NITRATE NITROGEN POLLUTION BY RECHRGE IN AGRIVULTURAL AREA IN KUMAMOTO AREA, JAPAN

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***ABSTRACT*:** Kumamoto city located in the middle of the Kyusyu Island, Japan is a greatest city which uses groundwater for domestic water. There are 4 groundwater areas in Kumamoto prefecture, and the Kumamoto area is the biggest one in those 4 areas. In this area, all of domestic water for 1 million populations depends only on groundwater. In addition, this groundwater is used to agriculture and industrial too. And this groundwater is the important resource for supporting development of Kumamoto prefecture. However, groundwater level decreased year by year until 2004. It seems that paddy field having high ability for groundwater recharge is continuously decreasing. Because of that, Kumamoto city and 4 companies have performed the ponding water project on the farmland in the Middle Shira-River Area since 2004. The ponding water project is that farmer keep water on farmland which stops cropping rice by the acreage-reduction policy. In this way, groundwater level is rise up. However, recently, the nitrate nitrogen concentration of groundwater rises. And, it is said that the ponding water project is a cause of the nitrate nitrogen pollution of groundwater. Therefore the authors estimated quantity of nitrate nitrogen eluviation from ponding water on farmland in the Middle Shira-River Area. The typical crop fields are selected for analysis. As a result, it is considered that the ponding water project does not contribute to the nitrate nitrogen pollution.

KEYWORDS: recharge, groundwater, nitrate nitrogen pollution, ponding water project

1. INTRODUCTION

The Kumamoto groundwater area, Kyushu, Japan has comprises 11 cities, towns and villages surrounded Kumamoto-city with commanded area of 1,041km^2 and 1 million in population. It is the largest area of groundwater (GW) consumption for domestic water in Japan with the mean annual amount of GW withdrawal 173MCM (Million cubic meters) (Kumamoto Prefecture et, al., 2010). The demand of GW use is decreasing little by little every year. However, the recharge from surface water is greatly limited due to the urbanized area development. The major GW recharge area is paddy field in the western plateau of the Mt. Aso (the Middle Shira-River Area) with high infiltration height of over 100 mm/day as shown in Fig.-1. Nowadays, planted area of rice has reduced due to

Fig. 1 Map of the Middle Shira-River Area in Kumamoto, Japan

the acreage-reduction policy by Japanese government (Ministry of Agriculture, Forestry and Fishries). Therefore, the gross of GW recharge rate is decreased and then GW might be not sufficiently use in the future. The evidence causes Kumamoto-city incorporated with the 4 companies have played the role and tried to increase GW recharge rate using ponding water in farmland (ponding water project) since 2004.

The continuously time-series observation of groundwater levels (GWL) both before and after ponding water in farmland was done. And, the quantity of spring water in the Ezu-Lake located in downstream of the groundwater flow (GWF) was also investigated. Furthermore, GW recharge rate by ponding water in farmland in the Middle Shira River Area was calculated as 9.2-2.1 MCM/year during 2004-2011 using field observation data of daily infiltration height in each ponding water field and ponding water record. The GW recharge rate increased in four years of the first half, but did not change in four years of the latter half. The spring rate in the Ezu-Lake was raised once but kept same level in afterwards.

The study on the estimation of effect from GW recharge by ponding water in farmland was carried out. As the results, GWL rise by ponding water in farmland is estimated almost 1.5-2m in just under recharging area during 2009-2011 (Hanajiri, S. et. al, 2009).

But there is another problem in this GW field. That is the nitrate nitrogen pollution problem. The nitrate nitrogen concentrations in almost points of GW pumping well are increased. Various guesses have been spread about the origin of this pollution. One of the sources in this pollution is thinking by the ponding water project. The authors observed the nitrate nitrogen concentrations of soils in the ponding water area. And afterward, we calculated the nitrate nitrogen rate in seepage water using observed data. In this paper, the authors show these results.

2. SOIL CONSTRUCTION AND GROUNDWATER CONDITIONS IN KUMAMOTO GROUNDWATER BASIN

2.1 Soil construction in KUMAMOTO GW basin

The existing cross-sectional geological profiles in Kumamoto groundwater basin was surveyed by the Kumamoto Foundation Society (KFS) with 1-km interval (Kumamoto Foundation Society, 2010). These geological features have much information to understand the GWF conditions. Fig.-2 shows the location of cross section with 1-km interval mesh.

As shown in Fig. 2, there are 27 lines in north to south direction and 15 lines in west to east direction respectively. Fig. 3 and Fig. 4 show the cross sectional geological features in line "21-21'" and "K-K'" in Fig. 2, respectively. In these soil deposits, 2nd to 3d pyroclastic flow sediments and 2-Lava layers are high permeable layer. Then these layers can be aquifer (2nd aquifer). Moreover, gravel and sand layer can be aquifer too (1st aquifer). Since Kumamoto area has two aquifers divided by the distributed clay layer areas as shown in Fig.5. The main recharge area of groundwater is around the Middle Shira-River Area as shown in Fig. 2 and 5.

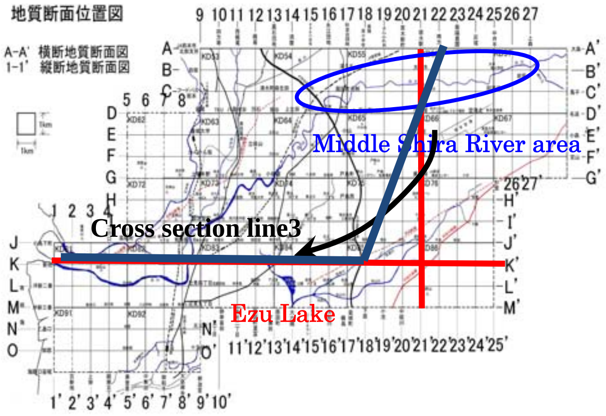

Fig. 2 Location of cross-section profiles surveyed by KFS

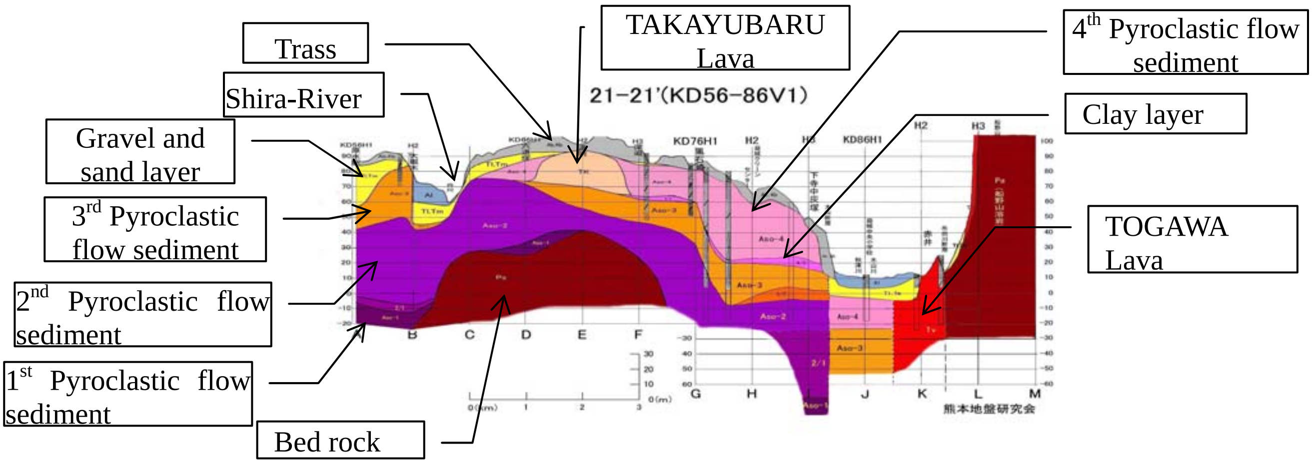

Fig. 3 Cross sectional geological features in line 21-21’

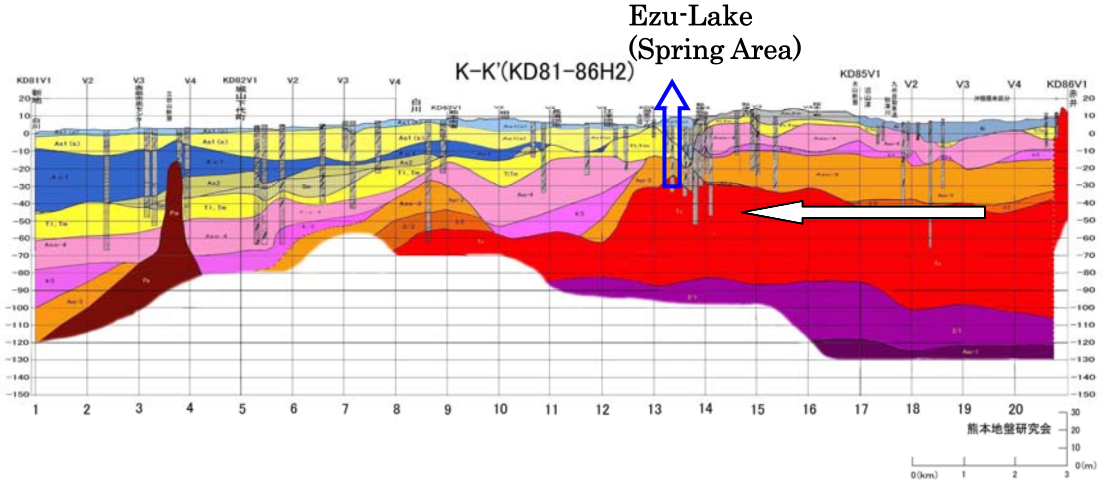

Fig. 4 Cross sectional geological features in line K-K’

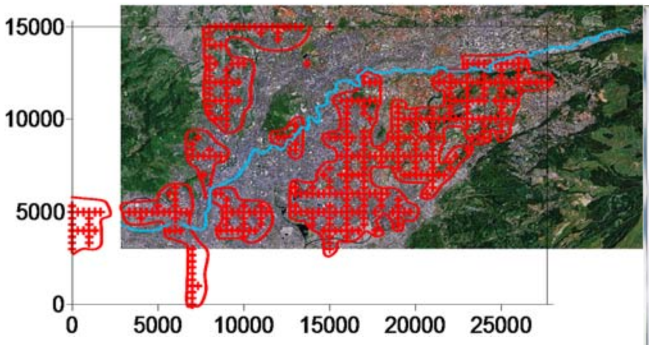

Fig. 5 Distribution of clay layer in Kumamoto GW Basin

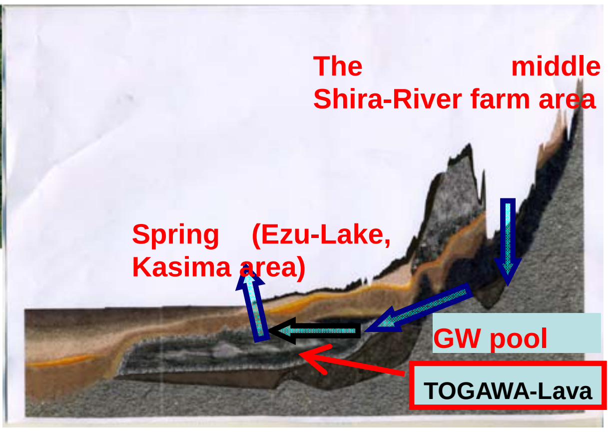

Fig. 6 Cross sectional geological features along GWF and groundwater flow passage

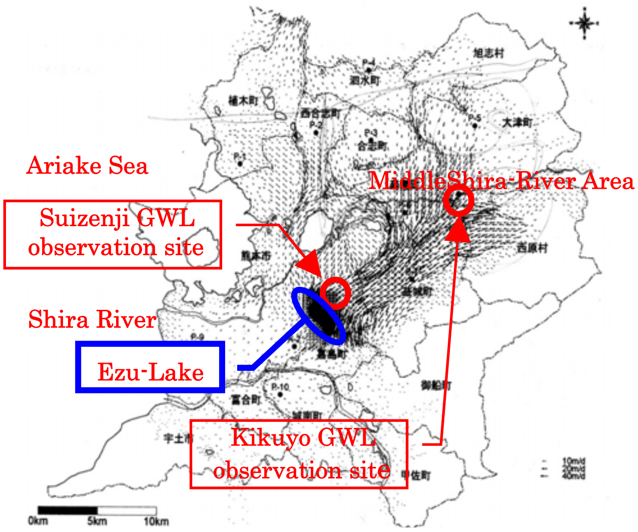

Fig. 7 GW flow in second aquifer in Kumamoto Groundwater Basin (Oct., 2004)

There is no clay layer in the recharge area (the Middle Shira-River Area) and spring area (Ezu-Lake).

Fig. 6 shows the cross sectional geological features along GW passage (class section line 3) as shown in Fig. 2. Recharging water through paddy field in the Middle Shira River Area goes down to the 2nd pyroclastic flow sediment directly and flow down to the TOGAWA Lava. After GW in the TOGAWA Lava, GW spring up to ground surface in the Ezu-Lake.

Kumamoto Prefecture and Kumamoto City do the quasi-three dimensional GWF simulation (Kumamoto Prefecture, 2005). Fig.-7 shows the GWF in second aquifer. From this figure, we can understand that GWF in second aquifer start around the Middle Sira-River Area and spring out in the Ezu-Lake.

2.2 GWL change and spring rate in the EZU-Lake

There are many GWL observation sites which were settled by Ministry of Land, Infrastructure and Transport, Kumamoto prefecture and Kumamoto City. The authors chose two GWL observation sites named Kikuyo and Suizenji which Kumamoto prefecture recorded. Those observation sites were located at just downstream of the Middle Sira River Aria and closed to the Ezu-Lake respectively, as shown in Fig.-7. Those observation well's casing positions were located in the 2nd aquifer of Kumamoto GW basin.

Fig. 8 and Fig. 9 show the GWL observation results in the Kikuyo and Suizenji observation sites during 1991 to 2004. Those annual GWL change patterns show the peak level in October and the lowest level in May which GWL had been risen up during planting of paddy season, and fallen after finished paddy season. The decreasing rate of 0.24

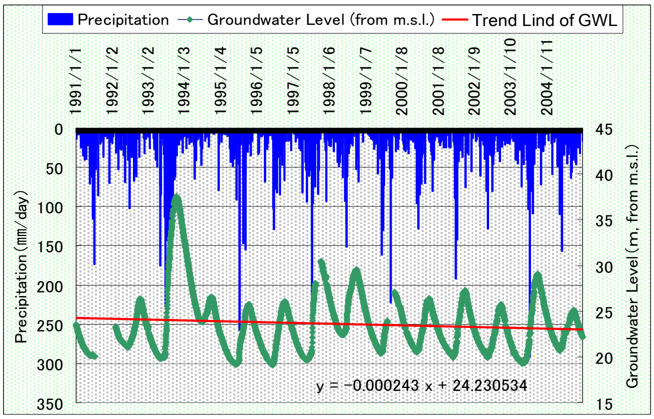

Fig. 8 Daily change of GWL, rainfall and trend line of GWL in Kikuyo observation sight

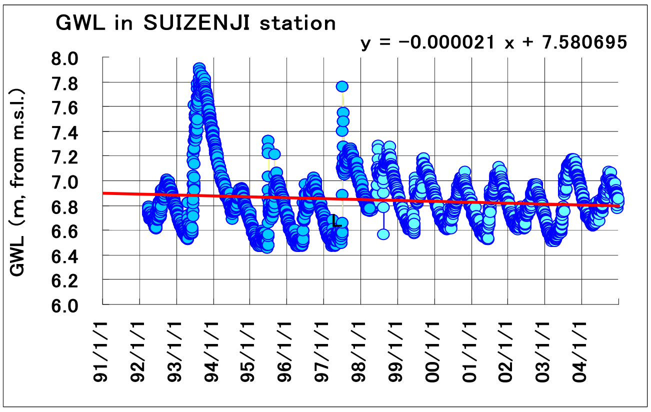

Fig. 9 Daily change of GWL, rainfall and trend line of GWL in Suizenji observation sight

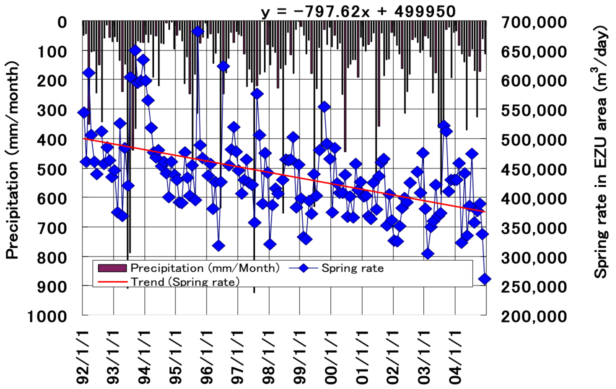

Fig. 10 Monthly change of spring rate, rainfall and trend line of spring rate in the Ezu-Lake

(8.87cm/year) and 0.021 (0.77cm/year) mm/day were found in Kikuyo and Suizenji GWL observation sites. The GWL change in the Suizenji site was not high rate because it was much closed to spring area with higher flow out as spring water.

The authors observed spring rate in the Ezu-Lake with monthly recorded since 1992 as shown in Fig. 10. The slope of trend line of spring rate was decreased with the rate of 797.62m^3/day/month (9,570m^3/day/year). Therefore, the GW storage in the Kumamoto area is decreasing year by year caused by the reduction of the paddy's planting area limited by urbanization and acreage reduction policy.

3. PONDING WATER IN FARMLAND AND EFFICIENCY TO GROUNDWATER RECHARGE

Recently, Japanese government has decided the acreage reduction of growing paddy, because of rice over production. Farmers must also reduce paddy area, but they can grow other cash crops with less water consuming in their farmlands. Particularly the rate of acreage-reduction area in the Middle Shira-River Area was shown in Fig.-11. Moreover, farmers are getting old age which they stopped cultivation and sold out the land to company as for housing and other uses. Therefore, the recharge rate from ground surface to aquifer is decreasing year by year.

Rate of acreage-reduction area is increase year by year as shown in Fig. 11. The ponding water project in these farmlands was promoted to develop by Kumamoto City incorporated with 4 companies since 2004 with the compensation money to farmer (see Pic. 1). The purpose of this project is to increase GW recharge.

Fig. 12 shows the change of recharge rate in each plot during 2004-2011, respectively. It was cleared that during 8 years of 1km^2 of paddy field was changed to the compacted soil as the impermeable layer (i.e. housing, load and etc.). Moreover, paddy area is reduced year by year with less than 50% of all paddy area. Therefore, the recharge rate through

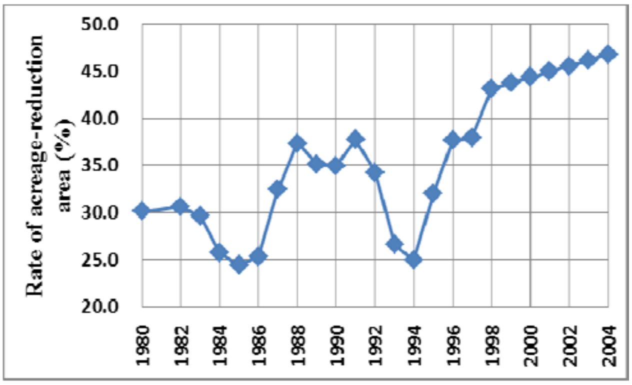

Fig. 11 Rate of acreage-reduction area

Pic. 1 The development of ponding water in farmland

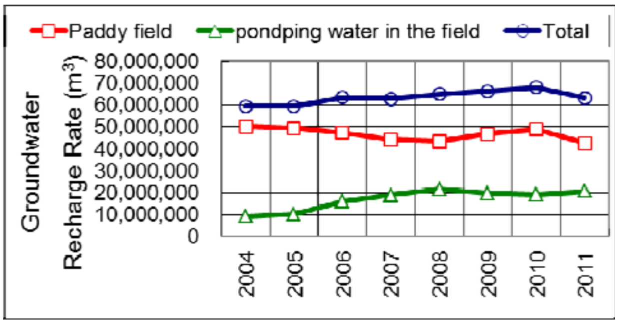

Fig. 12 Change of GW recharges rate in paddy field and ponding water in farmland

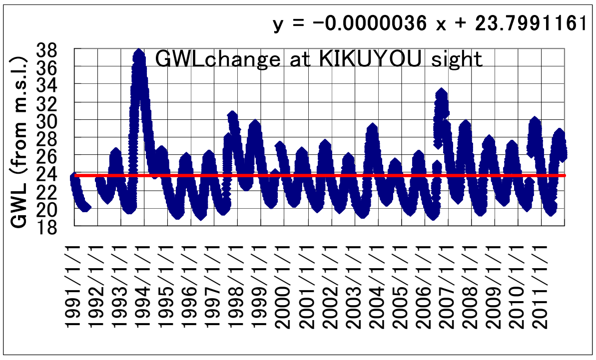

Fig. 13 GWL change at Kikuyo observation site

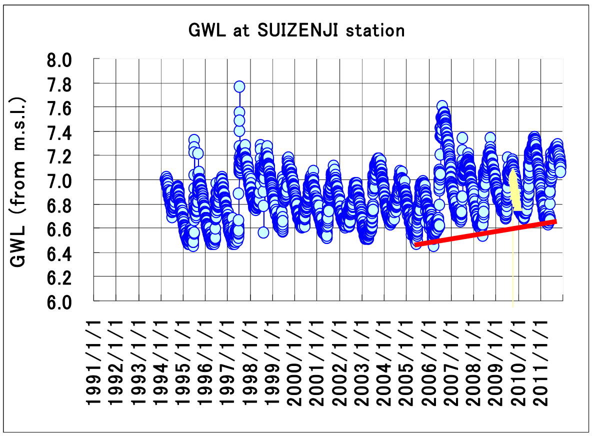

Fig. 14 GWL change at Suizenji observation site

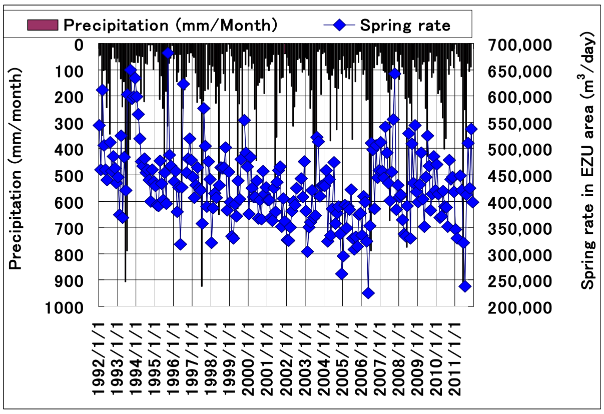

Fig. 15 Change of spring rates around the Ezu-Lake

paddy field is reduced (see Fig. 12). Since the recharge rate during 2004-2008 by ponding water in farmland was increased from 0.92 to 21MCM. The constant recharge rate was 20MCM/year after 2008.

The development of ponding water in farmland was started since 2004, after start the ponding water project, GWLs in Kikuyo and Suizenji, and spring rate in the Ezu-Lake were changed as shown in Fig. 13, 14 and 15, respectively. Those values were increased after the development of ponding water in farmland. However, GWL and spring rate were not raised much after 2008. So it can be said that the effect of the development of ponding water in farmland to recover the GW storage became a limit. The statistical analysis was done using Kikuyo GWL data observed in just downstream of the Middle Sira-River Area to evaluation of the effect of ponding water in farmland development (Hanajiri et. al. 2009). In this analysis, GWL rises during GWL rise up period by recharge rate are calculated. Fig. 16 shows the GWL rise in each factor. From this figure, GWL rise by paddy field and ponding water is almost 5-6m (3.5-4m by paddy field and 1.5-2m by ponding water project), and if rainfall during period of ponding water in farmland and paddy field (May to October) was less than 500mm, GWL rise by rain became zero.

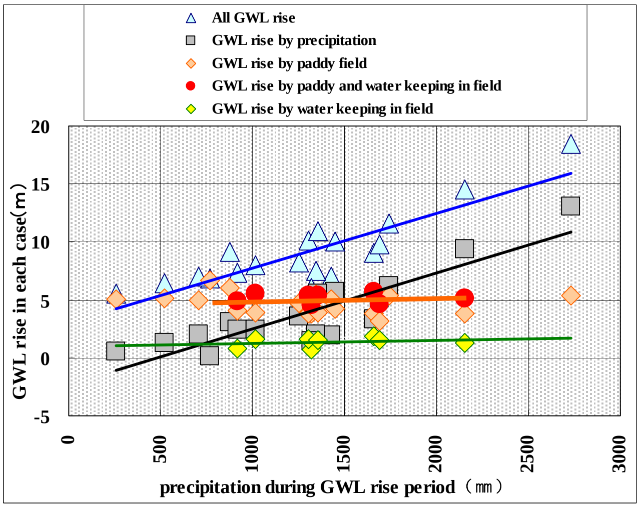

Fig. 16 GWL rise by each factor

4. NITRATE NITROGEN POLUTION BY PONDING WATER IN FARMLAND

4.1 Nitrate nitrogen pollution condition in Kumamoto GW basin

The nitrate nitrogen is included in fertilizer, and farmer put this fertilizer to farmland. But in usual, farmer put too much fertilization to farmland. As the results, a lot of nitrate nitrogen remains in soil, and rain water which infiltrate through ground surface to underground carry it to downward and then nitrate nitrogen reach to groundwater. The world health organization (WHO) set the upper limit value of nitrate nitrogen as 10mg/L for human health. In Japan, government (ministry of environment) set the same value for drinking water standard. The Kumamoto prefecture collects the observed value of nitrate nitrogen concentration in Kumamoto GW area as shown in Fig. 17 (Kumamoto Prefecture, home page). From this figure, we can see the area which is over the drinking water standard. Those areas are farm land. The Kumamoto city government observes nitrate nitrogen concentration in every place which pumping up GW for water supply. Fig. 18 shows the change of nitrate nitrogen concentration in Takuma observation well located in east part of GW flow area. As shown in this figure, nitrate nitrogen concentration in this observation well is over the drinking water standard (10mg/L) from 2004, then this well cannot pumping up GW for water supply. Fig. 19 shows the change of nitrate nitrogen concentration of spring water during April, 2009 to May, 2013 in the EZU-Lake. We can understand that nitrate nitrogen concentration in spring water (same to groundwater) is increase continuously. The GW contamination by nitrate nitrogen is concerned to ponding water in farmland. Because sprinkled fertilizer is remaining in the farm soil before ponding water, so there is worry of nitrate nitrogen pollution by downward flow of ponding water in farmland.

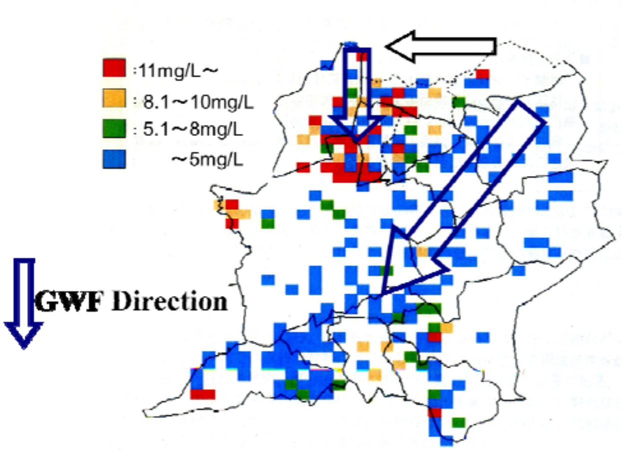

Fig. 17 Nitrate nitrogen concentration of GW in Kumamoto groundwater basin

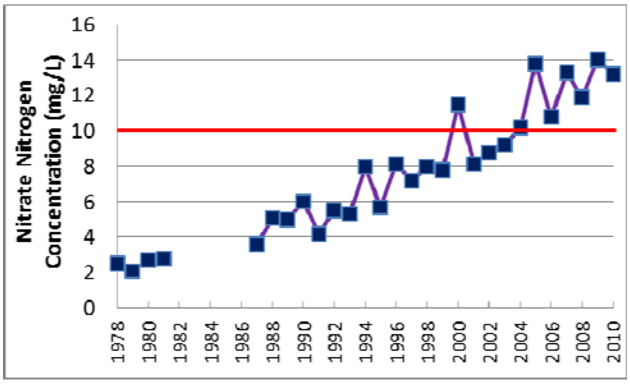

Fig. 18 Nitrate nitrogen concentration of GW in Takuma observation well

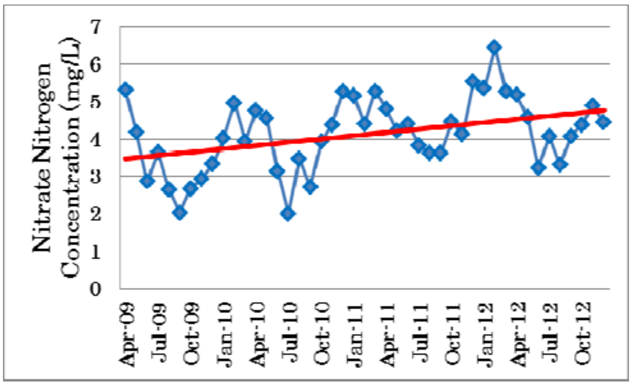

Fig. 19 The change of nitrate nitrogen concentration of spring water in the Ezu-Lake

4.2 Field observation

4.2.1 Leaching speed of nitrate nitrogen

The authors observed the change of nitrate nitrogen concentration in the ponding water field. Observation system is as shown in Fig. 20. The seepage speed in the Middle Shira-River Area is very high, and over 200mm/day in some place. In the soil, there are three types of nitrogen; that is ammoniac nitrogen (NH_4-N), nitrite nitrogen (NO_2-N) and nitrate nitrogen (NO_3-N). But ammoniac nitrogen and nitrite nitrogen will be change to nitrate nitrogen by oxidation during seepage down to groundwater. The authors set total nitrogen concentration by addition of these three types' nitrogen concentrations. The authors observed nitrogen concentration during 1 month with 3 or 4 days interval. The observation result is shown in Fig. 21. From this result, it seems that the leaching speed of nitrogen is over 50cm par 7 days. This means that seepage speed of infiltrated water under unsaturated condition in ponding water field is over 70mm/day.

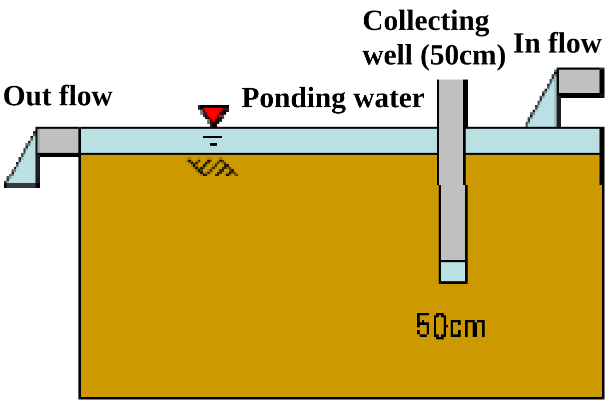

Fig. 20 Observation system in ponding water field

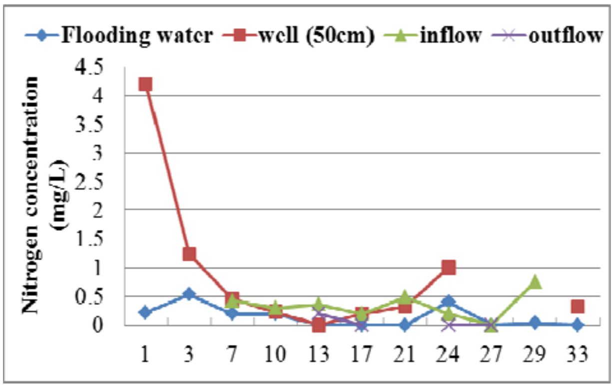

Fig. 21 Change of nitrogen concentration during ponding water in farmland

4.2.2 Soil sampling and simple soil nutrient analysis

The authors collect non-disturbance soils before and after ponding water in farmland, and observe the three types nitrogen concentration in soil by the simple soil nutrient analysis using digital commercial test kit (Kyoritsu Chemical-Check Lab., Corp.) (Kengo MATSUOKA et. al., 2008). Fig. 22 shows the sampling points. And Pic. 2 show the soil sampler and soil column (5cm diameter and 5 cm height).

The simple soil nutrient analysis is devised to estimate amount of nutritive salt in the forest and vegetation area where include low rate of nutritive salt. The ponding water is done in the farmland after

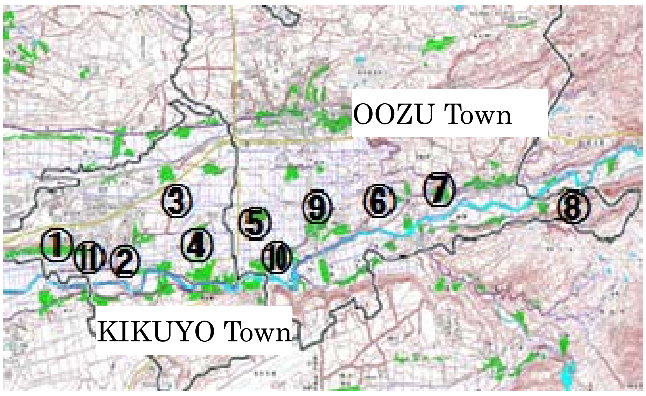

Fig. 22 Sampling points of non-disturbance soils

Pic. 2 Soil sampler and soil column

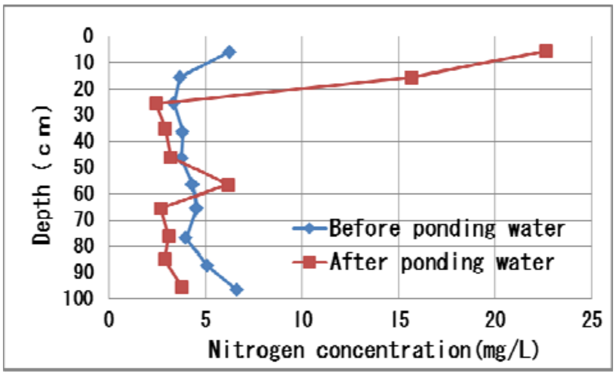

Fig. 23 Results of simple soil nutrient analysis

Table 1 Classification of crops, representative species and nitrogen concentration in each crop

Classification of crop	Representative species	Nitrogen weight par unit area (kg/m^2)
Root crops	Carrot	0.0013
Fruit	Melon	0.0034
Miscellaneous cereals	Wheat	0.0002
Forage crops	Grass	0.0132
Vegetables	Sweet corn	0.0003

harvest. During ponding water, it seems that the amount of nutritive salt is low. Then we choose this simple soil nutrient analysis.

The procedure of this analysis is as the following.

1) Soil samples are kept in the laboratory to drying condition during 1 week after observe weight.
2) Observe weight of dry soils.
3) Put dry soil to pure water with volumetric ratio soil 1: pure water 2, and observe weight of soil.
3) Mix by stirring during 3 minutes.
4) Filtering by pressure filter and get the filtrate.
5) Analysis by digital commercial test kit.

Fig. 23 shows a result of the simple soil nutrient analysis. In this figure, we can see that nitrogen concentration is decreasing in each depth without ground surface. This is caused by seaweed. During ponding water period, seaweed grows thick in the field. Then the authors take out the data in surface, until 30 cm, for nitrogen calculation of leaching to downward.

4.2.2 Estimation of nitrogen concentration in seepage water by ponding water project

There are various field crops before ponding water in farmland. Then the authors classify them to 5 main crops and get non-disturbance soils in each depth of representative species as shown in Table 1. In this table, average nitrogen concentrations in each species are shown, too.

During May to October 2011 of the ponding water project, farmer set water and kept for 1 month to 3 months and sent results report to the ponding water project office. The authors get those reports and calculate ponding water area (PWA), recharge rate (RR). The total leaching volume of nitrogen (TLVN) is calculated by following equation in each crop group.

(TLVN) = (PWA) x (PWD) x (DSS) x (NCSW)

Where,
(PWD) = ponding water days,
(DSS) = daily seepage speed,
(NCSW) = nitrogen concentration of seepage water in each crop.

Table 2 shows calculation results of the nitrogen concentration in seepage water by ponding water project. It is clear that the forage crop is the highest nitrogen concentration. But because recharge volume by forage crop is not so high, then total nitrogen concentration becomes low value as shown in Table 2. Then it can be said that the nitrate nitrogen pollution is not caused by ponding water project.

Table 2 Nitrogen concentration in seepage water by the ponding water project

Classification	Total area (m^2)	Total leaching volume of nitrogen (kg)	Recharge volume (m^3)	Nitrogen concentration (kg/m^3)	Nitrogen concentration (mg/L)
Rootcrops	1,283,333	1,700.4	8,507,300	0.00020	0.20
Fruit	28,216	95.9	78,134	0.00123	1.23
Miscellaneous cereals	1,352,004	219.9	7,224,480	0.00003	0.03
Forage crops	870,269	11,508.5	3,303,495	0.00348	3.48
Vegetables	150,870	38.9	886,500	0.00004	0.04
Total	3,684,692	13,563.7	19,999,909	0.00068	0.68

5. CONCLUSION

The nitrate nitrogen concentration of groundwater rises in Kumamoto groundwater basin. And, some doubt is caused by the ponding water project. Therefore the authors estimated quantity of nitrate nitrogen eluviation from ponding water on field in the Middle-Shira River Area. The field data of the crops before and after ponding water in typical crop field. As a result, the nitrogen concentration in seepage water by ponding water in field is very low. Then it is considered that the possibility of the nitrate nitrogen pollution by the ponding water project is low. But the forage crop is most high nitrogen concentration. Because of low seepage rate by forage crop, total nitrogen concentration becomes low value. If area of the forage crop becomes wider, nitrogen concentration will increase.

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