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Estimation of Amount of Groundwater Pumping Discharge and Its Effect on Salinization of Groundwater around Ito Campus, Kyushu University

by

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Abstract

Kyushu University has been constructing its new campus (Ito Campus) in an area spanning the Motooka-Kuwabara district in Fukuoka City. Agriculture is active in this area and a large amount of groundwater is used for irrigation and horticultural facilities. In recent years, land development for house building has proceeded and one of groundwater recharge sources, paddy area has decreased. Therefore, it is the urgent need to grasp the total amount of groundwater discharge by pumping wells. It was estimated that dividing into three usage ways; for living, agriculture and business. The result shows the daily average groundwater discharge is approximately 635m^3 and the percentages of groundwater usage are 59 percent for agriculture, 38 percent for living and 3 percent for business. Next, saline-affected groundwater by effects of groundwater pumping was evaluated from value changes of EC (electrical conductivity), Na and Cl at the wells for agriculture. Consequently, it was revealed that groundwater pumping has an effect on salinization of groundwater and its influences were reflected on the groundwater quality about one month later.

Keyword: Groundwater, Groundwater pumping discharge, Irrigation water, Saline-affected groundwater

1. Introduction

Kyushu University has been moving 3 campuses (Hakozaki, Ropponmatsu and Haramachi Campus) located in the center of Fukuoka City to the new campus called Ito Campus in an area spanning the Motooka-Kuwabara district in Fukuoka City since 2000. The Motooka-Kuwabara has an area of 243 ha with a population of 1,400. The geography is characterized by two features; a hill region in the north and an alluvial region in the south. There are forests and crop fields in the hill region, and paddy fields and horticultural facilities in the alluvial region. Since the study area is one

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of the most productive agricultural areas in Fukuoka City, a large amount of water are needed for irrigation and horticultural facilities. But there are not any big sources of water supply except for groundwater in this area, which results in much groundwater extraction. Groundwater is used not only for agriculture but also for business and living in this area.

The construction of the new campus is set to be completed in 2019 and approximately 187,000students will go to this campus. Land development around this campus has proceeded by constructing residential and commercial facilities where there used to be paddy fields and it increases impervious areas, causing a decrease in groundwater recharge.

Heavy pumping of aquifers can lower groundwater level and cause a landward migration of the interface separating fresh and salty groundwater in coastal aquifers[1)]. Inouchi and Yasutomi (2004) stated that not only the amount of groundwater, but also the positional relations between the sites of wells were important to evaluate groundwater salinization[2)]. Thus, the decrease in groundwater recharge, together with heavy pumping of groundwater, may cause serious problems, such as groundwater salinization or intake trouble at some wells, which could adversely affect crop growth. To evaluate the effect of groundwater pumping, quantification of groundwater discharge is of great importance. Nevertheless, it has not yet been grasped in the area.

In view of the above, the main objective of the study is, first, to estimate the total amount of groundwater discharge from 2007 to 2012 in this area dividing into three usage ways; for living, agriculture and business. Second, saline-affected groundwater by effects of groundwater pumping is evaluated from value changes of EC (electrical conductivity), Na and Cl at the wells for agriculture.

2. Estimation methods

This chapter gives an overview of methods for estimating groundwater discharge in the study area. The total amount of groundwater discharge is estimated on a monthly basis for 6 years, from 2007 to 2012, dividing into three usage ways; for living, agriculture and business.

2.1 Groundwater discharge for living

The amount of groundwater discharge for living can be estimated based on the population in the area[3)]. Also, the estimation takes into consideration a number of household members in family. According to Fukuoka City, water is consumed more efficiently as a number of household members increases, which means less water consumption per person in families of more members (**Table 1**).

Table 1 Household water consumption according to a number of household member in Fukuoka in 2002[4)].

Household menber	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Household water consumption[l/day•person]	262	246	205	182	166	158	144	138	115	119	125	87	−	110

In addition, household water consumption varies month to month (**Fig.1**). Therefore, the amount of water used for living is finally estimated from rate of monthly changes of water consumption and the average water consumption according to the number of household members and the population from 2007 to 2012.

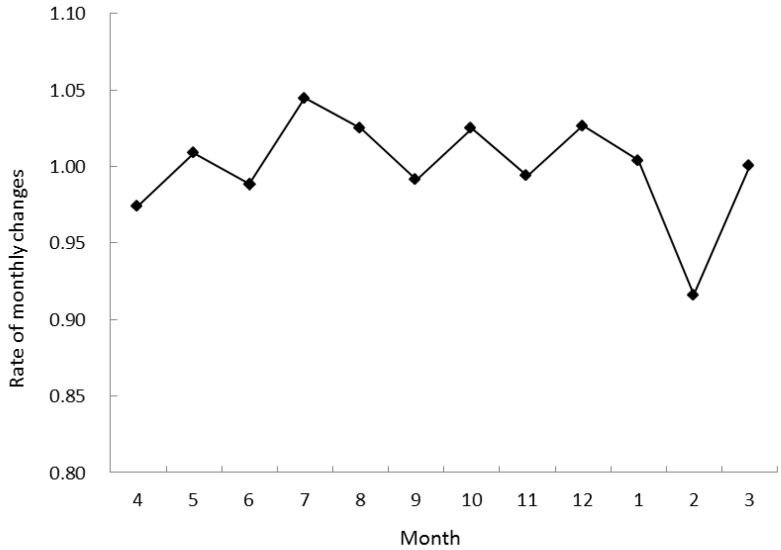

Fig.1 Rate of monthly changes in amounts of water supply in Fukuoka in 2012[5)].

2.2 Groundwater discharge for agriculture

In the study area, there is an irrigation union that manages 17 large wells (**Fig.2**). For agricultural purposes, groundwater is pumped up by privately owned wells and the irrigation union wells. Thus, the estimation of groundwater discharge is performed by dividing into two parts; groundwater discharge by privately owned wells and irrigation union wells.

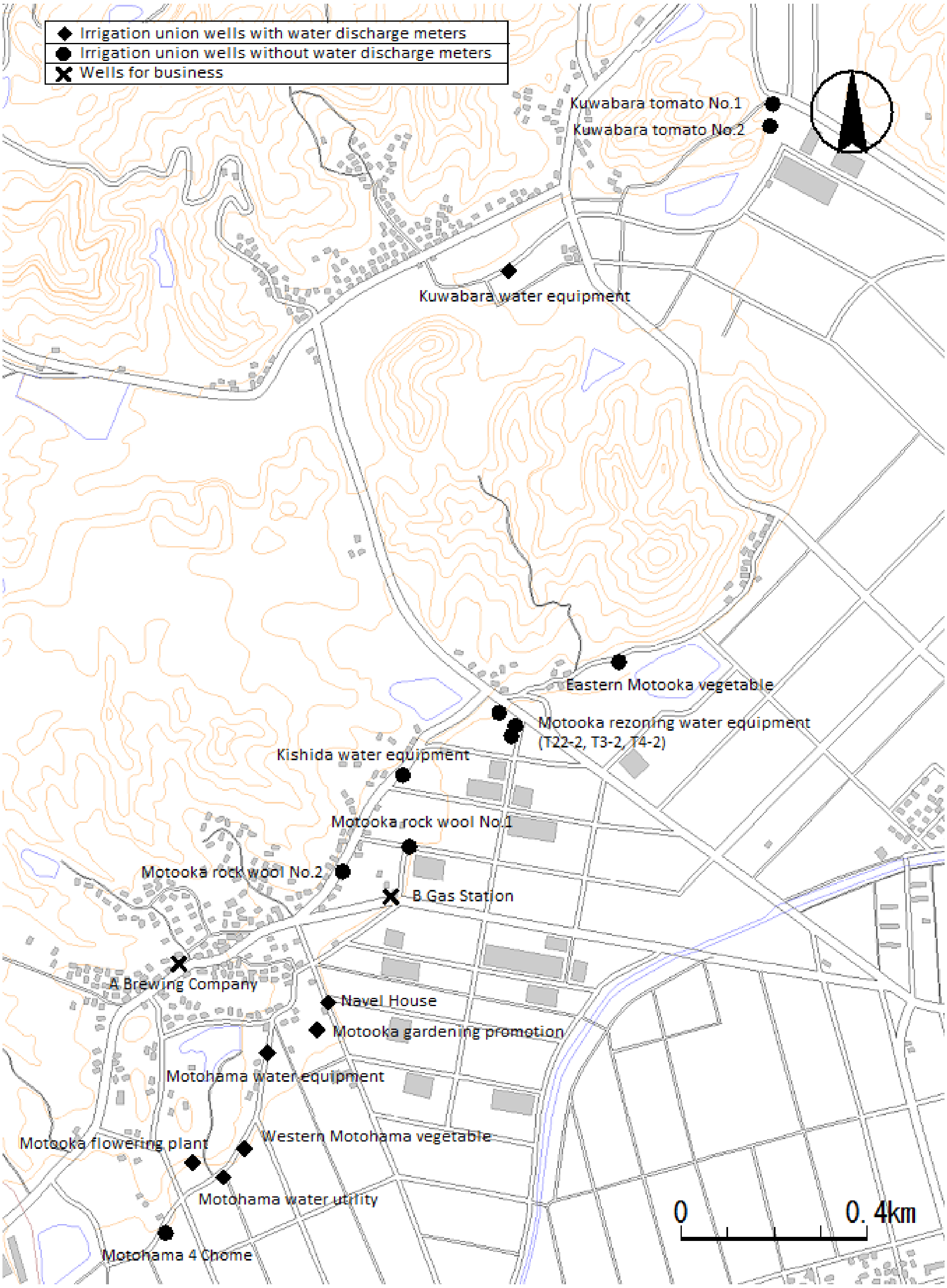

Fig.2 Location of large wells.

2.2.1 Privately owned wells

There are 66 wells privately owned by farmers in this area. Pumping capacity and operating time from the questionnaire survey (1995) conducted by Kyushu University relocation office are utilized for the estimation[6)]. An amount of groundwater pumped up by a privately owned well is calculated as;

$$Q = qt \tag{1}$$

Where Q is groundwater discharge (m^3/day), q is pumping capacity (m^3/s), t is operating time (s/day);
Using this equation, the amount of annual groundwater discharge is calculated for each well and added up for total discharge.

2.2.2 Irrigation union wells

The 17 irrigation union wells are used by farmers to pump up water for agriculture in this area. The amounts of discharge from the 7 wells with water discharge meters have been recorded every month since 2007. Assuming the amounts of groundwater discharge from the 10 wells without water discharge meters are proportional to these well diameters, they may be estimated from the amounts of groundwater discharge recorded by water discharge meters. The recorded discharge shows that the amounts of groundwater discharge become larger as the well diameters increase. According to Kamensky's experiment, an amount of groundwater discharge is proportional to well diameter under the condition that diameter is smaller than 200mm, and groundwater discharge becomes constant if diameter exceeds 200mm[7)]. All the irrigation union wells are less than 200mm in diameter, so that the amounts of groundwater discharge can be proportional to diameters of the irrigation union wells.

Tables 2 and **3** show diameters of all the wells with and without water discharge meters. As described above, the unrecorded groundwater discharge from the 10 irrigation union wells is estimated from the recorded groundwater discharge from the 7 irrigation union wells with water discharge meters and the diameters by the least square estimation method. **Figure.3** shows an example of how the estimation is done for a month (April, 2007). The best-fit straight line is drawn from recorded groundwater discharge to find unrecorded groundwater discharge. In this method, groundwater discharge from wells in same diameters is assumed to be same.

Table 2 Diameters of the wells with water discharge meters.

	Diameter (mm)
Kuwabara water equipment utility cooperative association	50
Navel House association	30
Motooka gardening promotion cooperative association	30
Motohama water equipment utility cooperative association	25
Motooka flowering plant cooperative association	50
Western Motohama vegetable producer's cooperative association	30
Motohama water utility cooperative association	50

Table 3 Diameters of the wells without water discharge meters.

	Diameter (mm)
Kuwabara tomato producer's cooperative association No.1	25
Kuwabara tomato producer's cooperative association No.2	40
Eastern Motooka vegetable producer's cooperative association	40
Kishida water equipment utility cooperative association	30
Motooka rock wool cooperative association No.1	30
Motooka rock wool cooperative association No.2	30
Motohama 4 Chome utility cooperative association	50
Motooka rezoning water equipment cooperative association (T22-2)	40
Motooka rezoning water equipment cooperative association (T3-2)	40
Motooka rezoning water equipment cooperative association (T4-2)	30

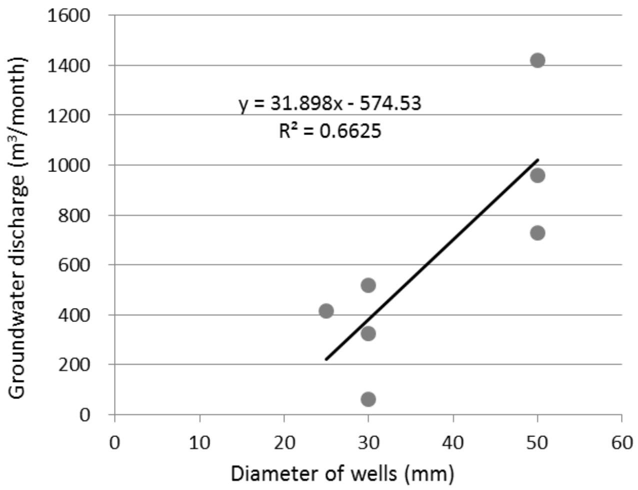

Fig.3 Relationship between amounts of groundwater discharge and diameters of the wells in April 2007.

2.3 Groundwater discharge for business

There are 2 places where large amounts of groundwater are pumped up for business; “A” Brewing Company and “B” Gas Station (see **Fig.2** above). “A” Brewing Company uses three wells for different kinds of products; Japanese sake, beer and others like liqueur, groundwater discharge from which is recorded every month. In “B” Gas Station, the main groundwater usage is washing cars and the average groundwater consumption is reported in the questionnaire survey.

3. Results

3.1 Groundwater discharge for living

Figure.4 shows household water consumption by years from 2007 to 2012. The population decreases by 76 inhabitants but the number of households increases by 90 for the 6 years. It is because the number of students living alone increases while the population decreases due to the outflow of population and aging population. As a result of this change, there has been a small reduction in water consumption for living for the 6 years. According to Fukuoka waterworks department, groundwater is used in old buildings while water in rivers is used in the new apartments for students living alone and commercial facilities in the developed areas[4)]. These could be reasons for the reduction in groundwater users and discharge for living. **Figure.5** shows the daily average water consumption for living by months. Household water consumption is at maximum in summer and at minimum in winter.

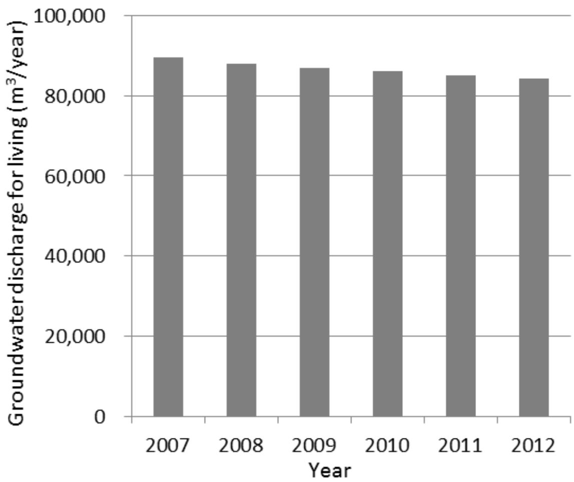

Fig.4 The annual water consumption for living from 2007 to 2012.

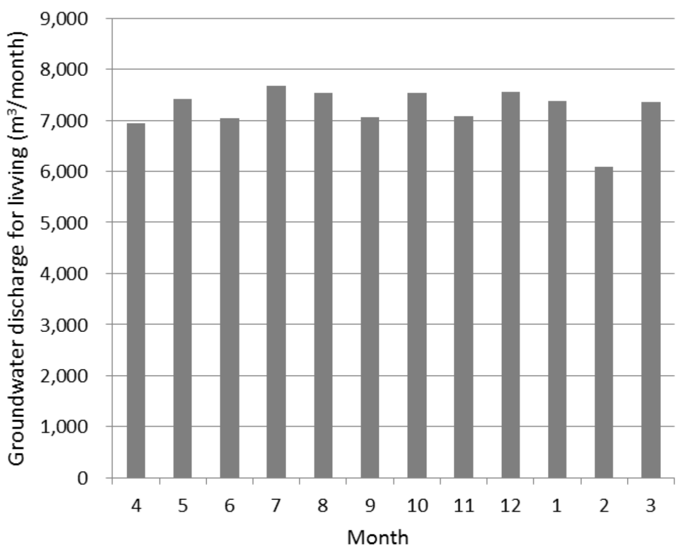

Fig.5 The monthly average water consumption for living from 2007 to 2012.

3.2 Groundwater discharge for agriculture

3.2.1 Privately owned wells

Groundwater of approximately 22,930 m^3 is discharged from the privately owned wells for agriculture every year from 2007 to 2012. Owing to lack of data, annual and monthly changes are not considered.

3.2.2 Irrigation union wells

According to the recorded discharge data, the monthly groundwater discharge has been recorded by water discharge meters at the 7 wells. Groundwater discharge is the largest at Kuwabara water equipment utility cooperative association. The reasons are likely that there is no other irrigation union well around it and it is relatively large in diameter. The recorded discharge has shown that the amounts of discharge increase with larger diameters except for a well named Navel House association.

Big annual variation of groundwater discharge for agriculture is not seen but the amount of groundwater discharge is strongly influenced by monthly variability, as seen **Figs.6** and **7**. The discharge is approximately twice in August or September as much as in January.

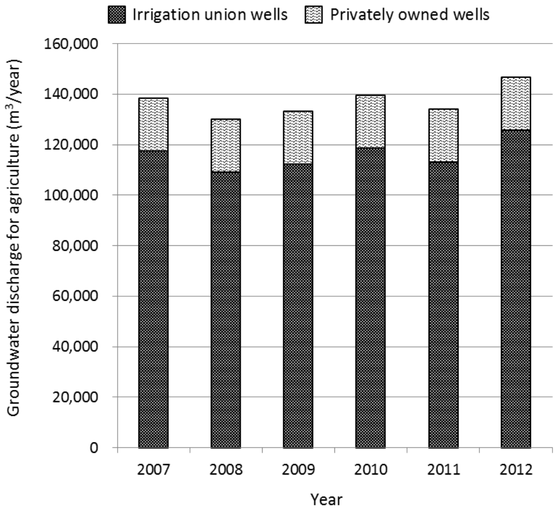

Fig.6 The annual groundwater discharge by the pumping wells for agriculture from 2007 to 2012.

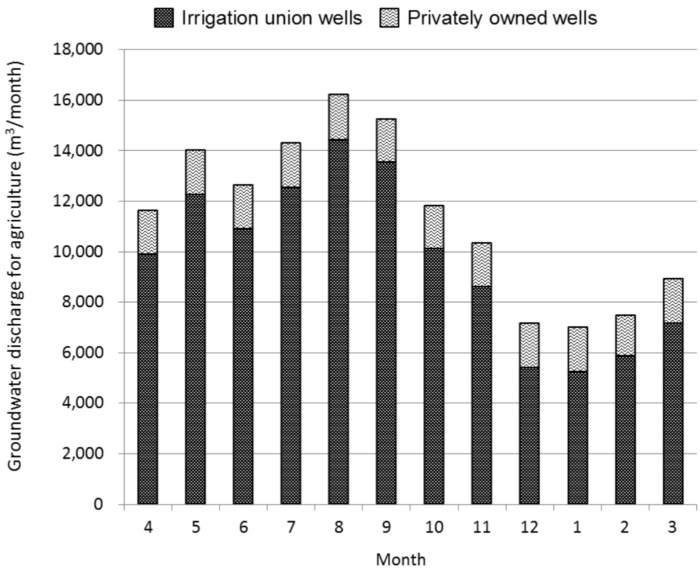

Fig.7 The monthly average groundwater discharge by the pumping wells for agriculture from 2007 to 2012.

3.3 Groundwater discharge for business

The groundwater discharge from the 3 wells in “A” Brewing Company is shown in **Fig.8**. “A” Brewing Company used to mainly product Japanese sake, but a production of beer has been increasing since 2008, resulting in an increase in groundwater discharge from the well for the production of beer. A large amount of groundwater is discharged in summer and winter since the production of beer increases in summer and the production of Japanese sake increases in winter. According to the questionnaire, “B” Gas Station uses groundwater of 2000L for carwashes every day.

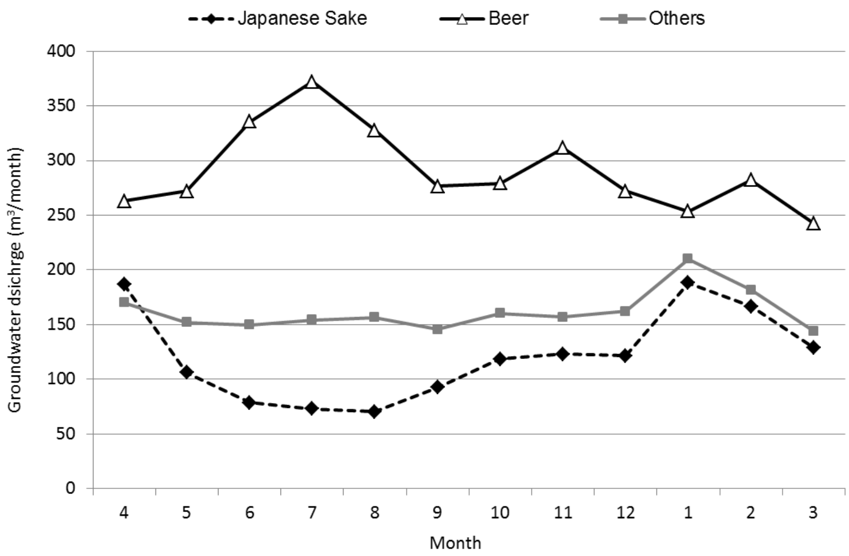

Fig.8 The monthly average groundwater discharge by the pumping wells in “A” Brewing Company from 2007 to 2012.

Figures.9 and **10** show the annual and monthly groundwater discharge for business. Since the daily water consumption is constant in “B” Gas Station, the amount of discharge is larger in summer and winter when the production increases in “A” Brewing Company. For business purposes, groundwater of 19m^3 is discharged per day; approximately 17m^3 in “A” Brewing Company and 2m^3 in “B” Gas Station.

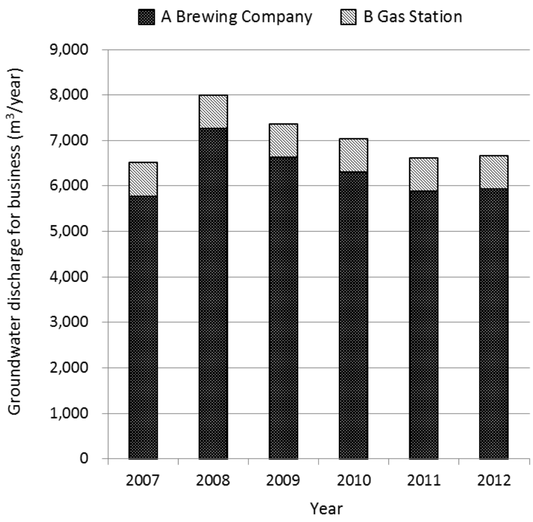

Fig.9 The annual groundwater discharge by the pumping wells for business from 2007 to 2012.

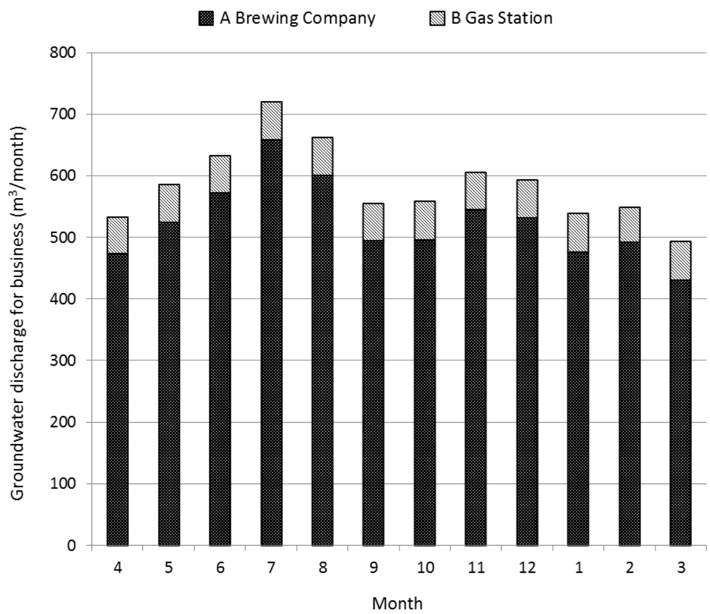

Fig.10 The monthly average groundwater discharge by the pumping wells for business from 2007 to 2012.

3.4 Summary

The daily average groundwater discharge is approximately 635m^3 in the study area; 236m^3 for living, 375m^3 for agriculture and 19m^3 for business. There is no big annual variation of groundwater discharge for the 6 years (**Fig.11**). **Figure.12** indicates that the amount of groundwater discharge varies on a monthly basis since groundwater discharge for agriculture changes significantly depending on crops and climate conditions. Accordingly, the daily average groundwater discharge is approximately 800m^3 in summer but only 500m^3 in winter.

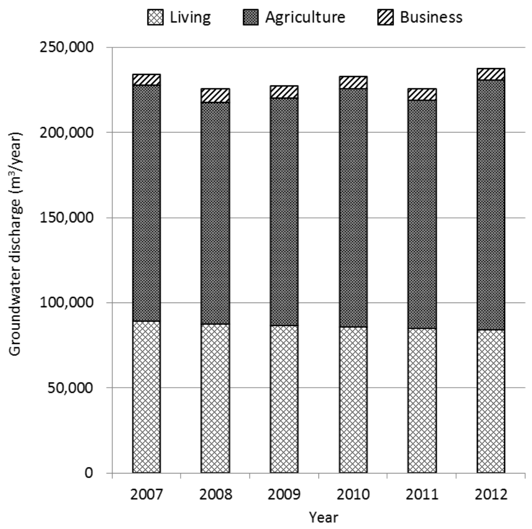

Fig.11 The annual groundwater discharge by the pumping wells from 2007 to 2012.

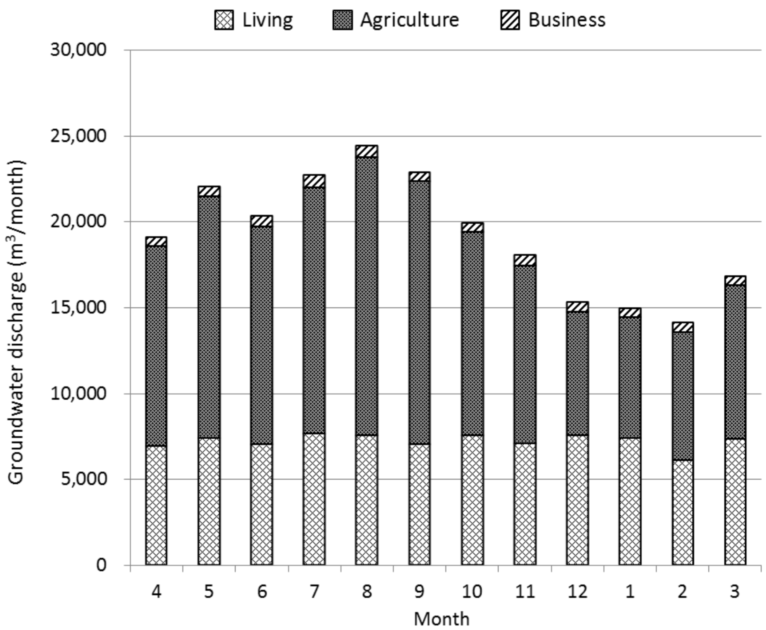

Fig.12 The monthly average groundwater discharge by the pumping wells from 2007 to 2012.

Consequently, the percentages of groundwater use are 59 percent for agriculture, 38 percent for living and 3 percent for business for this period. According to the Ministry of Land, in general, water is equally used for the 3 usage ways in Japan. It concludes that a larger amount of groundwater is used for agriculture in the study area[8)].

4. Evaluation of saline-affected groundwater

In this chapter, first, relationships between EC, Na and Cl measured at the 17 irrigation union wells are evaluated. Next, values of EC, Na and Cl are compared with recorded groundwater discharge to analyze the influence of groundwater pumping on salinization at the 7 irrigation union wells with water discharge meters.

4.1 Relationships between EC, Na and Cl

Relationships between EC, Na and Cl are evaluated at the 17 irrigation union wells. **Figure.13** shows relationships between EC, Na and Cl at Navel house association well. The values of Na and Cl tend to rise along with the EC-value increases. Therefore, it is clear that the EC-values rise due to an increase in amounts of NaCl.

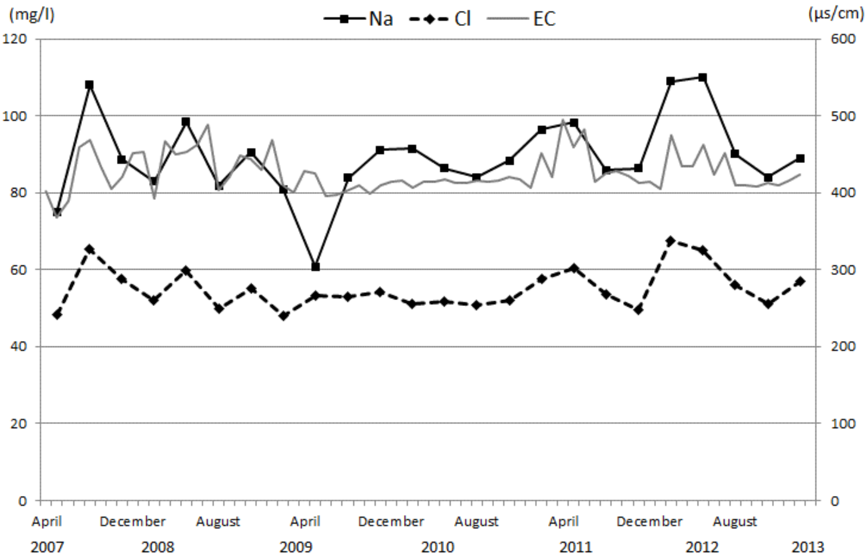

Fig.13 Relationship between EC, Na and Cl at Navel House.

Table 4 shows correlation coefficients between EC, Na and Cl at each irrigation union well. Kuwabara tomato producer's cooperative association No.1, Kuwabara tomato producer's cooperative association No.2 and Kuwabara water equipment utility cooperative association are located in the northern part. It is likely that groundwater quality in these wells is hardly affected by groundwater pumping from other wells since there are only three irrigation union wells in this area (**Table 4 (a)**). Hence, groundwater pumping does not have a big impact on salinization in the aquifer around these wells. But the values of EC, Na and Cl fluctuate and have strong correlations ($P < 0.05$) at Kuwabara tomato producer's cooperative association No1. It is the closest well to the beach of all irrigation union wells, so that it is most likely that salt-water intrudes into the aquifer around it.

There are 5 wells located within a radius of 500m; Eastern Motooka vegetable producer's cooperative association, Kishida water equipment utility cooperative association and Motooka rezoning water equipment cooperative association (T22-2, T3-2, T4-2). The placement of the wells near each other makes groundwater quality easy to get affected by pumping from other wells (**Table 4 (b)**). Also, Motohama water equipment utility cooperative association, Motooka rock wool cooperative association No.1, Motooka rock wool cooperative association No.2, Navel House, Motooka flowering plant cooperative association, Motooka gardening promotion cooperative association, Western Motohama vegetable producer's cooperative association, Motohama 4 Chome utility cooperative association and Motohama water utility cooperative association concentrate and pumping from these wells affects water quality in other wells (**Table 4 (c)**). Western Motohama vegetable producer's association and Navel House association especially have strong correlations between EC, Na and Cl ($P < 0.05$) since there are other wells within 100m distances from them. Motooka rezoning water equipment cooperative association (T22-2, T3-2, T4-2) has just been established; therefore there is no data before June, 2011.

Table 4 Correlation coefficients (and p-values) between EC, Na and Cl at each well
(a) Kuwabara tomato producer's cooperative association No.1, Kuwabara tomato producer's cooperative association No.2, Kuwabara water equipment utility cooperative association

Kuwabara tomato producer's cooperative association No.1

	Na	Cl	EC
Na	1		
Cl	0.832 (0.0000)	1	
EC	0.692 (0.00018)	0.701 (0.00014)	1

Kuwabara tomato producer's cooperative association No.2

	Na	Cl	EC
Na	1		
Cl	0.413 (0.0502)	1	
EC	-0.164 (0.456)	0.133 (0.545)	1

Kuwabara water equipment utility cooperative association

	Na	Cl	EC
Na	1		
Cl	0.347 (0.0967)	1	
EC	0.033 (0.878)	-0.274 (0.195)	1

(b) Eastern Motooka vegetable producer's cooperative association, Kishida water equipment utility cooperative association, Motooka rezoning water equipment cooperative association(T22-2, T3-2, T4-2)

Eastern Motooka vegetable producer's cooperative association

	Na	Cl	EC
Na	1		
Cl	-0.406 (0.0490)	1	
EC	-0.552 (0.00521)	0.623 (0.00115)	1

Kishida water equipment utility cooperative association

	Na	Cl	EC
Na	1		
Cl	-0.184 (0.389)	1	
EC	0.496 (0.00521)	0.623 (0.00115)	1

Motooka rezoning water equipment cooperative association(T22-2)

	Na	Cl	EC
Na	1		
Cl	-0.259 (0.575)	1	
EC	-0.719 (0.0684)	0.402 (0.372)	1

Motooka rezoning water equipment cooperative association (T3-2)

	Na	Cl	EC
Na	1		
Cl	0.657 (0.109)	1	
EC	0.644 (0.119)	0.673 (0.0978)	1

Motooka rezoning water equipment cooperative association(T4-2)

	Na	Cl	EC
Na	1		
Cl	0.932 (0.0203)	1	
EC	0.958 (0.000662)	0.907 (0.00483)	1

(c) Motohama water equipment utility cooperative association, Motooka rock wool cooperative association No.1, Motooka rock wool cooperative association No.2, Navel House, Motooka flowering plant cooperative association, Motooka gardening promotion cooperative association, Western Motohama vegetable producer's cooperative association, Motohama 4 Chome utility cooperative association, Motohama water utility cooperative association

Motohama water equipment utility cooperative association

	Na	Cl	EC
Na	1		
Cl	0.373 (0.0725)	1	
EC	0.007 (0.973)	0.313 (0.136)	1

Motooka rock wool cooperative association No.1

	Na	Cl	EC
Na	1		
Cl	0.314 (0.136)	1	
EC	0.136 (0.414)	0.792 (0.00000)	1

Motooka rock wool cooperative association No.2

	Na	Cl	EC
Na	1		
Cl	0.543 (0.00614)	1	
EC	0.352 (0.0919)	0.304 (0.149)	1

Navel House association

	Na	Cl	EC
Na	1		
Cl	0.813 (0.00000)	1	
EC	0.753 (0.00002)	0.875 (0.00000)	1

Motooka flowering plant cooperative association

	Na	Cl	EC
Na	1		
Cl	0.560 (0.00442)	1	
EC	-0.117 (0.585)	0.128 (0.551)	1

Motooka gardening promotion cooperative association

	Na	Cl	EC
Na	1		
Cl	-0.321 (0.126)	1	
EC	0.640 (0.000758)	0.107 (0.620)	1

Western Motohama vegetable producer's cooperative association

	Na	Cl	EC
Na	1		
Cl	0.705 (0.000121)	1	
EC	0.487 (0.0157)	0.869 (0.00000)	1

Motohama 4 Chome utility cooperative association

	Na	Cl	EC
Na	1		
Cl	0.546 (0.00581)	1	
EC	0.415 (0.0439)	0.268 (0.206)	1

Motohama water utility cooperative association

	Na	Cl	EC
Na	1		
Cl	0.385 (0.0635)	1	
EC	0.335 (0.110)	0.803 (0.00000)	1

4.2 Relationships between groundwater discharge, EC, Na and Cl

EC, Na and Cl are compared with recorded groundwater discharge from the 7 irrigation union wells with water discharge meters. **Figures.14** and **15** illustrate the relationships between groundwater discharge and EC, and the relationships between groundwater discharge, Na and Cl at Kuwabara water equipment utility cooperative association. The EC-value rises with large amounts of groundwater discharge. Thus, it is reasonable to suppose that the EC-value is affected by groundwater pumping at this well.

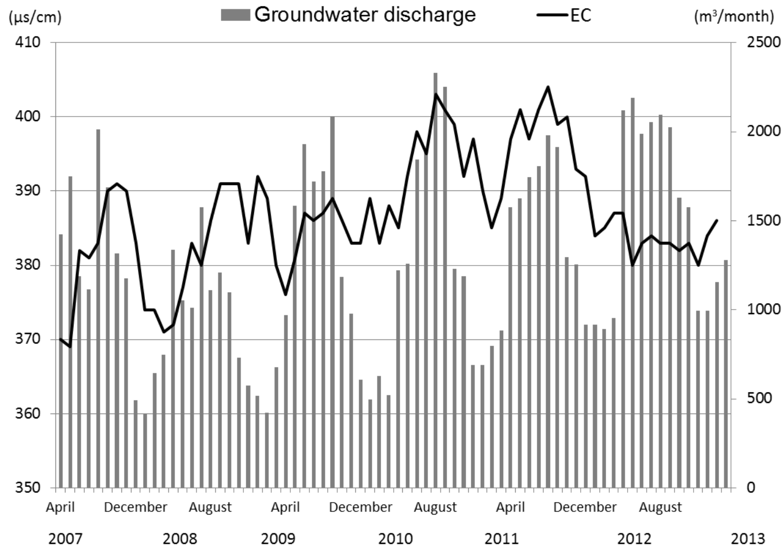

Fig.14 Relationship between groundwater discharge and EC at Kuwabara water equipment utility cooperative association.

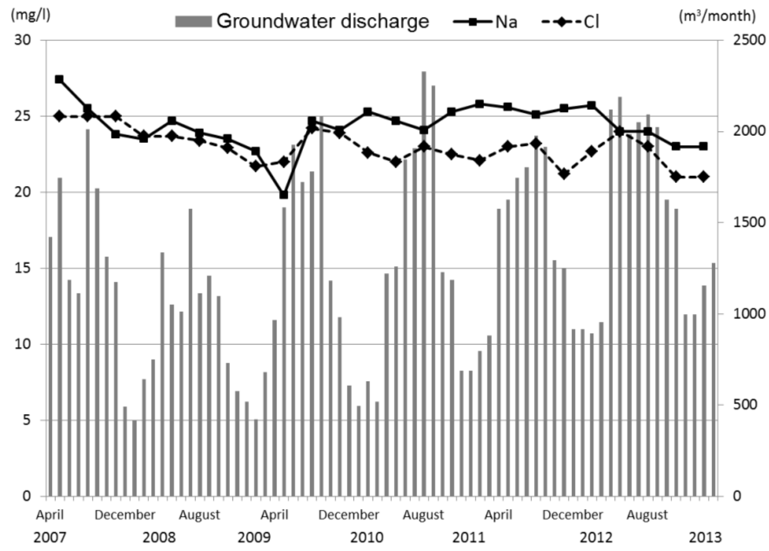

Fig.15 Relationship between groundwater discharge, Na and Cl at Kuwabara water equipment utility cooperative association.

The values of EC, Na and Cl change a little while after the amount of groundwater discharge changes. A similar tendency is also seen in the other wells, which suggests that it takes some time before groundwater quality is influenced by pumping. To find how long it takes, groundwater discharge for the current month is compared with EC-values after one, two or three months of groundwater pumping in the next section.

4.3 Relationships between groundwater discharge for the current month and EC after one, two or three months

As mentioned in the previous section, the EC-value changes a little while (one, two or three months) after changes of groundwater discharge (see **Fig.14** above). Groundwater discharge for the current month is compared with EC-values after one, two or three months of groundwater pumping to find the time before EC is affected by pumping.

Correlation coefficients are used to evaluate the relationships between groundwater discharge and EC. The correlation coefficients between the groundwater discharge and the EC-values for the current month are compared with those between the groundwater discharge for the current month and the EC-values after one, two or three months. The correlation coefficients between the groundwater discharge for the current month and the EC-values after one month are the biggest of the four relationships at most of the wells (Motohama water equipment utility cooperative association, Western Motohama vegetable producer's cooperative association, Kuwabara water equipment utility cooperative association, Motohama water utility cooperative association, Motooka flowering plant cooperative association), as seen in **Fig.16**. As a result, the EC-values are not affected immediately after groundwater pumping but affected after approximately one month of groundwater pumping.

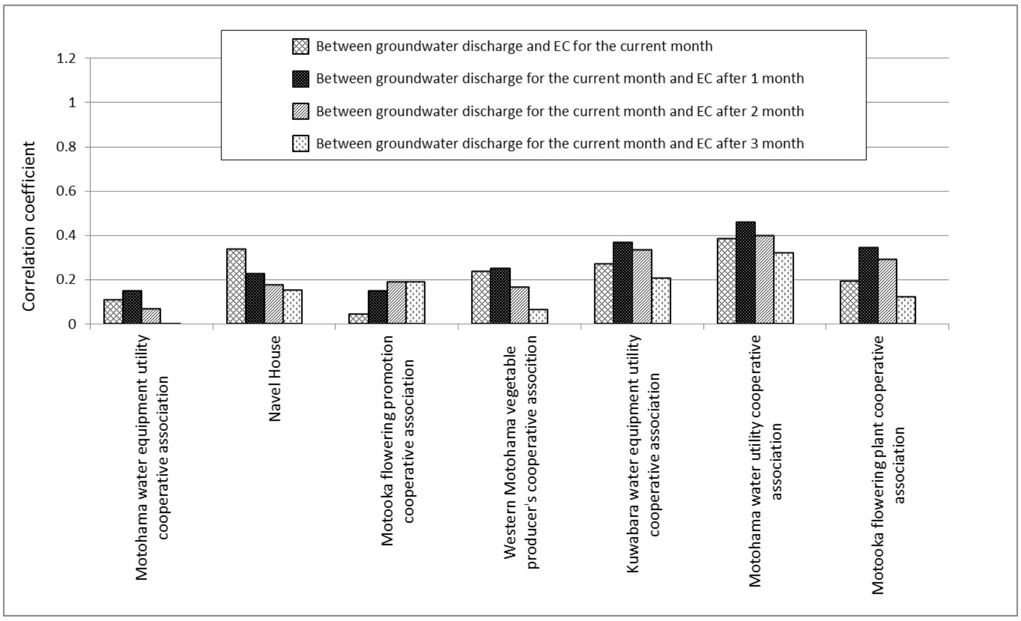

Fig.16 Correlation coefficients between groundwater discharge by the pumping wells and EC.

5. Conclusion

In the study area, there has been rapid urbanization since the construction of Ito campus started, which increases impermeable areas and adversely affects groundwater. In order to evaluate groundwater condition, the amount of groundwater discharge needs to be quantified using the recorded groundwater discharge at the wells.

By dividing groundwater usage into 3 ways, the estimation result shows that the daily average groundwater discharge is approximately 635m^3 in the whole area and the percentages of groundwater usage are 59 percent for agriculture, 38 percent for living and 3 percent for business. Groundwater is much discharged for agriculture, so that the total amount of groundwater discharge is 1.6 times as much as in winter since much water is needed for agriculture in summer.

In addition, the relationship between groundwater salinization which can be caused by urbanization and groundwater pumping was evaluated since heavy pumping of groundwater can be a factor causing groundwater salinization. The result shows that there are correlations between EC, Na, Cl and groundwater discharge at the 7 irrigation wells, which implies that saline water moves towards the wells after groundwater pumping. But the result also shows that the EC-values are not affected immediately after groundwater pumping but rise after approximately one month of it.

It is expected that land use will change more than ever. As mentioned above, it is likely that groundwater storage will change significantly due to the increased impermeable areas, together with heavy pumping of groundwater, which will result in groundwater salinization. Therefore, not only groundwater discharge but also recharge needs to be quantified for a detailed evaluation of groundwater salinization.

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