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Review

Experiences of Mass Pig Carcass Disposal Related to Groundwater Quality Monitoring in Taiwan

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Abstract: The pig industry is the most crucial animal industry in Taiwan; 10.7 million pigs were reared for consumption in 1996. A foot and mouth disease (FMD) epidemic broke out on 19 March 1997, and 3,850,536 pigs were culled before July in the same year. The major disposal method of pig carcasses from the FMD outbreak was burial, followed by burning and incineration. To investigate groundwater quality, environmental monitoring of burial sites was performed from October 1997 to June 1999; groundwater monitoring of 90–777 wells in 20 prefectures was performed wo to six times in 1998. Taiwanese governmental agencies analyzed 3723 groundwater samples using a budget of US $1.5 million. The total bacterial count, fecal coliform, *Salmonella* spp., nitrite-N, nitrate-N, ammonium-N, sulfate, non-purgeable organic carbon, total oil, and total dissolved solid were recognized as indicators of groundwater contamination resulting from pig carcass burial. Groundwater at the burial sites was considered to be contaminated on the basis of the aforementioned indicators, particularly groundwater at burial sites without an impermeable cloth and those located at a relatively short distance from the monitoring well. The burial sites selected during outbreaks in Taiwan should have a low surrounding population, be away from water preservation areas, and undergo regular monitoring of groundwater quality.

Keywords: burial; environmental indicator; foot and mouth disease; groundwater; pig; soil

1. Background of the Pig Industry in Taiwan

The pig industry is the most crucial and well-established animal industry in Taiwan, because of the rapidly growing demand for animal protein resulting from increases in population size and real income after World War II. Pork, the preferred meat in Taiwan, accounts for approximately 60% of the total meat consumption. The per capita consumption averaged 38 kg of pork in 1996. Taiwan has been reported to have the world's highest density of pig farms [1]. Approximately 10.7 million pigs were reared for consumption on 25,400 farms in November 1996, yielding more than 1.0 million tons of product annually. In 1996, Taiwan was the major exporter of pork to Japan and was one of the top 15 pork producers globally. During this period, agricultural exports were worth approximately US $5.48 billion and represented nearly 5% of Taiwan's total annual exports. The 6 million pigs exported to Japan contributed US $1.6 billion to the value of Taiwan's total annual exports. In addition to Japan, Hong Kong and the United States are Taiwan's principal markets for pork exports. The pig industry was approximately 20% of the economic value of the total agricultural output in Taiwan. However, Taiwan governmental agencies reported a foot and mouth disease (FMD) (*Aphthae epizooticae*) epidemic on 19 March 1997. FMD was announced by the Ministry of Agriculture the following day, and it was effectively controlled by 20 May 1997 [1].

FMD is an infectious and sometimes fatal viral disease affecting cloven-hoofed animals such as cattle, sheep, pigs, goats, and deer [1]. This disease has disastrous effects for farmers and the country, because it is highly infectious and can rapidly spread from infected to uninfected animals through air or contact with contaminated farming equipment, vehicles, clothing, and feed [2]. This disease results in enormous financial damage to individuals, the agricultural industry, and the country [3]. Within one week of the FMD outbreak, the pig price dropped by 60%, decreasing from US $167 per 100 kg to US $63 per 100 kg. The reduced price mainly resulted from the immediate loss of export markets and the initial sharp drop in domestic consumption. Therefore, after the outbreak, the number of pigs reared for consumption in Taiwan abruptly decreased to approximately 6.0 million on 21,891 farms [1].

In this review paper, the history of the FMD outbreak in 1997 is briefly described, including the disposal of pig carcasses and the burial processes of culled pigs, and the effect of pig carcass burial on groundwater quality is further discussed to characterize groundwater quality at the burial sites for guidelines of groundwater quality indicators for livestock carcass disposal around the world.

2. Foot and Mouth Disease Outbreak in 1997

2.1. Process of Outbreak

Taiwan had previous FMD epidemics during 1910–1930 but had since been spared, and Taiwan was considered FMD-free in as late as the 1990s [1]. However, on 19 March 1997, a sow at a farm in Hsinchu Prefecture, Taiwan, was diagnosed with a strain of FMD that only infects pigs. The mortality rate in the infected herd was approximately 100%. Smuggled pig or contaminated meat was identified as the likely source of the disease. The causes for the rapid spread of this disease included a high pig density of up to 2500 pigs per square kilometer, the feeding of pigs with untreated garbage, and the farms' proximity to slaughter houses. Systemic issues such as the lack of laboratory facilities, the slow response, and the initial absence of a vaccination program further contributed to the spread of this disease. In addition to Hsinchu, the hot spots of FMD included Taipei, Miaoli, Changhua, Yunlin, Chiayi, Tainan, Kaohsiung, and Pingtung (Figure 1). Farmers allegedly intentionally introduced FMD to their flocks, because the payment offered for culled pig, at that time, was higher than the market value. The pigs with FMD were identified to be infected with the O1 type. This type was reconfirmed by the Institute of Animal Health at Pirbright Laboratory and Plum Island Animal Disease Center of United States Department of Agriculture during the period from March to May 1997 on the basis of the results of analysis of 188 samples.

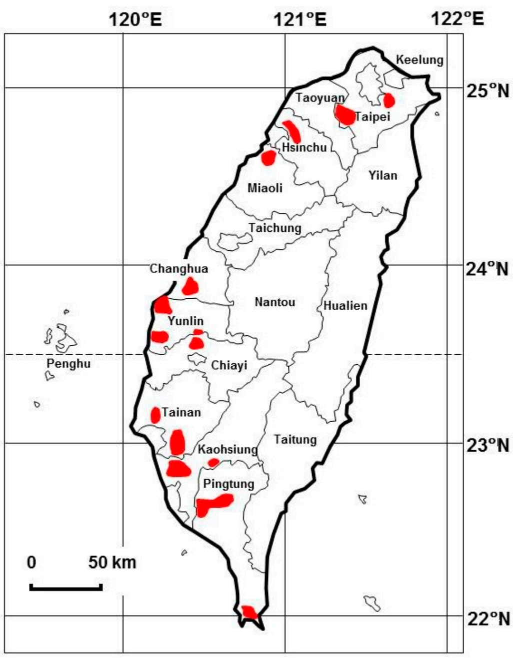

Figure 1. Hot spots of foot and mouth disease in Taiwan in 1997.

Livestock loss is regarded as a normal part of farm operations and can be attributed to different causes, such as disease, accidents, and inter-animal competition [4]. However, the outbreak of a highly contagious disease, such as the FMD outbreak in Taiwan in 1997, requires the culling of a large number of pigs and can be a serious threat to the national economy and public health [5]. During the FMD outbreak in Taiwan in 1997, more than 3.8 million pigs were culled at a cost of US $6.9 billion. Before April, fewer than 1.0 million pigs were culled, but this number rapidly increased to more than 3.5 million (Figure 2). The FMD outbreak had devastating effects on the Taiwanese pig industry and export market. Although Taiwan was considered FMD-free in 2007, vaccination programs were still conducted at that time, restricting the export of pork from Taiwan.

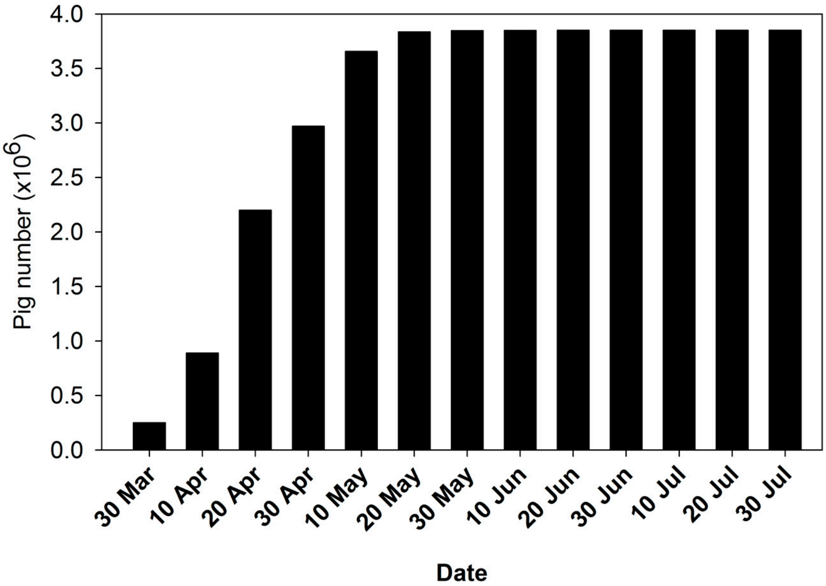

Figure 2. Number of culled pigs with foot and mouth disease in Taiwan in 1997.

2.2. Depopulation and Disposal of Culled Pigs

Available information from 17 June 1997 indicated that pigs in 6144 farms were affected, involving 1,011,421 FMD-infected pigs, 184,231 dead pigs, and 3,850,536 culled pigs. The depopulation of pigs with FMD was a massive undertaking, with the substantial manpower from military. The immediate steps taken for a farm with FMD-infected pigs included stopping the export of pigs, culling all infected pigs, spreading lime around infected areas and hallways, spreading alkali flakes in sewage around fence, sterilizing pig fences with a strong acid or alkali solution, strictly controlling infected areas, adding organic acid to the pigs' drinking water, and vaccinating them as soon as possible. However, the disease spread rapidly among pig herds in Taiwan, with 200–300 new farms being infected daily.

At peak capacity, 200,000 pigs per day were culled (Figure 3). In total, more than 97% of infected pigs were culled through electric shock and only 2.55% were culled through methods such as poisoning and drowning. The disposal options for infected and potentially infected animal carcasses included burial, burning, incineration, composting, rendering, alkaline hydrolysis, and anaerobic digestion [6]. During the FMD outbreak in 1997, burial was the major option, followed by burning and incineration. Burial was also the major disposal method of pig carcasses in the 2001 FMD outbreak in the United Kingdom [2]. However, the United States Environmental Protection Agency recommended land disposal through on-site burial, composting, and off-site landfill burial [7]. During burial, an impermeable cloth is placed or lime is spread at the bottom, and the sites are covered with calcium carbonate and a clean soil layer of least 1.5 m (Figure 4). During the FMD outbreak in 1997, approximately 80% of the pigs were disposed of through the burial of pig carcasses in large municipal landfills, and a capacity of 200,000 pig carcasses per day was achieved. Lime was applied during both the construction and subsequent operation of burial sites to impede the survival of pathogens and the possibility of off-site pathogen transfer. However, high water tables and other environmental concerns complicated these procedures in Taiwan.

(**a**) (**b**)

Figure 3. Foot and mouth disease-infected pig carcasses in Pingtung Prefecture, Southern Taiwan (**a**); culling of foot and mouth disease-infected pigs through electric shock (**b**).

(**a**) (**b**)

Figure 4. Disposal of foot and mouth disease-infected pig carcasses by landfilling with plastic liner and lime addition (**a**); the disposal site covered with clean soil (**b**).

Burning was avoided in water resource protection areas in Taiwan, which considerably impeded the efficiency of carcass disposal. From an environmental perspective, incineration may not have been a viable option because of the generation of harmful combustion byproducts. In support of this observation, Chen et al. found that the concentrations of polycyclic aromatic hydrocarbon and heavy metals in flue gas were significantly higher in the incinerators of FMD-infected pig carcasses than those from general medical waste incinerators in Taiwan [8,9]. Composting and rendering may be more suitable alternatives because they provide quick removal, reduce farm mortality, and do not produce undesirable byproducts. However, composting has concerns related to the management of the compost area; leachate management; appropriate temperature, moisture content, and aeration maintenance; the creation of an adequate carbon to nitrogen ratio; and the final disposal of compost [10]. Rendering requires the transport of the pig carcasses to the facility, which introduces a very high risk of spreading FMD [6].

3. Groundwater Quality Monitoring

3.1. Potential Effect of Land Burial of Livestock Carcass on Water Quality

Buried livestock undergo decomposition. During this process, nutrients, pathogens, and other components of the animal carcass are released into the environment. Because these substances are released into the surrounding environment, they may be broken down, transformed, lost to air, or otherwise immobilized so that they pose no environmental threat. Ritter and Chirnside concluded that the pollution from burial pits is similar to that from domestic septic tanks and can be controlled with legislation synonymous with on-site wastewater treatment regulation [11]. For instance, the Dead Animal Disposal Act in Ontario, Canada, outlines three legal disposal methods for dead cattle, pig, sheep, goats, and horses: pickup by a provincially licensed collector; composting under 60 cm of organic substrate, such as sawdust or straw; and burying under 60 cm of soil and far away from all waterways [4]. However, few studies have investigated the effect of carcass burial on groundwater quality. On-farm burial pits are typically constructed without liners, and any leachate produced may infiltrate into the soil and groundwater. To date, investigations of the groundwater quality impact due to animal carcass disposal have largely focused on poultry carcass disposal, and a limited number of routinely measured contaminants, including nutrients, chloride, and fecal pathogens, have been examined [6]. Increased concentrations of ammonia, nitrate, chloride, and fecal pathogens in groundwater have been observed on farms with poultry carcass disposal pits [11]. Yuan et al. examined the concentrations of conventional contaminants, including chemical oxygen demand, total organic carbon, total nitrogen, total phosphorus, and solids, as well as veterinary antibiotics and steroid hormones in leachate and electrical conductivity values over a period of 20 months after the land burial of cattle carcasses. They found that most contaminants were detected in leachate after 50 days of carcass decomposition, reaching a peak concentration at approximately 200 days and decreasing to baseline levels by 400 days [12].

MacArthur et al. reported the average leachate levels of ammonium-N (3290 mg/L), alkalinity (9400 mg/L), biochemical oxygen demand (BOD; 12,700 mg/L), and chemical oxygen demand (COD; 20,400 mg/L) on a burial site with FMD mortalities [13]. A field study investigated leachate quality after the burial of poultry, bovine, and pig carcasses in separate pits that were isolated from the surroundings with a 0.04-inch polyethylene liner [14]. That study detected elevated levels of ammonium-N (12,600 mg/L), alkalinity (46,000 mg/L as bicarbonate), chloride (2600 mg/L), sulfate (3600 mg/L), potassium (2300 mg/L), sodium (1800 mg/L), and phosphorus (1500 mg/L) and relatively low levels of iron, calcium, and magnesium in leachate samples. These data provide crucial information on the potential for groundwater contamination resulting from the leachate produced by most on-farm mortality pits in the Unites States [12]. During the 2001 FMD outbreak in the United Kingdom, approximately 61,000 tons of carcasses were disposed of at four mass burial sites, and groundwater vulnerability maps were used to locate suitable mass burial sites [15]. Such an approach can identify potential on-farm burial sites to minimize the risk of environmental pollution and can offer viable and practical options to farmers for disposal of on-farm mortalities.

3.2. Framework of Monitoring Plans for Groundwater during the FMD Outbreak in Taiwan in 1997

Because many culled pigs with FMD are disposed of at landfills, groundwater contamination is a critical concern for people living near these landfills and burial sites [16]. In Taiwan, approximately 2,850,000 pig carcasses were buried in 1997. Environmental monitoring in the areas surrounding these burial sites was crucial for public health. Therefore, monitoring plans were developed to determine the effect of carcass burial on groundwater quality. These monitoring plans were implemented from October 1997 to June 1999, approximately 6 months to 2.5 years after burial. In 1998, groundwater was sampled two to six times depending on the number of buried pigs and the groundwater table in 90–777 wells in 20 infected prefectures to monitor groundwater quality. The Taiwanese government analyzed 3723 groundwater samples, and the total budget of this monitoring project was approximately

US $1.5 million in 1998. These samples were evaluated to monitor the groundwater quality at burial sites of FMD-infected pig carcasses for comparison with current water quality standards to assess the safety of drinking water.

3.3. Effect of Pig Carcass Burial on Groundwater Quality

Taiwan is characterized by high temperatures and humid climate. The annual rainfall ranges from 1800 to 2400 mm and mainly occurs in June–September. The mean annual air temperature is 22.5 °C, and the mean monthly temperature ranges from 15 °C to 30 °C. In this paper, four pig carcass burial sites with various groundwater monitoring wells were studied, namely Linlo, Chawchou, Shinbei, and Pousan. The Pousan site is located in Hsinchu Prefecture in northern Taiwan, and the other three sites are located in Pingtung Prefecture in southern Taiwan. Before the FMD outbreak in 1997, the number of pigs reared for consumption in Pingtung was much higher than that in Hsinchu; thus, the number of pig carcasses was much higher in Pingtung than in Hsinchu (Table 1). Pousan was the first area to present with the FMD outbreak in 1997, and its geographic condition is considerably different from that of Pingtung. Therefore, the Pousan site was also involved in the groundwater monitoring plan. The three monitoring sites of Pingtung are located in alluvial plains with fine-size Holocene sediments and exhibit high seasonal water tables ranging from more than 2.0 m to less than 0.5 m. In contrast, the Pousan site in Hsinchu is composed of coarse Quaternary gravel. All burial pits were 2–5 m in depth.

Table 1. Information on pig burial sites and groundwater monitoring wells.

Burial Site	Carcass Number	Impermeable Liner	Monitoring Well	Distance of Well from Burial Site (m)
Linlo	14,000	some	A [1]	250
			B [1]	200
			C [2]	250
			D [2]	400
			E [3]	2000
Chawchou	10,000	with	F [1]	100
			G [2]	10
Sinbei	110,000	with	H [1]	100
			I [2]	500
Pousan	1000	without	J [1]	7
			K [2]	20
			L [3]	2000

[1] At a location upstream of buried site in groundwater flow; [2] At a location downstream of buried site in groundwater flow; [3] At a location with a different catchment from buried site in regards to groundwater flow.

In addition to the potential introduction and subsequent survival of pathogenic bacteria in soil and water as a result of carcass burial, burial may lead to the proliferation of pathogens and the subsequent pollution of groundwater and drinking water. Many factors affect the transport of pathogens from soil to groundwater, including soil type, permeability, water table depth, and rainfall. However, adsorption, filtration, and predation by natural microbial populations significantly reduce the amount of pathogens transported to the underlying groundwater [17]. The microbial and chemical characteristics of groundwater in the monitoring wells are shown in Table 2. The average total coliform in Well K was much higher than that in Wells J and L at the Pousan site. However, no significant difference was observed in total coliform in wells at the other sites. The average fecal coliform at the Chawchou, Sinbei, and Pousan sites increased from upstream to downstream, indicating the negative effect of pig carcasses on groundwater quality. However, the FMD virus was not detectable in any samples throughout the period, because the virus could be inactivated by the heat and acidity of the organic acid-generating processes under the anaerobic conditions in the buried pits. In addition, it was difficult to evaluate the effect of the burial of pig carcasses on COD in groundwater because of the substantial variation in the data of the upstream and downstream wells. The nonpurgeable organic carbon (NPOC), total oil, and total dissolved solid (TDS) levels were clearly higher in the downstream wells than those in the upstream and control wells at all sites. The time sequence profiles of COD and TDS in Well K at the Pousan site indicated that these levels changed seasonally as follows: a slight increase in December 1997, rapid increase in January–March, gradual decline in April 1998, and rapid increase again in May 1998 (Figure 5).

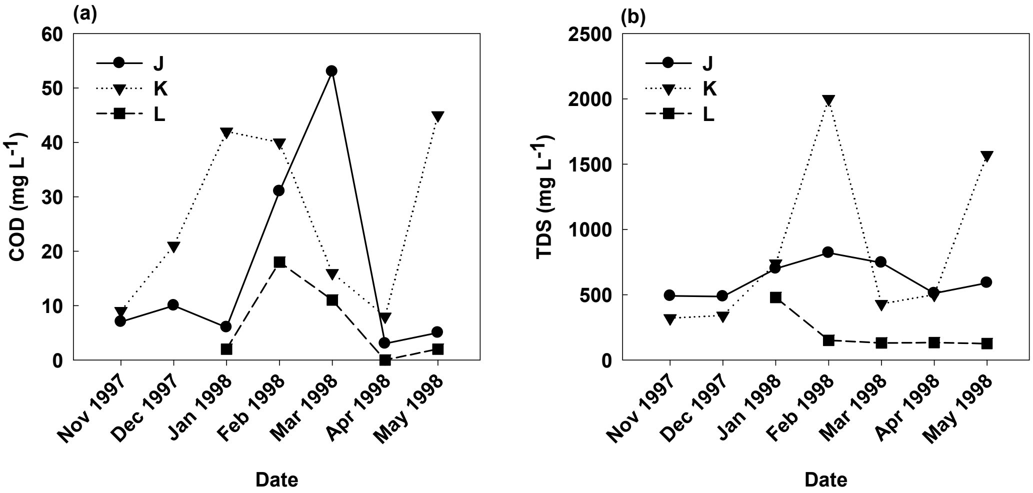

Figure 5. Groundwater quality: chemical oxygen demand (**a**); and total dissolved solid (**b**) at the Pousan site.

Table 2. Microbial and chemical characteristics of groundwater in the monitoring wells. Data are presented as mean ± standard deviation.

Burial Site	Well	TC [1]	FC [2]	COD [3]	NPOC [4]	Total Oil	TDS [5]
Linlo	A	1.5×10^2 ±180	2.9×10^2 ±540	2.8 ±4.0	1.434 ±0.764	1.7 ±1.4	360 ±85
	B	2.1×10^3 ±2300	2.4×10^4 ±61,000	61.4 ±117.3	2.552 ±2.046	3.5 ±2.2	507 ±72
	C	1.8×10^1 ±28	5.0×10^0 ±10	15.7 ±33.9	1.411 ±1.045	4.0 ±5.9	296 ±112
	D	2.5×10^3 ±6100	4.7×10^3 ±13,000	5.7 ±5.9	1.265 ±1.356	3.7 ±3.1	444 ±152
	E	8.0×10^3 ±14,000	2.7×10^3 ±4400	5.3 ±3.1	1.101 ±0.648	1.6 ±1.0	410 ±109
Chawchou	F	1.3×10^3 ±1100	1.5×10^4 ±36,000	7.3 ±8.5	1.316 ±1.246	1.9 ±1.3	619 ±146
	G	1.9×10^2 ±250	2.1×10^4 ±50,000	4.2 ±4.5	0.895 ±0.512	1.9 ±1.3	546 ±211
Sinbei	H	1.2×10^3 ±2500	1.4×10^3 ±2400	1.7 ±2.1	1.010 ±0.829	2.7 ±3.8	159 ±52
	I	4.4×10^2 ±520	2.8×10^3 ±5800	1.7 ±2.8	0.640 ±0.417	1.4 ±1.1	319 ±186
Pousan	J	7.9×10^3 ±7400	3.6×10^2 ±470	16.1 ±18.7	1.873 ±1.016	3.3 ±3.0	633 ±176
	K	2.7×10^4 ±20,000	7.8×10^2 ±810	26.0 ±16.4	4.092 ±2.454	7.8 ±4.3	823 ±727
	L	2.0×10^3 ±4100	1.3×10^2 ±180	6.6 ±7.8	1.143 ±0.859	1.8 ±0.4	204 ±120

[1] Total coliforms (CFU 100 mL^{-1}); [2] Faecal coliforms (Most Probable Number 100 mL^{-1}); [3] Chemical oxygen demand ($mg \cdot L^{-1}$); [4] Non-purgeable organic carbon ($mg \cdot L^{-1}$); [5] Total dissolved solid ($mg \cdot L^{-1}$).

The chemical composition of groundwater in the monitoring wells at the four sites is shown in Table 3. Elevated levels of BOD, NH_4-N, TDS, and Cl were commonly found within or very close to the burial pits of livestock carcasses. Although the chloride concentrations are generally lower than those of other contaminants, elevated chloride levels are the optimal indicator of burial-related groundwater contamination [4,18]. Moreover, chloride is a conservative ion that does not undergo significant oxidation/reduction reactions, adsorption on to mineral grains, or complexation [19]. At the investigated sites, a peak concentration of chloride was observed in January and February 1998, but the chloride concentration declined after March 1998 (Figure 6). The chloride concentration was significantly higher in the downstream wells, except for the wells at the Linlo site. The nitrogen concentration, particularly ammonium-nitrogen, was higher in the downstream wells than in the upstream wells (Table 3). The sulfate concentration also increased from the upstream wells to the downstream wells at all sites. At the Pousan site, the average concentrations of Cu, HS, and Fe were not only higher in Well K than in Wells J and L, but also peaked in January and February 1998 (Figure 6).

Table 3. Chemical composition ($mg \cdot L^{-1}$) of groundwater in the monitoring wells. Data are presented as mean ± standard deviation.

Burial Site	Well	NO_3^-N	NO_2^-N	NH_4-N	SO_4^{2-}	Cl^-	Cu	HS^-	Fe
Linlo	A	1.21 ±1.06	0.035 ±0.030	ND [1]	91.7 ±2.9	12.1 ±1.2	ND [1]	0.034 ±0.010	ND
	B	6.57 ±17.55	0.081 ±0.102	0.546 ±0.465	112.9 ±50.8	21.9 ±10.6	0.21 ±0.24	0.104 ±0.061	2.75 ±1.62
	C	4.13 ±0.26	0.024 ±0.029	ND	67.3 ±12.6	9.1 ±0.3	ND	0.034 ±0.010	ND
	D	5.67 ±0.58	0.035 ±0.028	0.004 ±0.133	80.8 ±27.1	10.5 ±1.0	0 ±0.1	0.051 ±0.028	ND
	E	7.09 ±0.78	0.035 ±0.032	0.031 ±0.081	89.8 ±32.9	8.8 ±3.2	ND	0.078 ±0.049	0.06 ±0.15
Chawchou	F	5.65 ±2.92	0.026 ±0.035	ND	54.0 ±24.0	8.7 ±0.9	ND	0.048 ±0.025	ND
	G	6.95 ±6.90	0.023 ±0.024	0.024 ±0.044	184.2 ±85.9	23.7 ±3.1	ND	0.041 ±0.019	ND
Sinbei	H	2.35 ±3.26	0.023 ±0.025	ND	33.5 ±22.8	6.2 ±3.2	ND	0.052 ±0.019	0.03 ±0.09
	I	9.96 ±2.73	0.823 ±2.254	0.356 ±0.941	43.9 ±17.3	10.9 ±2.1	ND	0.037 ±0.029	0.02 ±0.07
Pousan	J	0.09 ±0.14	0.078 ±0.046	0.312 ±0.115	71.2 ±26.2	27.1 ±4.7	0.53 ±0.46	0.200 ±0.092	1.01 ±0.45
	K	1.2 ±1.99	0.095 ±0.107	0.510 ±0.431	28.3 ±22.2	26.4 ±22.1	0.83 ±1.36	0.295 ±0.394	0.91 ±1.19
	L	0.09 ±0.17	0.010 ±0.021	0.078 ±0.047	21.3 ±44.6	13.6 ±7.0	0.02 ±0.04	0.033 ±0.006	0.15 ±0.33

[1] Not detectable.

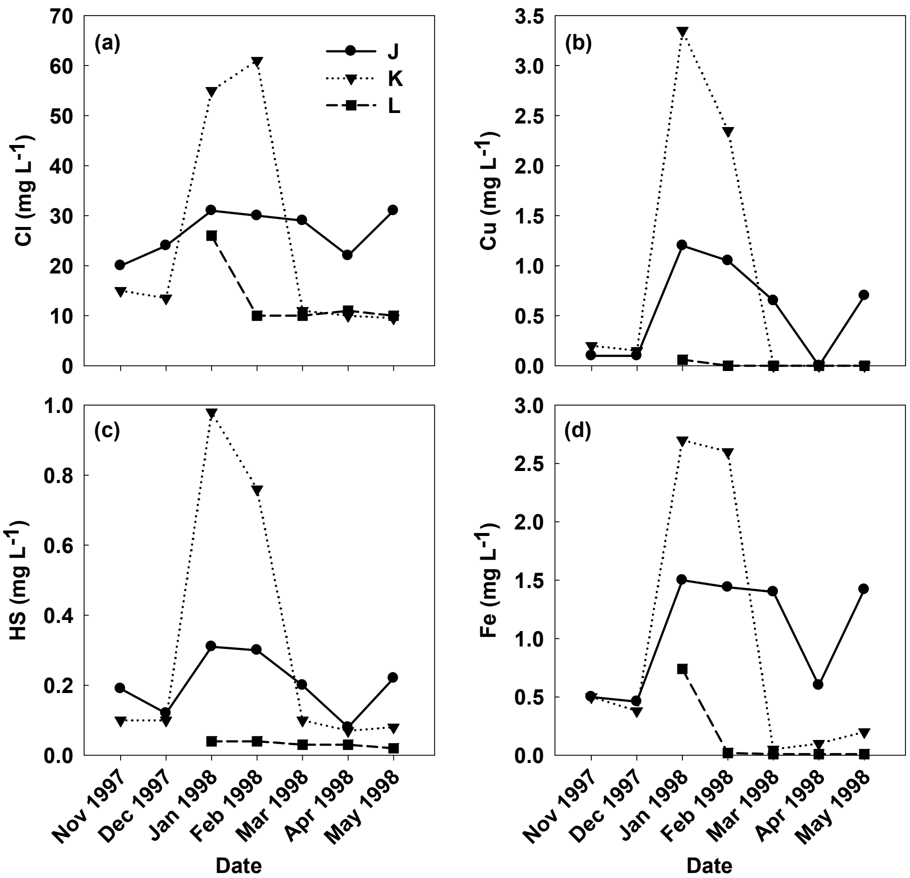

Figure 6. Indicators of groundwater quality: Cl (**a**); Cu (**b**); HS (**c**); and Fe (**d**) at the Pousan site.

Several indicators of groundwater quality were selected and found to be associated with contaminants released from the pig burial sites. These indicators included total bacterial count, fecal coliform, *Salmonella* spp., nitrite-N, nitrate-N, ammonium-N, sulfate, NPOC, total oil, and TDS. The soil particles were much finer at the Linlo, Chawchou, and Sinbei burial sites in Pingtung than at the Pousan site in Hsinchu. Thus, the groundwater quality shown in Tables 2 and 3 indicates that the Pousan site was heavily contaminated compared with the other sites. In addition to soil texture, burial without an impermeable cloth and the relatively short distance of the burial site from the monitoring well may contribute to the contamination of groundwater at the Pousan site. The total bacterial count, fecal coliform, ammonium-N, iron, and copper (100 cfu·mL^{-1}, 100 cfu·mL^{-1}, 0.1 mg·L^{-1}, 0.3 mg·L^{-1}, and 1.0 mg·L^{-1}, respectively) in some of the monitoring wells exceeded the limits of drinking water standards of Taiwan. Therefore, the groundwater at these sites is not recommended for drinking. Appropriate disinfection and boiling of the water is required before drinking.

4. Future Directions

Policy makers should ensure that animal carcasses are buried at sites with low surrounding populations, away from water preservation areas, and with constant monitoring of ground water quality to ensure the safety of drinking water. The water table, land topography, and soil type of the available land determine if burial is a valid option. The optimal soil type for burial pits is heavy clay soils, because there is less contamination potential of groundwater. Burial pits should be located on flat land to avoid water erosion of the burial site and potential contaminated runoff. Burial is not recommended if the water table is seasonally high at any time of the year; this was the reason for the higher concentrations of groundwater indicators at the burial sites in Pingtung, Taiwan (Tables 2 and 3). This study confirmed that the microbial and chemical contamination of groundwater around mass pig carcass burial sites can occur and last for a significant duration depending on the environmental conditions. Various contaminants may originate from decaying pig carcasses and endogenous subsurface microorganisms [5]. In Korea and Great Britain, the contaminants resulting from the mass burial of pig carcasses were still detectable in groundwater two years after burial [5,12]. Because of their introduction into groundwater, contaminant breakdown can be extended and is expected to last less than one year at the burial sites in Taiwan. Therefore, the possibility of groundwater contamination should not be overlooked in Taiwan because of the very high level of human activities on land, even though the pig decomposition rate is higher than that in Korea and Great Britain. However, novel methods of livestock disposal, such as bioreduction and fermentation, should first be screened for environmental safety and biosecurity [6]. Additional studies should develop and utilize these novel disposal methods on a large scale, particularly if they are to gain legislative acceptance for mass livestock mortality in Taiwan.

5. Conclusions

Although burial is widely used to dispose of the large number of pig carcasses generated from FMD outbreaks, this disposal method has not undergone comprehensive scientific investigation. After the burial of culled pigs, dissolved components from carcass decomposition are slowly released into the external environment in the form of leachate, depending on the local environmental conditions. Nevertheless, the properties of groundwater, including total bacterial count, fecal coliform, *Salmonella* spp., nitrite-N, nitrate-N, ammonium-N, sulfate, NPOC, total oil, and TDS, are recognized as indicators of groundwater contamination resulting from the pig carcass burial during the FMD outbreak in Taiwan. Because very few studies have been performed, there is not enough information on the characteristics of groundwater at the burial sites, duration of pig carcass decomposition, and effects of leachate on groundwater quality worldwide. Although information on the biological and chemical characteristics of leachate is gradually being accumulated from the limited number of studies, guidelines for groundwater quality control should be established for livestock carcass disposal in all modern countries.

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Conflicts of Interest: The authors declare no conflict of interest.

References

1. United State Department of Agriculture (USDA). *Foreign Animal Disease Report. Animal and Plant Health Inspection Service*; United State Department of Agriculture (USAD): Riverdale, MD, USA, 1998.
2. Keeling, M.J.; Woolhouse, M.E.J.; Shaw, D.J.; Matthews, L.; Chase-Topping, M.; Haydon, D.T.; Cornell, S.J.; Kappey, J.; Wilesmith, J.; Grenfell, B.T. Dynamics of the 2001 UK foot and mouth epidemic: Stochastic dispersal in a heterogeneous landscape. *Science* **2001**, *294*, 813–817. [CrossRef] [PubMed]
3. Thompson, D.; Muriel, P.; Russell, D.; Osborne, P.; Bromley, A.; Rowland, M.; Creigh-Tyte, S.; Brown, C. Economic costs of the foot and mouth disease outbreak in the United Kingdom in 2001. *Rev. Sci. Tech.* **2002**, *21*, 675–687. [CrossRef] [PubMed]
4. Freedman, R.; Fleming, R. *Water Quality Impacts of Burying Livestock Mortalities*; Report Presented to the Livestock Mortality Recycling Project Steering Committee; Ridgetown College: Ridgetown, ON, Canada, 2003.
5. Kim, H.S.; Kim, K.J. Microbial and chemical contamination of groundwater around livestock mortality burial sites in Korea—A review. *Geosci. J.* **2012**, *16*, 479–489. [CrossRef]

6. Gwyther, C.L.; Williams, A.P.; Golyshin, P.N.; Edwards-Jones, G.; Jones, D.L. The environmental and biosecurity characteristics of livestock carcass disposal methods: A review. *Waste Manag.* **2011**, *31*, 767–778. [CrossRef] [PubMed]
7. U.S. Environmental Protection Agency (U.S. EPA). *Disposal of Domestic Birds Infected by Avian Influenza—An Overview* of Considerations and Options; EPA530-R-06-009; U.S. Environmental Protection Agency: Washington, DC, USA, 2006.
8. Chen, S.J.; Hsieh, L.T.; Chiu, S.C. Emission of polycyclic aromatic hydrocarbons from animal carcass incinerators. *Sci. Total Environ.* **2003**, *313*, 61–76. [CrossRef]
9. Chen, S.J.; Hung, M.C.; Huang, K.L.; Hwang, W.I. Emission of heavy metals from animal carcass incinerators in Taiwan. *Chemosphere* **2004**, *55*, 1197–1205. [CrossRef] [PubMed]
10. Fonstad, T.A.; Meier, D.E.; Ingram, L.J.; Leonard, J. Evaluation and demonstration of composting as an option for dead animal management in Saskatchewan. *Can. Biosyst. Eng.* **2003**, *45*, 619–625.
11. Ritter, W.F.; Chirnside, A.E.M. Impact of dead bird disposal pits on ground-water quality on the Delmarva Peninsula. *Bioresour. Technol.* **1995**, *53*, 105–111. [CrossRef]
12. Yuan, Q.; Snow, D.D.; Bartelt-Hunt, S.L. Potential water quality impacts originating from land burial of cattle carcasses. *Sci. Total Environ.* **2013**, *456–457*, 246–253. [CrossRef] [PubMed]
13. MacArthur, A.J.; Milne, J.C. Leachate characteristics and management requirements arising from the foot & mouth operations in Scotland. In Proceedings of the Waste 2002, Integrated Waste Management and Pollution Control: Research, Policy, and Practice, Stratford upon Avon, UK, 24–26 September 2002; pp. 305–314.
14. Pratt, D.L.; Fonstad, T.A. Livestock mortalities burial leachate chemistry after two years of decomposition. In Proceedings of the 3rd International Symposium on Management of Animal Carcasses, Tissue, and Related by-Products, Davis, CA, USA, 21–23 July 2009.
15. Anderson, I. *Foot and Mouth Disease 2001: Lessons to Be Learned Inquiry*; The Stationary Office Limited: London, UK, 2002.
16. Lim, H.H.; Shin, H.S.; Jeon, T.W.; Shin, S.K.; Jeung, Y.W. Arachidonic acid and fatty acid profiles as indicators of contamination from the leachates of animal carcasses. *Water Sci. Technol.* **2016**. [CrossRef]
17. Beal, C.D.; Gardner, E.A.; Menzies, N.W. Process, performance, and pollution potential: A review of septic tank-soil absorption systems. *Aust. J. Soil Res.* **2005**, *43*, 781–802. [CrossRef]
18. Glanville, T.D.; Ahn, H.K.; Richard, T.L.; Shiers, L.E.; Harmon, J.D. Soil contamination caused by emergency bio-reduction of catastrophic livestock mortalities. *Water Air Soil Pollut.* **2009**, *198*, 285–295. [CrossRef]
19. Engel, B.A.; Lim, K.J.; Choi, J.Y.; Theller, L. Chapter 14: Evaluating Environmental Impacts. In *Carcass Disposal: A Comprehensive Review*; National Agricultural Biosecurity Center, Kansas State University: Manhattan, KS, USA, 2004.