# Nitrogen and Phosphorus Contamination of Groundwater in Some Agricultural Area of Taiwan

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## Abstract

To understand the current status of nitrogen and phosphorus contamination of groundwater resulting from fertilization on farmland, the history data from monitoring network by Water Resources Agency (WRA) and Environmental Protection Administration (EPA) have been analyzed and with groundwater quality on some agricultural regions sampled and measured. The results reveal quiet high percentages of monitoring wells set by WRA and EPA with $NH_4^+$-N contents in groundwater exceeding drinking water quality standard (0.1 mg/l), even higher than the limit of the second type groundwater pollution monitoring standard (0.25 mg/l). Based on the investigation of agricultural regions, the $NH_4^+$-N contamination from agricultural area seems similar as that from different land uses monitored by WRA or EPA. There are less 10 % of monitoring wells by WRA or EPA or sampled from agricultural regions of which $NO_3$-N contents are higher than the limit of drinking water and exceeding the limit of drinking water quality standard (10 mg/l). However, no data higher than the limit of the second type groundwater pollution monitoring standard (25 mg/l) are observed. There is no significant correlation between the N content in groundwater and soil profile texture. However, the N contamination has been getting gradually higher on some agricultural region located in head recharge area of Choshui alluvial fan with few mud layers in the geological profile, even the soil texture is clay. One of the reasons might be attributed to heavy rate of fertilization by local farmers and need to be further confirmed in the future. The results also indicate almost the total P is much lower than limit of the groundwater quality standards (0.15 mg/l) stipulated by the Netherland.


**Keywords:** Nitrogen, Phosphorus, Groundwater, Agriculture


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## Introduction

The contamination of the groundwater resulting from agriculture fertilization is getting more concerned than that from industry, recently. According to an investigation, the nitrogen efficiency is lower than 50 % in paddy field, much less in upland than in paddy field and only 11 % in vegetable land in Taiwan (Lian *et al*., 1996; Lian and Wang, 1997). The improper fertilizer use will result in the nutrient loss and emission to the environment. When nutrients input exceeding over the amount that can be uptake by crop, it might leach into and contaminate the groundwater rendering hazards to human health (Lal and Stewart, 1994). The nutrient loss via the runoff to surface water might cause eutrophication and through denitrification might emission to become the greenhouse gases (Forman *et al*., 1985；Addiscott *et al*., 1991; Janzen *et al*., 2003).

The nitrate concentration of groundwater under agricultural land was becoming higher and higher in some area of Taiwan according to reports of some studies. Furthermore, 75 % of tap water sources from groundwater in Taiwan, yet, 30 % of that have already been contaminated to different extent. The nitrogen contamination of groundwater is not only from the application of chemical fertilizer but organic fertilizer (Bruno and Ritchie, 2005).

There are two networks of quality monitoring for groundwater in Taiwan. One is the environmental water quality monitoring and information system build by the Environmental Protection Administration (EPA), Executive Yuan, the other is groundwater monitoring network build by the Water Resources Agency (WRA), the ministry of economic affairs. However, Due to the establishment of the monitoring networks with their specific purposes, the monitor data might not be easy apprehensive for the contamination status of groundwater from agriculture.

To access the present status of groundwater quality influenced by fertilization at agricultural region, not only the history data of networks mentioned above have been reviewed, but also conducted the investigation for the groundwater in some agricultural region in this study.

## Material and Methods

The sampling and monitoring of two reviewed networks and the investigation of groundwater at some agricultural regions were described as the followings:

**(1) Groundwater monitoring network by WRA**

The preliminary monitoring groundwater started from 1958 by the water resources agency (WRA). However, the whole monitoring network was established until 1995. The wells were installed with depth 25-300 m to monitor the lower aquifer. Groundwater samples were regularly collected and analyzed. The frequency of the monitoring is once half a year. Some monitoring has been conducted for the understanding for the hydrology of geology, and monitoring for groundwater resource and quality for important groundwater region then gradually conducted. Some stations were established specifically for the monitoring and study for the subsidence near seashore in southwestern Taiwan. The purpose of the network is to realize the environment of groundwater, including the geographical and hydrological characteristics, water level and quality, and establish the database to provide the related information based on the spatial and temporal change of groundwater amount and quality for decision making and strategy analysis. The data for analysis in this study were retrieved from network of WRA.

**(2) Network of groundwater quality monitoring by the EPA**

The long term monitoring for groundwater has started from 1995 by the EPA. Most of the wells were installed with depth 10-20 m to monitor the uppermost aquifer. Groundwater samples were regularly collected and analyzed. The frequency of the monitoring is once each season. The purpose of the network is to establish the long term database and maintain the national source of the groundwater and prevent the contamination from point pollution.

Since each monitoring network has their specific purposes, their sampling sites, depth, frequency, interval are different. The differences between the networks are as the Table 1. Items of water quality measured by both monitoring network are similar, including the $NH_4^+$-N, $NO_3$-N. As for maintaining convenience, the monitoring wells of both networks were installed at school or public organization, hence, monitoring sites might far from agricultural region. The data for analysis in this study were retrieved from network of EPA.

**(3) Investigation for the quality of groundwater at some agricultural region**

To realize the present status of groundwater quality under agricultural region, the main agricultural region in middle and south Taiwan are planed to be investigated. However, the project have not yet finished up to this day, only the whole Changhwa county and part of Yunlin and Pingtung county have been investigated from May to Oct. ,2008. The sampling period for Chunghwa area is from 04/03/2008 to 06/02/2008，for Yunlin area from 06/02/2008 to 06/11/2008, for Pingtong area from 09/09/2008 to 10/22/2008.

There are 5 to 30 groundwater samples per town at agricultural region. The groundwater was sampled randomly from farmers' wells for irrigation. The sampling sites were located by GPS. Most of the wells are shallow well about 20-30 m in depth. The sampled groundwater are kept in 4 $^{o}$C refrigerator from sampling site to lab and measured by the following methods regulated by EPA:

1. pH: Electrode Method (EPA, 2004)
2. EC: Electrical Conductivity Method (EPA, 2000).
3. $NH_4^+$-N: Indophenol Colorimetric Method (EPA, 2005)
4. $NO_3$-N: Cadmium Reduction Method (EPA, 2000).
5. Total P: ICP-AES Method (EPA, 2004)
6. $SO_4^{-2}$: Nephelometry Method (EPA, 2000)
7. $CL^-$: Mercuric Nitrate Method (EPA, 2002)

## Result and Discussion

To assess the quality status of groundwater, the data were compared to "drinking water quality standards" and "The second type groundwater pollution monitoring standards". The second type groundwater is defined as groundwater outside the water sources and quality protection area for drinking water. The $NH_4^+$-N limits for each standard are 0.25 ppm and 0.1 ppm, respectively. The $NO_3$-N limits for each standard are 10 ppm and 25 ppm, respectively. The $NH_4^+$-N standard of the second type groundwater falls between the standards of UK and US (Table 2). The $NO_3$-N standards of UK, US and the Netherland are about 10 mg/l. It is similar with the standard for drinking water. The $NO_3$-N standard of the second type groundwater is much higher than that of other countries. Most countries have no standard for phosphorous in groundwater except the Netherland. The limit for phosphorous in groundwater is stipulated 0.15 mg/l by the Netherland.

The limit of Nitrate-N content for drinking water in many countries, such as UK, US, Germany and WHO, is about 10 mg/l the same as that in Taiwan.

Based on results of the team of groundwater investigation on 61 wells in Chunghwa and Yunlin area in1956, the nitrate content in groundwater was 0.02-1.8 mg/l, the mean is was about 0.16 mg/l (Team of groundwater investigation, 1957). These data are the lost early data among the investigation. They could serve as background of the groundwater that have not yet contaminated.

**(1) Groundwater monitoring network by WRA**

The $NH_4^+$-N and $NO_3$-N contents in groundwater data are recorded in database of network in 2001. The phosphorous contents have not been measured until now. The number of total monitoring wells and percentage of wells with $NH_4^+$-N and $NO_3$-N content higher than limit of drinking water quality standards and the second type groundwater pollution monitoring standards are listed in the table 3 and Table 4, respectively.

The percentages of wells with $NH_4^+$-N content higher than limit of drinking water quality standards and the second type groundwater pollution monitoring standards are higher and higher from 2000 to 2007. The $NH_4^+$-N contamination becomes worse without prevention control, even the depths of well are quiet deep about 25-300 m. Unfortunately, the background situation has not yet founded to compare the current status.

As to the nitrate-N contents, < 1 % of total monitoring wells are higher than the limit of the drinking water quality standards (10 mg/l). The results reveal current status of $NO_3$-N contamination is not as serious as $NH_4^+$-N contamination; even though nitrate is easier to leaching than ammonium through soil profile.

**(2) Network of groundwater quality monitoring by the EPA**

The $NH_4^+$-N and $NO_3$-N contents in groundwater data are recorded in database of network in 2000. The phosphorous contents have not been measured until now. The number of total monitoring wells and percentage of wells with $NH_4^+$-N and $NO_3$-N content higher than limit of drinking water quality standards and the second type groundwater pollution monitoring standards are listed in the table 5 and Table 6, respectively.

The percentages of wells with $NH_4^+$-N content higher than limit of drinking water quality standards and the second type groundwater pollution monitoring standards are quite high from 2000 to 2007. It seems the contamination is very serious, especially in Taipei, Tainan, Kaohsiung, Pingtung and Changhwa counties. However, the percentages are become lower gradually and the contamination is well controlled gradually.

The Change of $NH_4$+-N contents in some monitoring with higher contents are as the fig.1. The highest one is found at Tongshan element school in Ilan. The high $NH_4^+$-N contents maintained between 50-70 mg/l from 2000 to 2007. As is located between the downtown and agricultural area, the $NH_4^+$-N contamination might be caused by both of communities and agriculture. The high $NH_4^+$-N content may be due to very shallow groundwater level about 1.8-2 m. Another two high contents are contaminated from communities in Taipei and Hsinchu city. The groundwater level of the monitoring well at Hsinchu city is 80-90 cm. The $NH_4^+$-N contamination is apparently from community. The $NH_4^+$-N contamination is reduced in Taipei city gradually, but not reduced in Hsinchu city. One of the monitoring well is located in agricultural area at Chiku town, Tainan County. The groundwater level is about 2 m. The $NH_4^+$-N contamination is suggested from agricultural practice and becomes higher and higher gradually.

As to the nitrate-N contents, about 1-2 % of total monitoring wells are higher than the limit of the second type groundwater pollution monitoring standards (25 mg/l). While 8 % of wells are higher than the limit of the drinking water quality standards (10 mg/l). As the results of monitoring by WRA, it reveals current status of $NO_3$-N contamination is not as serious as $NH_4^+$-N contamination; even though nitrate is easier to leaching than ammonium through soil profile.

**(3) Current status of groundwater quality at some agricultural region**

There are 440 groundwater samples already collected until now. The ranges of items measured for groundwater samples are listed in Table 7. The range is quite wide for the EC, $SO_4^{-2}$, $Cl^-$ content in groundwater.

There is no standard for the phosphorous content in the groundwater and drinking water in Taiwan and many countries. However, that of groundwater is stipulated as 0.15 mg/l in the Netherland. There are only 3 data sampled from coast area of Chunghwa County with P content higher than 0.15 mg/l. The highest P content around 6.3 mg/l is much higher than the limit of standard. Sustained efforts should be continually made to identify the source of the contamination and prevent the contamination in the future. Another higher P content about 0.48 and 0.18 mg/l are slightly higher than the limit of standard. The rest data are under the limit range. Based on the distribution of P in monitoring, apparently, the P contaminations only appear at few sites in agricultural land.

About 52 % of $NH_4^+$-N contents of groundwater samples exceeded the limit (0.25 mg/l) of the second type groundwater pollution monitoring standards. About 70 % of those exceeded the criteria of the drinking water quality standard (0.1 ppm) based on the analysis on the total of sampled data (Table 8). The $NH_4^+$-N contamination from agricultural area seems similar as that from different land uses monitored by WRA or EPA. While compared to that of groundwater quality monitoring network by EPA in 2007, the $NH_4^+$-N contamination from agricultural area seems more serious than the data from other different land uses.

The $NH_4^+$-N contaminations in Changhua and Yunlin counties are more serious than that in Pingtung area (Fig. 2,4,6). The highest value in Chunghwa County is 7.5 mg/l, approximately 30 times the limit. All of the samples collected from Shengang, Siansi, Yuanlin, Dacun and Pusin Township are higher than 0.25 mg/l. The highest value in Chunghwa County is 8.3 mg/l, approximately 34 times the limit.

The $NO_3$-N concentrations of all samples are lower than the criteria of the second type groundwater pollution monitoring standards (25 ppm). However, there are about 8 % of samples exceeding the limit of drinking water quality standards (10 ppm) (Table 7). Compared to that of groundwater quality monitoring network by EPA in 2007, the $NO_3$-N contamination from agricultural area seems similar with the data from other different land uses.

There are 278 samples collected in Changhua area and some groundwater has been collected at Mingchien town by another project in 2002 (Fig. 3). Some of the investigated wells with $NO_3$-N contents are higher than the limit of drinking water quality standards (10 mg/l). For examples, two samples from Fangwan Township are are 19.59 and 20.74 mg/l, respectively. Besides, the samples from Tienchung, Chichou, Changhwa and Mingchien, Nantou that located in head recharge area of Choshui alluvial fan. There are few mud layers in the geological profile, so the nitrate leaching is abundant (Chen, *et al*., 2003). The N contamination has become higher and higher gradually in that region.

There are 41 samples collected in Yunlin area (Fig. 5). The nitrate-N contents of two samples are higher than the limit of drinking water quality standards (10 mg/l) at Tzutung and Kukeng Townships, respectively. The area with higher $NO_3$-N contents seems also located the head recharge area of alluvial fan.

Among all of the samples, the area with higher $NO_3$-N contents is located in Pingtung county (Fig. 7), and about 21 % of wells of total 121wells sampled with $NO_3$-N are higher than the limit of drinking water quality standard. (Fig. 9). The higher $NO_3$-N contents are distributed at Kaoshu, Yenpu and Chungtzu townships especially. The $NO_3$-N leaching situation are very obvious at Changtzu Township, The nitrate-N concentrations of 12 samples of total 21 samples are higher than the quality of drinking water standards (10 mg/l).

Due to texture of the heavy soil with higher water holding capacity than light soil, the nitrogen leaching can be expected to be more serious in sandy soil than in heavy soil (Lian *et al*., 1996). Based on the study in lysimeter, The nitrogen leaching to one meter below soil were < 1 % of applied rate during the growth stage in medium and fine texture soil. While the nitrogen leaching might be reach 20 % of applied rate if growth of vegetable was not well in sandy soil. (Chen *et al*., 2006).

For better understanding the correlation between the nitrogen leaching and soil texture, 5 classes for soil profile texture of soil management group in soil database established by the agricultural research institute are used on this study. The five classes are defined as the followings: 1. fine texture, 2. medium and fine texture, 3. medium and coarse texture, 4. coarse texture. 5. shallow soil layer. However, the correlation is not significant between the nitrogen content $NH_4^+$-N or $NO_3$-N content in groundwater and classes of soil profile texture in this investigation (Fig. 8,9). However, the results reveal that the potential of the $NO_3$-N leaching will increase in sandy soil or shallow soil layer field. Besides, one of the reasons might well be attributed to the heavy rate of fertilizer used by local farmers.

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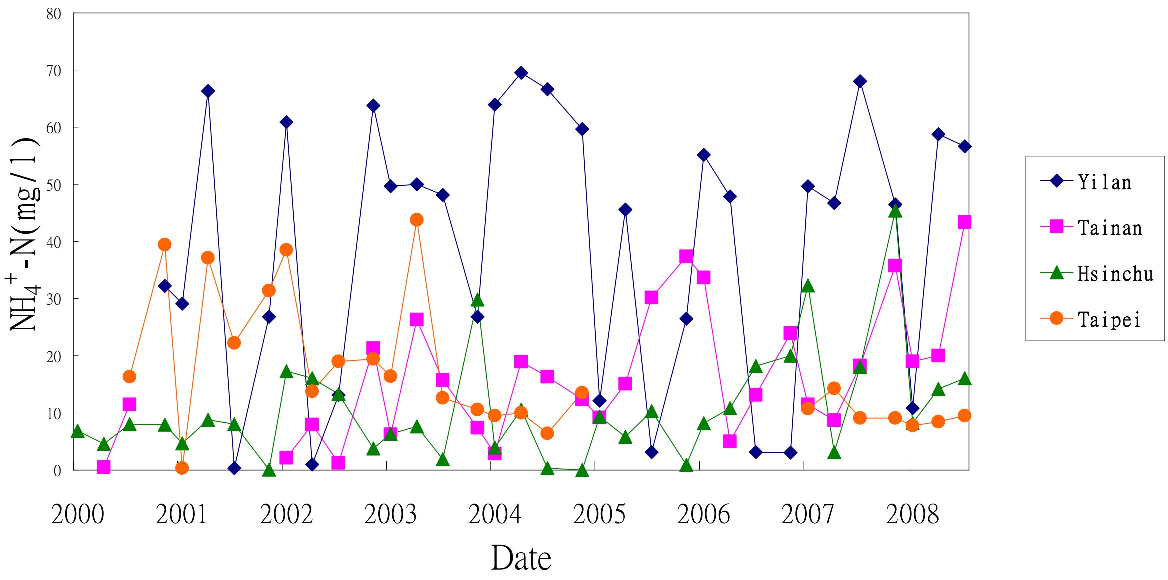


**Fig. 1.** Higher $NH_4^+$-N contents in groundwater monitored from some sites by EPA.

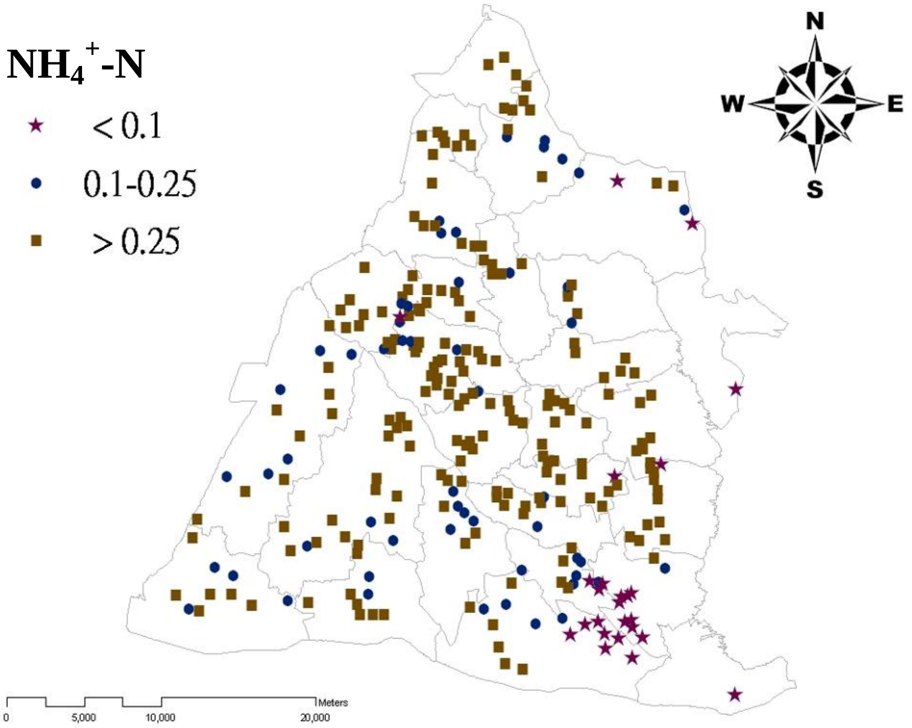


**Fig. 2.** $NH_4^+$-N Contents in groundwater monitored in Changhua area.

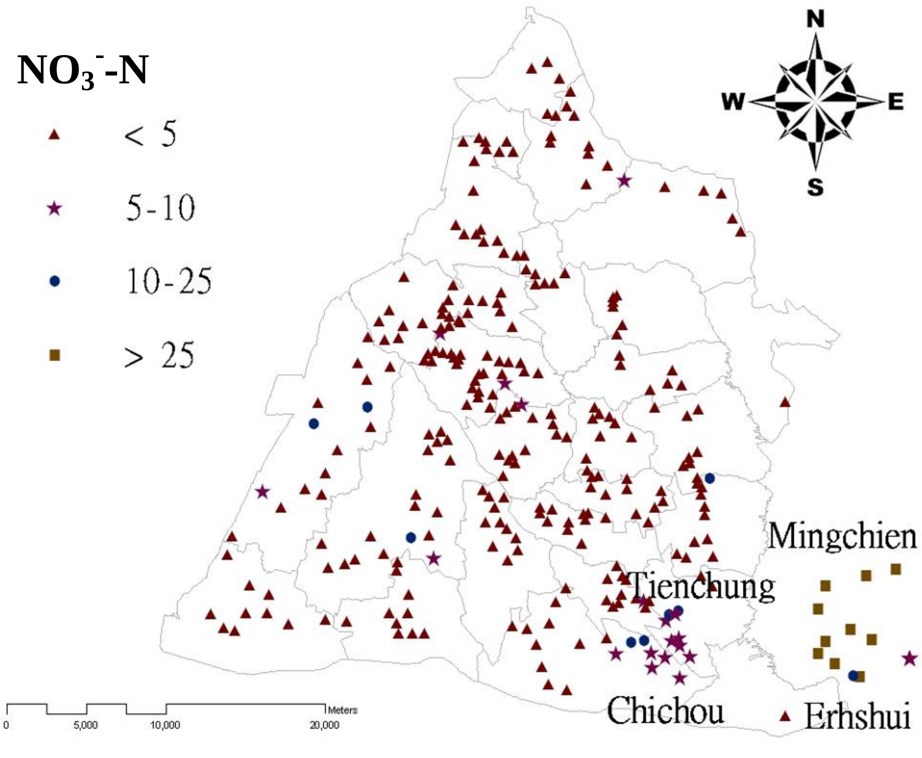


**Fig. 3.** $NO_3^-$-N Contents in groundwater monitored in Changhua and Nantou areas.

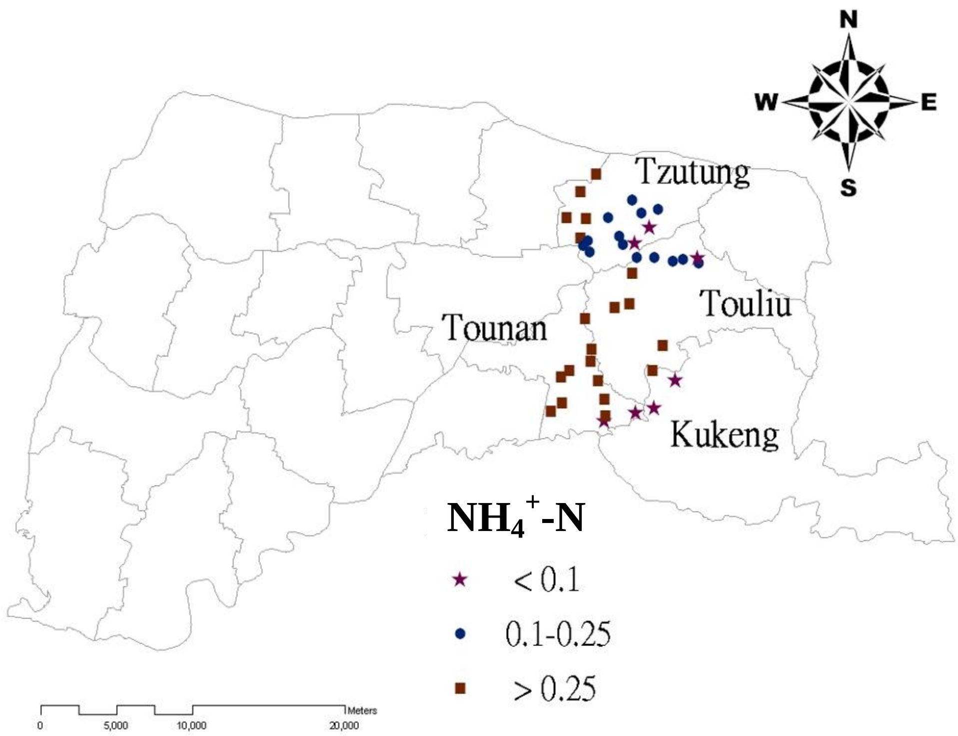


**Fig. 4.** $NH_4^+$-N Contents in groundwater monitored in Yunlin area.

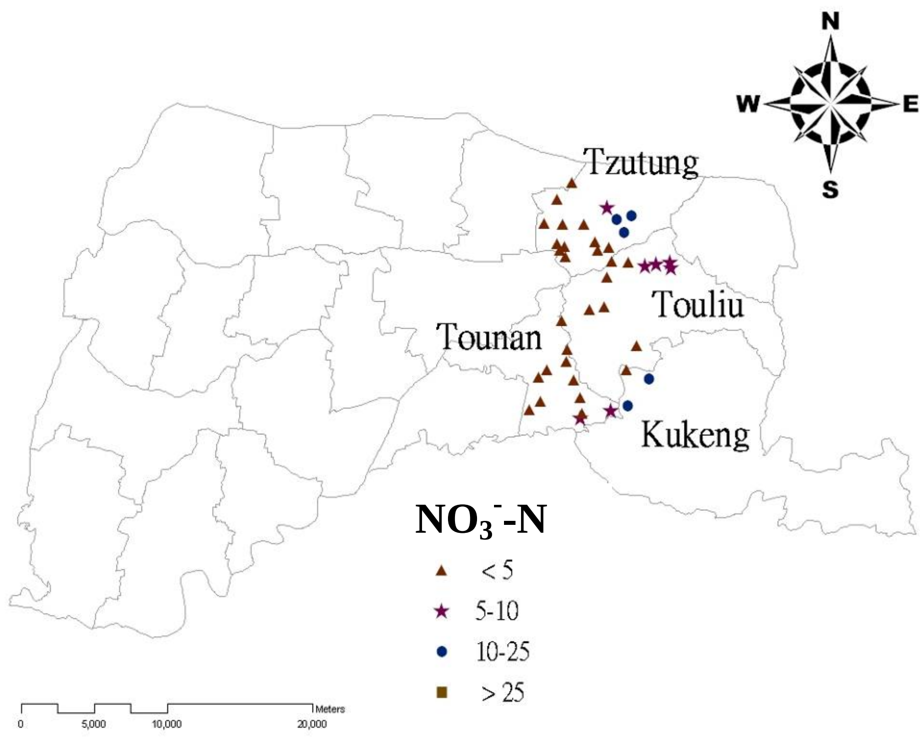


**Fig. 5.** $NO_3^-$-N Contents in groundwater monitored in Yunlin area.

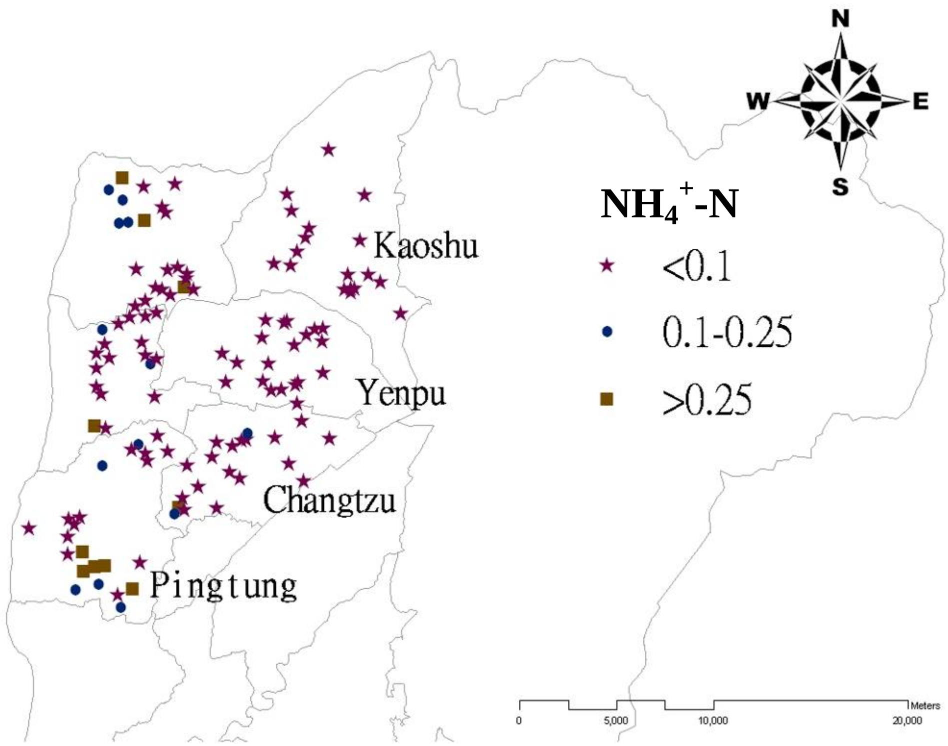


**Fig.6.** $NH_4^+$-N Contents in groundwater monitored in Pingtung area.

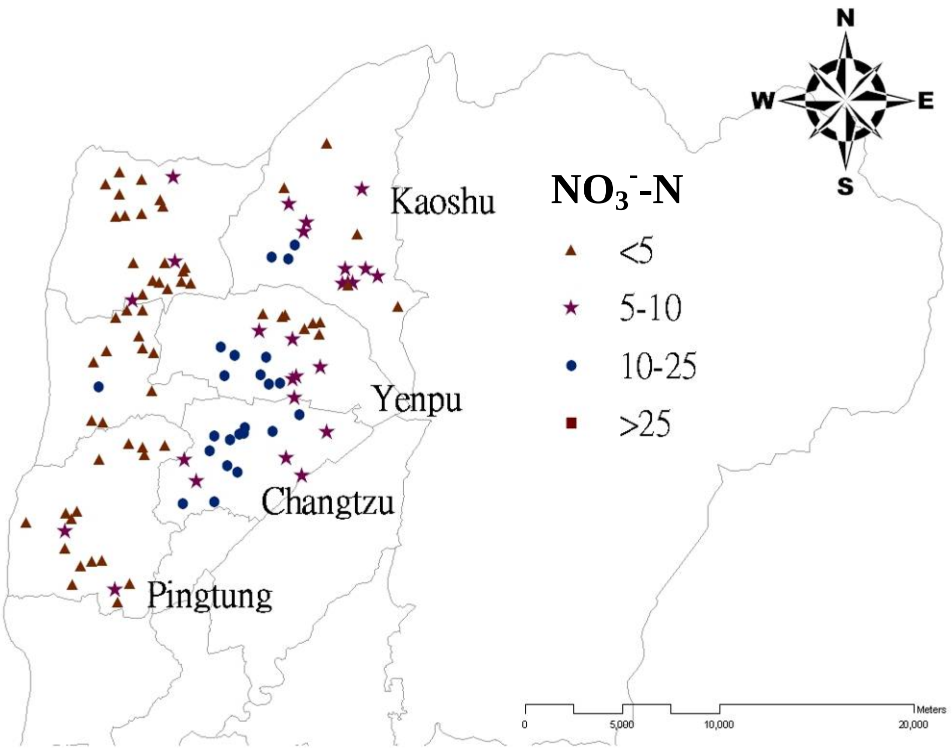


**Fig. 7.** $NO_3^-$-N Contents in groundwater monitored in Pingtung area.

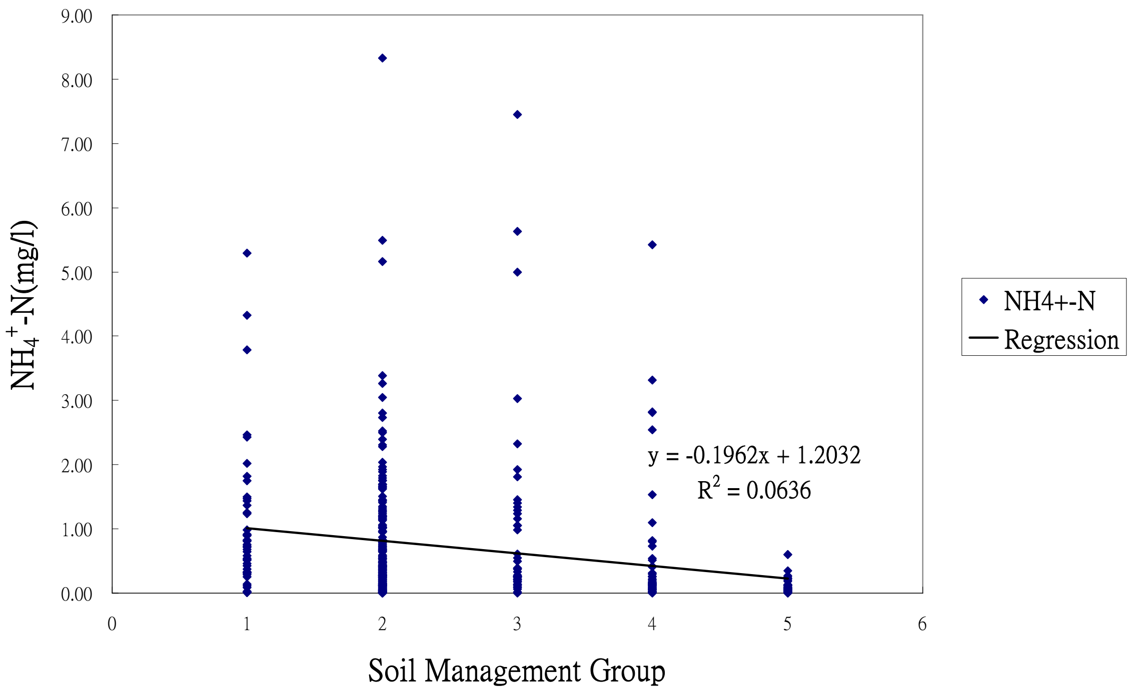


**Fig. 8.** Relationship between $NH_4^+$-N contents in groundwater and Soil texture of the total sampled data from some agricultural area.

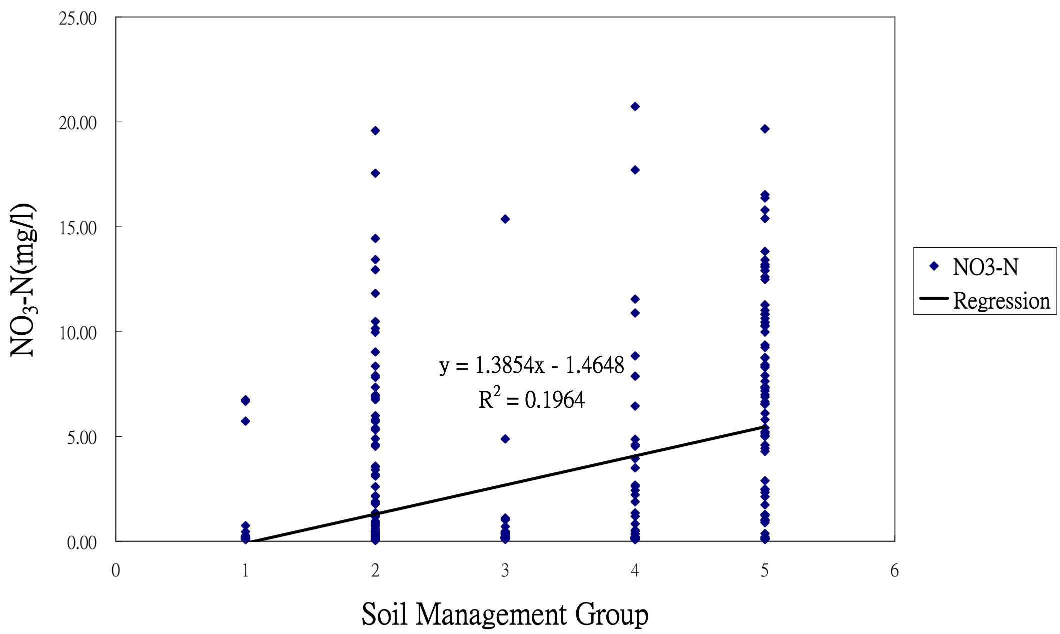


**Fig. 9.** Relationship between $NO_3^-$-N contents in groundwater and Soil texture of the total sampled data from some agricultural area.

**Table 1.** Comparison between two networks for monitoring groundwater

| Organization | WRA | EPA |
|---|---|---|
| Initial year | 1958 | 1995 |
| Purpose | 1. Realize the the hydrology of geology<br>2. Monitor the water resource and quality<br>3. Monitor the subsidence | 1. Monitor the water quality<br>2. Prevent the contamination |
| No. of monitoring | 244 (575) | 394 |
| Depth of well | 25 - 400 m | 10 - 20 m |
| Sampling frequency | Once half a year | Once each season |
| Item | 28, including $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N | 23, including $NH_4^+$-N, $NO_2^-$-N, $NO_3^-$-N |
| Monitoring region | groundwater resource region | 1. groundwater resource region<br>2. Subsidence area |
| Site of monitoring | School or public organization | School or public organization |

**Table 2.** Groundwater quality standards of various countries

| Country | Groundwater Standards (mg/L) | | |
|---|---|---|---|
| | Ammonia-N | Nitrate-N | P |
| N.J.A.C., UK[1] | 0.5 | 10 | |
| Utah, US | 0.5 | 10 | |
| Virginia, US | 0.025 | 5 | |
| North Carolina, US | | 10 | |
| Wisconsin, US | | 10 | |
| The Netherland | | 10 | 0.15 |
| Taiwan | Type I [2] Type II[2] | Type I TypII | |
| | 0.05 0.25 | 5 25 | |

1. Groundwater of special ecological significance by National Joint Advisory Council (N.J.A.C.), UK.
2. Type I: groundwater under water sources and quality protection area for drinking water, Type II: Others.

**Table 3.** Percentages of wells with $NH_4^+$-N contents in groundwater monitored by WRA higher than water quality limit.

| Year | No. of wells monitored | $NH_4^+$-N (mg/l) | No. of wells with $NH_4^+$-N > 0.1 mg/l (%) | No. of wells with $NH_4^+$-N > 0.25 mg/l (%) |
|---|---|---|---|---|
| 2001 | 368 | 0.06-16.60 | 66 (18) | 57 (15) |
| 2002 | 506 | 0.07-60 | 139 (27) | 131 (26) |
| 2003 | 547 | 0.01-39.9 | 273 (50) | 175 (32) |
| 2004 | 374 | 0.05-171 | 240 (64) | 225 (60) |
| 2007 | 450 | 0.03-259.2 | 357 (79) | 276 (61) |

* There are many missing data in 2005, 2006 in the database.

**Table 4.** Percentages of wells with $NO_3^-$-N contents in groundwater monitored by WRA higher than water quality limit.

| Year | No. of wells monitored | $NO_3^-$-N (mg/l) | No. of wells that $NO_3^-$-N > 10 mg/l (%) | No. of wells that $NO_3^-$-N > 25 mg/l (%) |
|---|---|---|---|---|
| 2001 | 368 | 0.05-17.8 | 3 (1) | 0 (0) |
| 2002 | 506 | 0.04-25.8 | 1 (0) | 1 (0) |
| 2003 | 547 | 0.02-48 | 34 (6) | 7 (1) |
| 2004 | 374 | 0.06-17.30 | 2 (1) | 0 (0) |
| 2007 | 450 | 0.03-3120 | 6 (1) | 3 (1) |

* There are many missing data in 2005, 2006 in the database.

**Table 5.** Percentages of wells with $NH_4^+$-N contents in groundwater monitored by EPA higher than water quality limit

| Year | No. of wells monitored | $NH_4^+$-N (mg/l) | No. of wells that $NH_4^+$-N > 0.1 mg/l (%) | No. of wells that $NH_4^+$-N > 0.25 mg/l (%) |
|---|---|---|---|---|
| 2000 | 281 | 0.01-39.4 | 251(90) | 193(69) |
| 2003 | 413 | 0.02-50 | 329(80) | 235(57) |
| 2006 | 395 | 0.02-55.2 | 236(60) | 165(42) |
| 2007 | 430 | 0.02-68 | 232(54) | 168(39) |

**Table 6.** Percentages of wells with $NO_3^-$-N contents in groundwater monitored by EPA higher than water quality limit.

| Year | No. of wells monitored | $NO_3^-$-N (mg/l) | No. of wells that $NO_3^-$-N > 10 mg/l (%) | No. of wells that $NO_3^-$-N > 25 mg/l (%) |
|---|---|---|---|---|
| 2000 | 281 | 0.01-166 | 10(4) | 2(1) |
| 2003 | 413 | 0.02-97.70 | 38(9) | 9(2) |
| 2006 | 395 | 0.01-65.40 | 36(9) | 3(1) |
| 2007 | 430 | 0.01-41.30 | 34(8) | 3(1) |

**Table 7.** The range of items measured for groundwater

| Item | Unit | Range |
|---|---|---|
| pH | | 6.2-8.0 |
| EC | µS/cm | 197-3070 |
| $SO_4^{2-}$ | µg/ml | 8-913 |
| Cl | µg/ml | 3-415 |
| $NH_4^+$-N | µg/ml | nd-8.3 |
| $NO_3$-N | µg/ml | 0.05-20.7 |
| P | µg/ml | nd-6.3 |

**Table 8.** Percentages of wells with $NH_4^+$-N contents in groundwater of agricultural area higher than water quality limit.

| Area | No. of wells monitored | No. of wells that $NH_4^+$-N > 0.1 mg/l (%) | No. of wells that $NH_4^+$-N > 0.25 mg/l (%) |
|---|---|---|---|
| Chunghwa | 278 | 253 (91) | 199 (72) |
| Yunlin | 41 | 34 (83) | 20 (49) |
| Pingtung | 121 | 23 (19) | 10 (8) |
| Total | 440 | 310 (70) | 229 (52) |

**Table 9.** Percentages of wells with $NO_3^-$-N content in groundwater of agricultural area higher than water quality limit.

| Area | No of wells monitored | No of wells that $NO_3^-$-N > 10 mg/l (%) | No of wells that $NO_3^-$-N > 25 mg/l (%) |
|---|---|---|---|
| Chunghwa | 278 | 8 (3) | 0 (0) |
| Yunlin | 41 | 5 (12) | 0 (0) |
| Pingtung | 121 | 25 (21) | 0 (0) |
| Total | 440 | 36 (8) | 0 (0) |