Geoenvironmental Assessment for Nitrate Pollution of Surface and Groundwater by Fertilization (A Study in Shiroishi Plain, Japan)

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Abstract— **In the view of the above this research paper is aimed at presenting the results and findings on the effects of all these developed agricultural practices, as well as over fertilization, on the surface water quality, shallow groundwater and deep groundwater table. Shiroishi Plain in Japan is selected for this ideal study. Sampling was continued for year- around subject to different climatic condition and tillage systems. Several samples of the drainage water at the outlet of the creeks in to the interceptor drains, deep groundwater (around 80 m deep) and interceptor drain waster samples were measured in monthly basis.**

This research found that nitrate-N concentration in samples collected in subsurface drainage shows the highest figures with compared with the others. It implies that the nitrate-N derived from the fertilizers applied to the agricultural beds are retained in the subsurface drainage water. The Ariake clay layer lies under the bed does not allow the nitrate-N to leached into the under ground due to its special physical, chemical and engineering characteristics. Therefore, underground water remains unpolluted and not vulnerable to even contamination by fertilizers and the degree of vulnerability gets higher because there is no leaching process of nutrients through the ariake clay layer. Therefore, it is proposed carry out more in-depth studies to investigate the sustainability of present agricultural practices and developed more environmentally unfriendly and economically unviable. When we consider the economic aspects of current practices, the removal of nutrients through subsurface drainage is considered to be great economical loss to farmers. It help to preserve the quality of water in interceptor drains so that farmers could be able to reuse this water in case of water shortage in the area. This would subsequently help reduce extraction of excessive ground water for agricultural use and thereby could be able to reduce the magnitude of land subsidence in the area by considerable extent.

Key words: groundwater pollution, contamination, fertilizer, nitrate

I. INTRODUCTION

Shiroishi Plain in Saga Prefecture is reclaimed from Ariake Sea. It is approximately around 100 km^2, consists of Ariake clay, and general elevation falls within the range of 0-5 m below the high tidal water level of Ariake Sea. Average rainfall is around 1690 mm. It is one of the most agricultural area in Japan and most densely paddy-cultivated area in Kyushu Island (See Figure 1).

The area had a river system and naturally occurring creeks for movement of surface runoff. These creeks help to store water from rivers and subsequently use for irrigation purposes. But the amount of water in these rivers and in creeks was not sufficient to irrigate all paddy land in the Shiroishi Plain. Therefore the area has been developed with a view to improve the infrastructure necessary for paddy cultivation and other crops being cultivated in rotation.

The area has shown the highest ratio of paddy cultivated area within the Saga Prefecture. Paddy is cultivated once a year and corn, wheat, barely, lotus, onion, leaks, cabbage, asparagus and strawberry are cultivated during the rest of the year. Many research had been carry out to find out the behavior of Ariake clay and lot of researches are going on.

In the view of the above, this research paper is aimed at presenting the results and findings on the effects of all these developed agricultural practices, as well as agricultural fertilization, on the surface water quality, shallow groundwater and deep groundwater table.

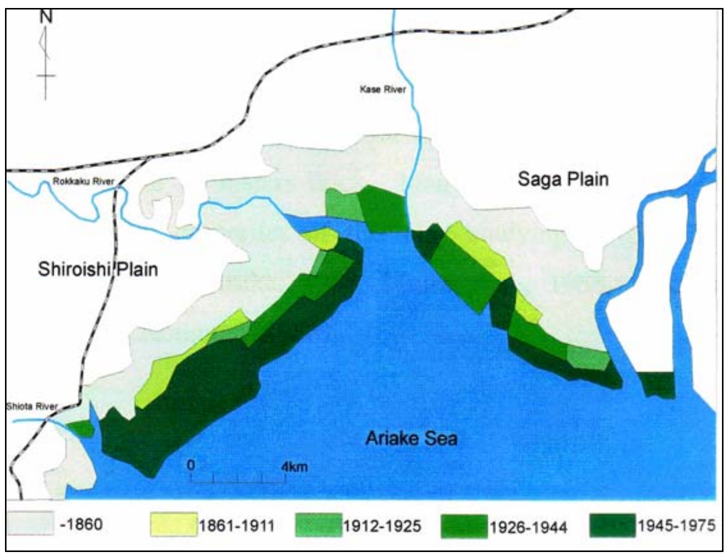

Fig. 1 Reclamation stages of the Shiroishi and Saga Plains

II. METHOD AND MATERIALS

Field studies were commenced in December 2000 and a total of 82 numbers of shallow wells were drilled within the upper most soft Ariake clay, at the selected locations. The base map with 1 square kilometer grid reference in Fukudomi, Shiroishi and Ariake areas were being used (Figure 2).

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Locations have been selected within the study area, considering that fact that there is no other possible nitrate source other than from nitrate fertilizers were influenced. Each of these wells was approximately 1.5 m in depth. Sampling was continued for year- around subject to different climatic condition and tillage systems. Several samples of the drainage water at the outlet of the creeks in to the interceptor drains, deep groundwater (around 80 m deep) and interceptor drain waster samples were measured in monthly basis.

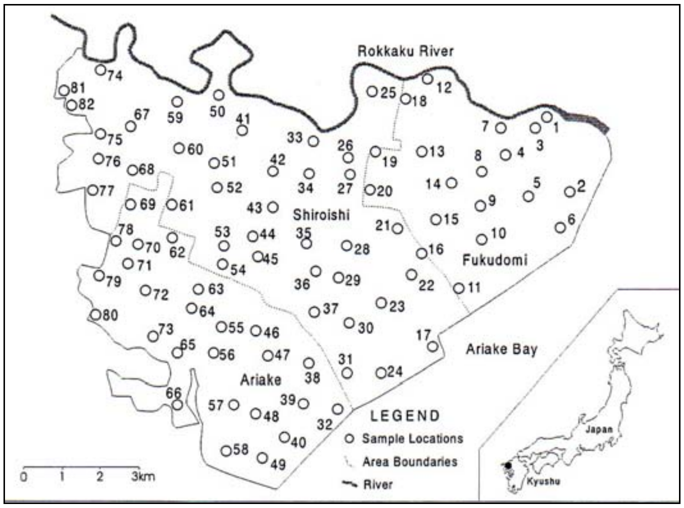

Fig. 2 Location Map of the Study Area

Before the groundwater sampling is carried out, the static well water depth was measured. The water sampling bottles are rinsed and pre-cleaned with the distilled water and finally washed with groundwater at the time of sampling. The first volume of sample collected into these bottles according to the designated grid number as shown in the base map with 1 square kilometer grid reference in Shiroishi Plain using a submersible type pump.

Under the laboratory works, it was proposed to determine Nitrate ions, phosphate ions, ammonium ions, chloride ions concentrations and pH value of collected water samples from groundwater sampling wells. As there is subsurface drainage system to drain excess water from the agricultural beds water samples from these drainage pipes and creeks also collected. Analysis was carried out in monthly intervals in order to assess the trends of chemical contaminations due to use of agricultural fertilizers.

The portable HACH Dr/2010 spectrophotometer was used for insitu analysis of Nitrate ions, phosphate ions and Ammonium ions concentrations with the accuracy of 0.8 ppm for nitrate and 0.01 ppm for phosphate ions. In addition, following tests were carried out in the laboratory to determine the same in the water samples collected for laboratory analysis.

The results of chemical analysis were statistically analyzed with respect to seasonal changes, various crop types cultivated, and the type of samples obtained (whether from the shallow tube well, deep tube well, sub-surface drainage pipes, interceptor drains, streams etc.).

III. Results and discussion

This research was carried out to investigate the nature of the nitrate pollution in shallow groundwater in the Shiroishi Plain due to application of fertilizer for the various agricultural crops.

A. *Effect of Crop Type and Fertilization*

According to the information collected from agricultural school on application of fertilizer, it was revealed that different type of fertilizers are applied to agricultural beds in different quantities for different crops (Table 1 and 2). Table 1 shows that different paddy varieties need different quantities of fertilizer in several times. The special types of fertilizers have been applied for Hinohikari and Hiyokumochi varieties. The total area of paddy cultivation is around 4000 hectares in Shiroishi area and a large amount of different type of fertilizers applied throughout the year.

TABLE I
THE SCHEDULE OF THE APPLICATION OF FERTILIZERS FOR PADDY IN THE SHIROISHI PLAIN

Name of the paddy variety	Application time	Fertilizer name		Amount of fertilizer (Kg/hec.)			Percentage of N:P:K
				N	P	K	
Yumeakogare	May	BB464		300	400		
	July	BB602		150			16:10:12
Yumesizuku	June	BB464		300	200-400		
	August	BB602		150			,,
	June	BB464		250			14:16:14
		LP BB464		300			
Hinohikari	July	BB464		150			,,
	August	BB602		200			16:10:12
		LP BB602		200			
	Special Fertilizer for Hinohikari			500			
		BB 464		250			14:16:14
	June	LP BB464	Mountain	500			
			Plain	350			
	July	BB464		150			,,
Hinokumochi		BB602		250			
	August	LP BB804	Mountain	400			
			Plain	400			
	August	BB602		100			16:10:12
	September	BB602		100			
	Special Fertilizer for Hinokumochi		Mountain	550			
			Plain	500			

Paddy is rotated with barley or wheat cultivation and then with soybean. Farmers use large quantities of fertilizer to paddy, barley and wheat. Besides fertilizer, lime and minerals apply for barley and wheat cultivation.

TABLE 2
THE SCHEDULE OF THE APPLICATION OF FERTILIZERS FOR OTHER CROPS IN THE SHIROISHI PLAIN UNITS FOR MAGNETIC PROPERTIES

Type of crop	Application time	Fertilizer name	Amount of fertilizer (Kg/hec.)			Percentage of N:P:K
			N	P	K	
Onion	Before planting		900	40 0		25:25.2:17.4
	January	BB602	600			
	March	NK-2	400			16:10:12
Corn	30 days before planting	CDUS5 55	1000			25.2:28.5:23.4
	40 days after planting	BB602	250			16:10:12
	60 days after planting		250			
Cabbage	10 days before planting	BB464	130	50	50	
	40-50 days after planting	BB602	60	50	50	
	40-50 days before planting August		50		50	
Barley	December	BB464	50			
	January	BB602	20			
	March		10			
	Lime		60			
	Mineral		100			
Wheat	December	BB464	50			
	January	BB602	30			
	March		15			
	Lime		60			
	Mineral		100			

They cultivate soybean after barely or wheat harvesting hoping to reduce nutrients content in soil layer. The total area of soybean cultivation in 2001 is 1035 hectares. There is no fertilizer application for soybean in Shiroishi Plain. Other crops are being rotated as farmers decide to do so in winter season. Onion and cabbage crops start to cultivate in November or December and harvest in March, April or May. It is a significant fact that they need much fertilizer than other crops. Quantities of fertilizer applied, type and application period are shown in Table 2.

Among the drilled wells, 21 wells were located within onion-cultivated fields, 18 wells were located within wheat crop fields, 19 wells were inside paddy fields, one well was near cabbage field, one was in strawberry field, one was in Asparagas field and others were located with the field where there was no cultivation during sampling. Chemical analysis of the samples collected from the study area indicates that nitrate concentration in shallow groundwater varies between 1.4 ppm as NO3-N. The average nitrate level of the shallow groundwater in Shiroishi plain was calculated to be 1.4 ppm and considered as the background nitrate concentration of the area. As many of the researcher pointed out (Angle et.al, 1993, hubbard et.al, 1987, Kanwar, et.al, 1995 and 1996, Spalding et.al, 1993), the nitrate-N level above 1 ppm indicates contamination of water, shallow groundwater in the large part of the study area is considered vulnerable for nitrate pollution due to application of fertilizers. Sixty four percent (64%) of the samples analyzed appeared to be not contaminated as they indicate NO3-N levels less than 1 ppm. Twenty six percent of the samples showed nitrate concentration between 1 ppm and 3 ppm as NO3-N. Around 10% of the sampled wells showed nitrate contamination more than 3 ppm. Ammonia concentrations in groundwater were also measured to study whether there is any correlation exists with the agricultural practices, geological and land reclamation history as well as groundwater levels and drainage system.

Variation of nitrate-nitrogen concentration in subsurface water in the areas where paddy and onion cultivated is shown in Figure 3. Accordingly, it appears that fairly low nitrate concentrations (<1 ppm) have shown in December and May, during which onion is cultivated in those fields. The approximate amount of fertilizer applied for onion cultivation is 600 and 400 kg/hec. in January and March respectively.

Highest values are shown in the samples collected in January-March. Rapid decrease in nitrate concentration could be observed in samples collected after harvesting onion in May. Subsequently the land area where onion cultivated is being prepared for paddy cultivation since May. During the period of paddy cultivation, the nitrate concentrations in groundwater reported to be fairly increased due to application of fertilizer. The amount of fertilizer applied for paddy cultivation in shown in Table 1.

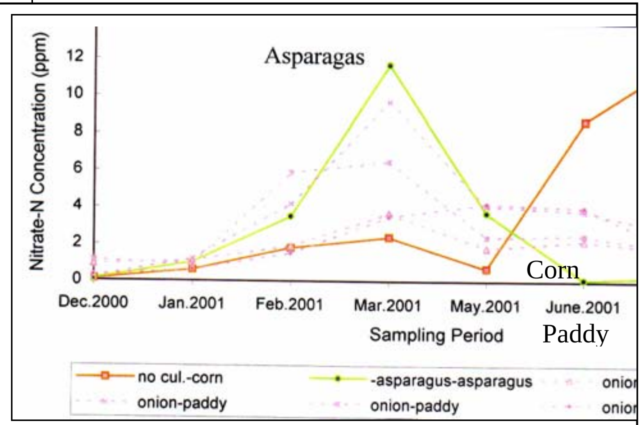

Fig. 3 Variation of Nitrate Concentration in Shallow Well Samples with Crop Type

Based on the observations and calculations of nitrate input and the intake by cultivation together with the results of similar case elsewhere in the world, it was estimated that percentages of nitrogen fertilizer loss as nitrate-N from paddy fields and onion-cultivated areas are respectively 15% and 42% per hectare.

Similar variation of nitrate concentration is observed in the groundwater samples collected from the fields where corn and asparagus cultivated. Even though the concentration of nitrate in December was reported as less than 0.5 ppm NO3-N, it was noticed that the concentrations increase during January to March and reached the maximum value of 12 ppm (in asparagus cultivated fields).

Cabbage and barely cultivation around location 2, 10, 7, 25, and 74 showed a remarkable increase of the nitrate-N content in groundwater (Figure 4). The subsequent gradual decrease of nitrate-N with time can be accounted as a result of the rapid uptake by these cultivations and obviously the leaching –out from the upper soil layer. The low value of nitrate concentrations in December sampling which was also similar to the values in March-May sampling after harvest of the Winter crops indicate the use-up of the nitrate fertilizers applied for the crops. This difference of nitrate levels might be attributed to the different types and compositions of fertilizers applied to various crops and the different up-taking capacity and the differences of drainage facilities arranged (for example, sub-surface drain pipes of lotus fields are kept closed for year around and for paddy fields, they are closed during the water logged period).

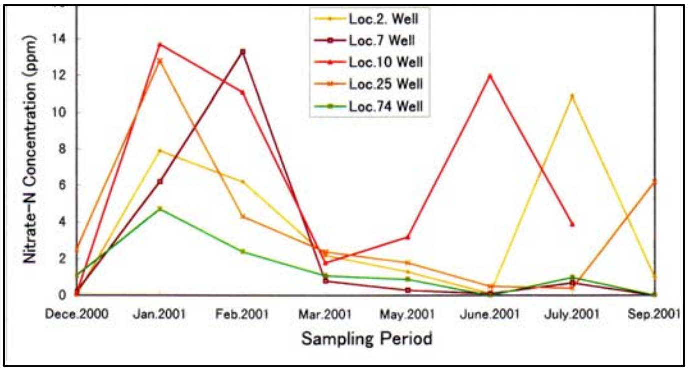

Fig. 4 Variation of Nitrate Level in Goundwater after fertilization

Even though most of the case studies done elsewhere in the world have proven that the densely populated agricultural areas badly affect to environment permanently or for at least for a longer duration, the variation of nitrate levels in the Shiroishi plain reveals that influence of the fertilization in Shiroishi Plain is a temporary process which had two cycles of high and lows during the year around (see Figure 3 and 4). However this yields much productivity to farmers in this area without making a big damage to the environment.

Comparing with the researches carried out in the lowland area in Central Province in Sri Lanka (Dissanayaka et.al., 1984, De Silva, 1995), it was clearly mentioned that cultivated and irrigated soils have given significant contamination of the shallow aquifer by nitrate derived from fertilizers. However the nature of the subsurface material may have played a major role in these two different cases as sandy soil with relatively deeper groundwater table in the above case and a shallow groundwater level and clayey soil in Shiroishi Plain. However, rather than the difference of groundwater depth, the special ability of absorbing nutrients from Ariake Clay may have protected the shallow water from contaminants in Shiroishi Plain.

B. *Estimation of Mass Loading in Shiroishi Plain*

The transition of nitrogen load derived from the estimated amount of agricultural fertilizer applied for the Shiroishi area is described in the figure 5. The total volume of water was calculated from the pumping amount of deep groundwater and pumping volume from river water for cultivation. Table 3 shows the calculated amounts of dissolved fertilizers in groundwater.

TABLE 3
ESTIMATED AMOUNTS OF DISSOLVED FERTILIZER IN INFILTRATE WATER

Month	Crop Type	Applied Fertilizer amount to field (kg)	Infiltrate water amount (x 10 3 m3) (50% of total water amount in the area)	Dissolved fertilizer amount in infiltrate water as nitrogen (kg)
January	Onion Wheat Barley	369,808	90,677	1130
Febriaru			76,669	840
March		245,704	54,021	675
April			71,519	783
May	Paddy Soybean	42,420	65,022	670
June		226,240	280,073	2105
July		66,660	230,563	4025
August		218,160	49,599	310
September		17,210	100,029	100
October	Harvesting			
November				
December		863,820		

Table 4 illustrates the estimated amounts of all fertilizer applied to the area and dissolved amount in shallow groundwater and creeks with time. Accordingly, during the May-October season when the main crop is paddy, the loss of nitrate to the creek system is high with compared to the relatively low value estimated for winter crops.

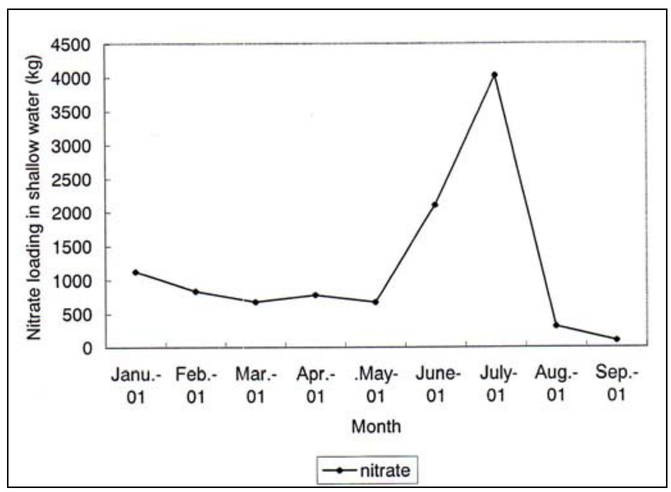

Fig. 5 Nitrate Loading due to Agricultural Fertilization

However, it is to be noted that the amount of fertilizer applied for paddy is relatively high. Figure 6 shows that lot of nitrogen fertilizers applied to land have been remained without dissolving in water. They are mostly removed from the fields by several ways such as loss to the air as gas, remains in organic matter, absorb by Ariake clay, and leach from the soil layer etc. in addition to the desired function of direct uptake by cultivation.

TABLE 4
ESTIMATED AMOUNTS OF THE LOSS OF FERTILIZER DURING THE TWO SEASONS

Duration	Applied fertilizer amount into land as Nitrogen (kg)	Dissolved fertilizer amount in infiltrate water as nitrogen (kg)	Dissolved fertilizer amount in creeks water as nitrogen (kg)	Percentage of loss fertilizer from field
January-April	59160	3428	3309	5.5
May-October	83184	7210	7540	9.1

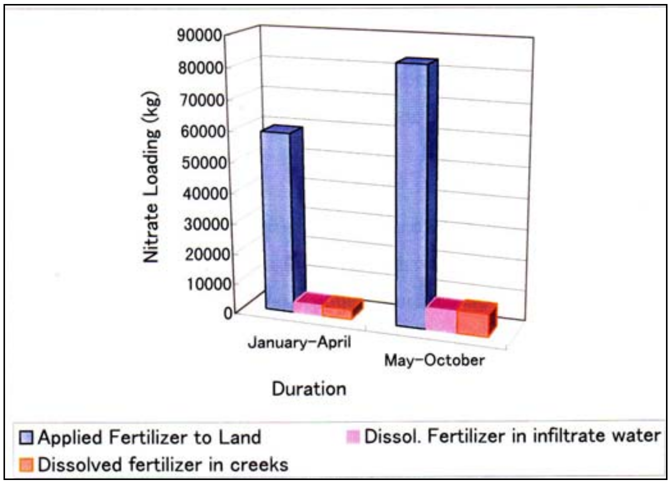

Fig. 6 Estimated Amounts of Fertilizer Applied and Lost During the Two Cultivation Periods

C. Effect of Climatic Conditions

Shiroishi Plain has shallow groundwater level through out the area ranging from 40 cm to 55cm depth from the earth surface. In rainy season it was observed that average groundwater level is 20 cm deep below the earth surface. But in dry season, these areas have mainly depended on the groundwater supply, as there is no sufficient water in rivers to meet the current demand for water. As a result, it has been observed that Shiroishi area has become one of the major land subsidence area in Japan due to over pumping of groundwater.

Figure 7 shows the correlation of nitrate variation in groundwater with rainfall. It clearly indicates the high nitrate levels in rainy season. The reason for this may be due to repeated application of fertilizer in June and July months for paddy cultivation and the intensive surface runoff and erosion due to heavy rain.

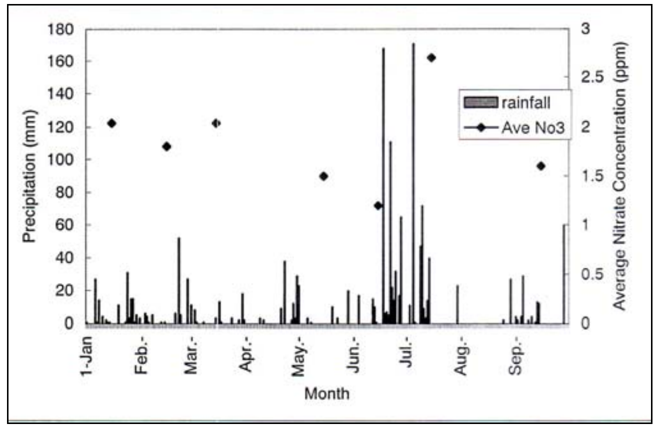

Fig. 7 Variation of nitrate concentration with rainfall

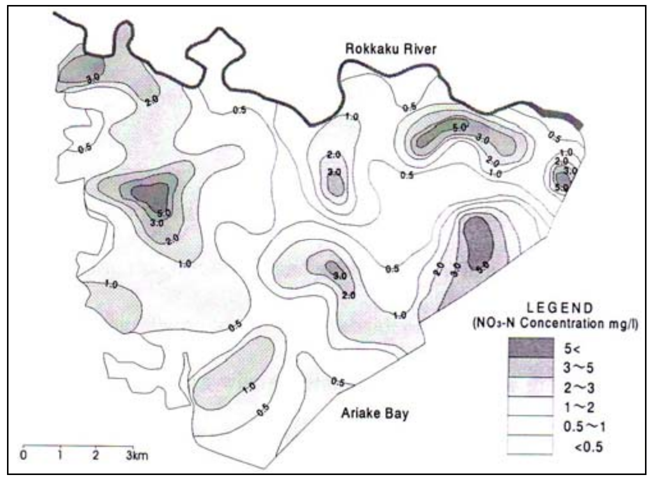

Fig. 8A Nitrate Variation Patterns in Winter Season

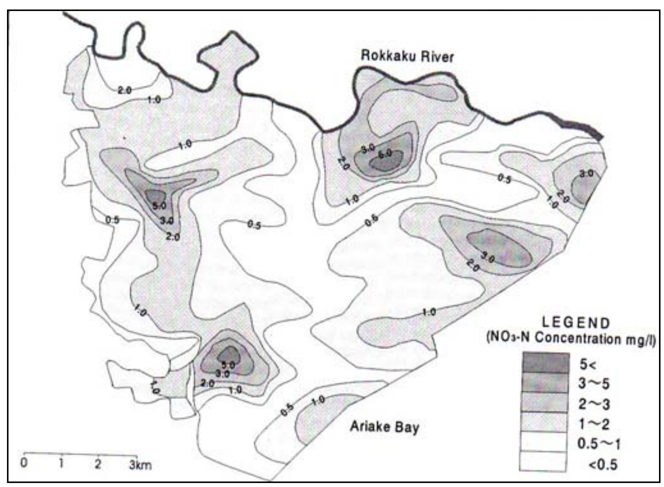

Fig. 8B Nitrate Variation Patterns in Summer Season

Figures 8A and 8B show the variation of nitrate concentrations in groundwater in Winter and Summer Seasons respectively. Highest nitrate level in winter in winter season was recorded as 29 ppm as NO3-N and showed only in the samples collected in March. This is due to application of fertilizers in several times for vegetables within very short period of time.

It was noticed that this nitrate levels and the pH level in the groundwater gradually get reduced along with the atmospheric humidity and temperature that has direct effects on the aeration regime of the soil in the Summer Season. The climatic condition in the summer is not favorable for nitrification process and therefore hinders the generation of nitrate ions. It has been widely understood from the previous researches that when the pH level lowers, slower the nitrification process. The heavy rainfall experienced in June and July also may have affected by washing away of nitrate ions in the root zone with the surface runoff resulting low nitrate levels in shallow groundwater.

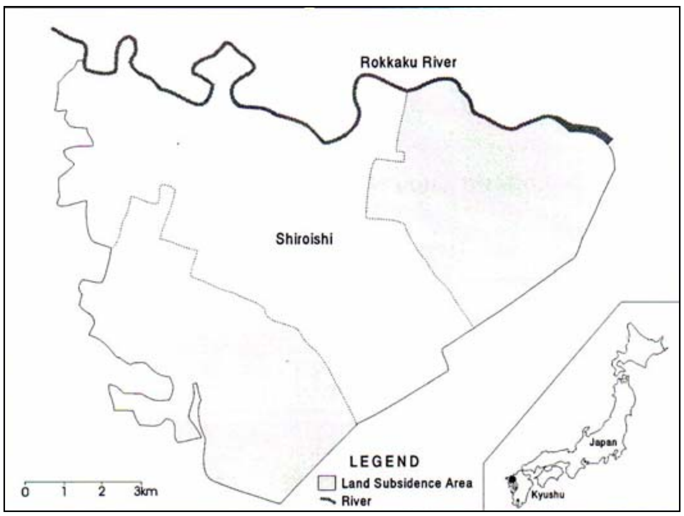

Fig. 9 Major Land Subsidence Area in Shiroishi Plain

Also it was noticed that there is a co-relation between levels of nitrate concentration and the magnitude of land subsidence. When it compare the nitrate levels with the magnitude of land subsidence in Saga Prefecture (Figure 9) it clearly indicates that the nitrate level in shallow groundwater shows fairly high values in the areas where the land subsidence is occurred and considered significant. The land subsidence had been reported to be occurred as a result of excessive extraction of groundwater for agricultural uses. It was clear that the vacuum generated under ground due to excessive extraction of groundwater results both evaporation of water underground and the occurrence of land subsidence be which subsequently be the causes for increase the concentrations on Nitrate ions in groundwater. On the other hand, land subsidence can spilt the Ariake clay layer and thereby groundwater can be directly contaminated with the water in drainage pipes and in creeks where considerable nitrate level in ever exists. Variation patterns of nitrate level as well as groundwater depth level with pumping amounts are correlated in the Table 5 and further described in Figure 10.

TABLE 5

VARIATION OF NITRATE-N LEVEL AND GROUNDWATER DEPTH LEVEL DUE TO OVER PUMPING

Month/Year	Pumping Amount X $10(m^3)$	Nitrate Concentration (ppm)	Groundwater Level depth (m)
01/2001	35.385	2.40	-6.653
02/2001	33.846	1.80	-5.979
03/2001	42.462	2.00	-5.821
04/2001	37.538	2.00	-5.579
05/2001	45.385	1.50	-5.284
06/2001	146.154	1.21	-6.674
07/2001	126.154	2.60	-7.411
08/2001	199.231	2.80	-9.347
09/2001	58.077	1.60	-9.200
10/2001	45.385	1.00	-8.505
11/2001	40.000	0.76	-7.642
12/2001	49.615	0.53	-7.200

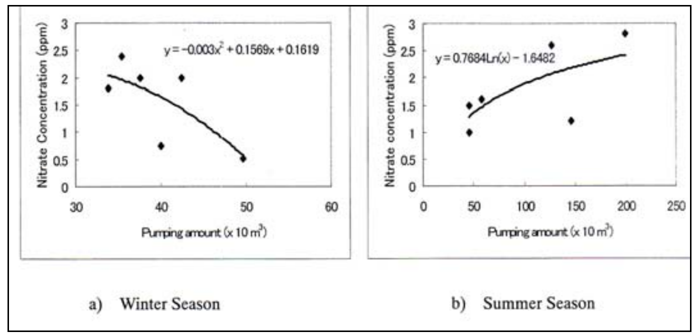

Fig. 10 Variation Patterns of Nitrate Level as well as Groundwater Depth Level with Pumping Rate

D. *Effect of subsurface drainage system*

During the process of reclamation, the natural creeks exist in the area have been modified and new creeks have been redesigned and reconstructed to store surface water to cope up with the high demand for water for irrigation activities. Subsurface drainage system has been introduced in order to supply oxygen for paddy, release excess water in soil of agricultural beds. These drainage pipes have been laid underground at the 0.5 m deep from the surface in parallel to each other and the distance between two pipes in approximately 20 m. Runoff from the fields flows into the interceptor drains and then into the creeks.

The total area of these creeks has estimated around 221.5 ha. And total volume of the creeks in Shiroishi Plain is about 1,683,000 m^3 accounting for approximately 2% of the total volume of water required for paddy field irrigation each year, which is approximately 74,252,000 m^3. The mean water depth in the creeks is 1.17 m. The estimated data showed that these creeks are used mainly as canals rather than water storage in this area.

Figure 11 and 12 shows the variation of nitrate nitrogen levels in drilled shallow wells (0.5-1 m) and sub-surface drainage pipes. It indicates the low nitrate levels in wells and relatively high levels in sub-surface drainage pipes.

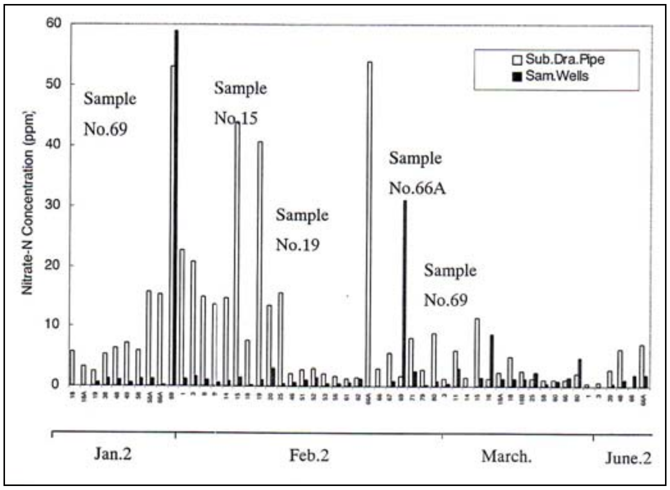

Fig. 11 Variation of Nitrate Levels in Sub-surface Drain Pipes and Sample Wells

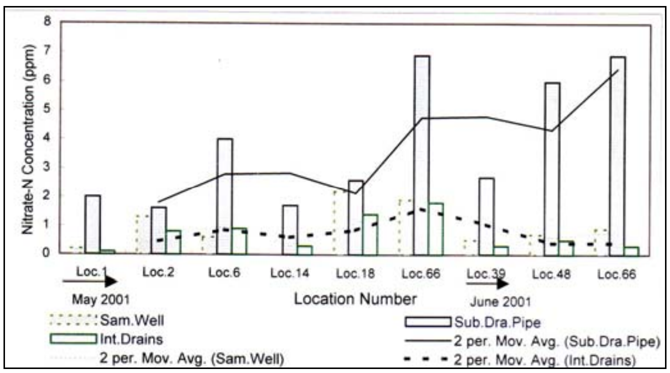

Fig. 12 Comparison of the Variation of the Nitrate Level within the Wells, Drain Pipes and nearby Interceptor Drain/Creeks

Fig. 13 Occurrence of Algae along the Interceptor Drains as a Results of Eutrophication

The average value of nitrate-nitrogen in samples collected from subsurface drainage pipes was 8 ppm, which is considered to be fairly high compared with the standards. This nitrate –N directly flows to the interceptor drains through the sub-surface drainage and get accumulated there. Due to higher concentration of nutrient in the interceptor drains, eutrophication process takes place in the interceptor drains and subsequently looks green and become polluted (Figure 13). According to Figure 11, a ground water sample collected in January from sampling well shows higher nitrate-N concentration, which is considered abnormal with compared with other values.

E. *Effect to deep groundwater table*

It was observed that nitrate concentrations of the deep groundwater samples were very low (negligible) claiming that the deep groundwater is least vulnerable for agricultural nitrate pollution in this area. The pH of the groundwater was ranged between 4-5 at the time of sampling. According to Hart et.al, 1994, it was reported that within this pH range, nitrification process become slower and therefore, increases the ammonium ions concentration. Hence, ammonium ions concentrations in the samples also were to be very low values. That means that both nitrate and ammonium ions concentrations level in the deep ground water are maintained below the contamination level. The reasons for this situation can be the special ability of bearing more nutrients within clay lattice of Ariake clay. It was reported that ammonium ions readily interchange with K^+ ions in the interlayer phases of clays releasing K^+ ions into water (Paul et al, 1989). In addition, soil tests done by El-Shafei in the year 2000 has revealed that Al^{3+} and OH^- ions into groundwater. This special ability of bearing more nutrients within clay lattice of Ariake clay accumulates nitrate and ammonia ions in upper soil layer without leaching into the groundwater.

IV. Conclusion

According to the results of this study, it can be summarized that, current intensive systems of vegetable production are not essentially harmful to the environment. However, the environmental conditions including the property of subsurface materials, various agricultural practices and the timing and amounts for fertilizer applied directly influence the potential groundwater contamination. It is thereby necessary to take steps to minimize even the temporary affects of the groundwater contamination during the year around for sustainable agricultural practices without causing significant ecological damage.

This research found that nitrate-N concentration in samples collected in subsurface drainage shows the highest figures with compared with the others. It implies that the nitrate-N derived from the fertilizers applied to the agricultural beds are retained in the subsurface drainage water. The Ariake clay layer lies under the bed does not allow the nitrate-N to leached into the under ground due to its special physical, chemical and engineering characteristics. Therefore, underground water remains unpolluted and not vulnerable to even contamination by fertilizers and the degree of vulnerability gets higher because there is no leaching process of nutrients through the ariake clay layer. Hence, this surface water remains in the interceptor drains has no more use in this area for domestic purposes. It cannot even be reused for agricultural for agricultural practices because of higher degree of pollution. This situation is not favorable for the areas where low average rainfall is experienced. As of the area gets low rainfall according to the climatic data and the insufficient surface water from rivers, it is an important task to preserve the quality of water remains in the interceptor drains so that water could be reused for agricultural purposes.

The one and only way that cause pollution of this interceptor drain is the application of fertilizers in the agricultural fields. Therefore, it is proposed carry out more in-depth studies to investigate the sustainability of present agricultural practices and developed more environmentally unfriendly and economically unviable. When we consider the economic aspects of current practices, the removal of nutrients through subsurface drainage is considered to be great economical loss to farmers.

An another advantage of this proposal is that if we develop an environmentally friendly and economically viable system for agriculture, it help to preserve the quality of water in interceptor drains so that farmers could be able to reuse this water in case of water shortage in the area. This would subsequently help reduce extraction of excessive ground water for agricultural use and thereby could be able to reduce the magnitude of land subsidence in the area by considerable extent.

One of the most important points to be noted is that the Ariake Clay has a good ability to bare more nutrients due to its high cation exchange capacity. Therefore assessment of soil nitrate content is necessary before fertilization for further requirements as it is greatly help the people to get the maximum advantages from the special properties of Ariake Clay and its behavior in nature.

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