 2 is grouped for their stages proposed by KMOE as explained [1]. The data points of each stage were analyzed for their correlation analysis. In Fig. 3, there are three tendency lines for each stage. Still, correlation coefficients are low.

In order to minimize the potential for statistical errors, all monitored data were included. As result, linear correlations were not shown between data based on conductivity; rather, the data were grouped, and their trend line is clearly shown (Fig. 4).

Monitored data of each stage were classified, and outlier and inner fence values were determined (see Table 2). In addition, we also show box plot data.

The concentration of ammonia nitrogen varied evenly across the stages, as shown in the Fig. 5. The second stage and third stage can be separated using the criteria of 15 mg/L, but the first-stage data clearly overlap with those of both the second stage and the third stage; for this reason, differentiation of the ammonia nitrogen concentrations (in terms of statistically significant difference) isn't possible. Chloride ions can be separated at each stage using the measurement criteria of 40 and 100 mg/L. This means that chloride ions can be used as an index to separate out each stage. The EC values for each stage can be grouped at 800 μS/cm.

4. Conclusions

In this research, we tried to prove the simple assumption that EC can be used as a sole indicator for monitoring of groundwater in the vicinity of an active burial site with carcasses.

Livestock burial sites are maintained in order to help conserve the environment. When the burial sites are determined to be defective or compromised, monitoring wells near the burial sites are monitored regularly. As the monitoring requires a large amount of resources, a more effective and deployable scheme is proposed in this research. Currently, chemistry and relative composition of ammonia nitrogen, chloride, and conductivity are the constituents to determine the integrity of the burial sites.

In this research, EC used to the sites are monitored. EC is reliable and can be affordably measured on-line. Furthermore, EC was successfully used as a variable to determine the integrity of the burial sites.

Acknowledgment

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References

[1] Korean Ministry of the Environment, Environmental Impact Assessment of Burial Sites, Korean Ministry of the Environment, Seoul, 2011.

[2] Korean Ministry of the Environment, Special Operation Procedure for Environmental Assessment for Burial Area, Korean Ministry of the Environment, Seoul, 2012.

[3] C.A.J. Appelo, D.D. Postman, Geochemistry, Groundwater and Pollution, third ed., Balkema, Rotterdam, 1996.

[4] E.A. Atekwana, E.A. Atekwana, R.S. Rowe, D.D. Werkema Jr., F.D. Legall, The relationship of total dissolved solids measurements to bulk electrical conductivity in an aquifer contaminated with hydrocarbon, J. Appl. Geophys. 56 (2004) 281–294.

[5] M. Jalali, Application of multivariate analysis to study water chemistry of groundwater in a semi-arid aquifer, Malayer, western Iran, Desalin. Water Treat. 19 (2010) 307–317.

[6] D.R. Pathak, A. Hiratsuka, An investigation of nitrate and iron concentrations and their relationship in shallow groundwater systems of Kathmandu, Desalin. Water Treat. 19 (2010) 191–197.