SUITABILITY ASSESSMENT OF SHALLOW GROUNDWATER FOR AGRICULTURE IN SAND DUNE AREA OF NORTHWEST HONSHU ISLAND, JAPAN

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Abstract. Groundwater quality is an inevitable factor for sustainable agriculture as a source of irrigation water. Therefore, the study was conducted in an irrigated sand dune area of northwest Honshu island in Japan to evaluate the groundwater quality for irrigation. Three observation wells were installed in the investigated field made of polyvinyl chloride (PVC) pipe with three plastic tubes to collect groundwater of 2.0 m, 2.5 m and 3.0 m. The sampling was performed every month from January to November, 2005. Assessment of groundwater quality was performed on the basis of total dissolved solids (TDS), concentration of sodium (Na), calcium (Ca) and magnesium (Mg), sodium absorption ratio (SAR), total hardness (H_T) and concentration of phosphate phosphorus (PO_4-P). Total dissolved solids in groundwater was ranged between 145.5-249.4 mg l^{-1} during the investigation period, revealed that irrigation using groundwater of the study area would not cause salinity hazards. Concentrations of Na, Ca, and Mg were decreased with depth throughout the investigation period. The average concentration of Na and SAR value were 18.8 mg l^{-1} and 0.81, respectively. Since groundwater of the study area contained low concentration of Na with low SAR values, there would not be any possibility of sodium hazards from irrigation using groundwater. On average groundwater of the study area contained 27.5 mg l^{-1} Ca and 9.35 mg l^{-1} Mg, which might contribute to moderate hardness of groundwater in the study area.
Keywords: *Groundwater quality, irrigation, sand dune area, Honshu island.*

Introduction

Groundwater is globally important for human consumption, crop production and industrial usages. The natural state of groundwater is generally of excellent quality, although harmful concentrations of certain ions such as iron and sodium, which can occur naturally and lead to problems [6].Groundwater quality is the physical and chemical characterization of groundwater, which measures its suitability for human and animal consumption, irrigation and other purposes. The quality of groundwater reflects inputs from the atmosphere, from soil and water-rock weathering, as well as from pollutant sources such as mining, land clearance, agriculture, acid precipitation, domestic and industrial wastes. As a source of irrigation water, it influences crops yield, physical and chemical properties of soil, development of the best management practices.

Groundwater contains a varying amount of different kinds of ions. Among them, the major cations are Ca, Mg and Na, which influence the suitability of groundwater for human consumption, agricultural irrigation and other purposes. Some of these cations are beneficial to crop production at expected concentration, otherwise cause toxicity to plants, affect properties of soil and management practices. Bohn *et al.* reported that the concentrations of ions in irrigation water are particularly important because some crops are susceptible to these elements at high concentrations [4]. In a previous study Prunty *et al.* reported that soil properties, crop yield and quality will be deteriorate if low quality water is used for irrigation [12]. Irrigation water with high total dissolved solids (TDS) value results in salinity hazard which cause loss of crop production. Salinity causes the plant to loose energy for extracting pure water from saline water and lack of energy results in reduced crop growth and yield. On the other hand, high sodium absorption ratio (SAR) of irrigation water associated with sodium hazard [13]. Salts from the irrigation water accumulated in the soil profile may deteriorate properties of soil [1].

Phosphorus is of environmental concern because excess amount in water bodies may cause eutrophication. On the basis of diffusion studies, Olsen and Watanabe reported that there was an eight times greater risk of phosphate pollution of ground water from sands than from clay [10].

Shallow groundwater quality of sand dune area in Aomori prefecture of Japan is an inevitable factor not only for crop production but also conservation of water bodies and surrounding environment. Mitra *et al.* studied the groundwater quality of this area in various aspects such as pH, electrical conductivity (EC), dissolved oxygen (DO), concentration of iron (Fe), potassium and nitrate nitrogen (NO_3-N) and the results indicated that values for all parameters would not have any threat to agricultural management practices and surrounding environment except high Fe concentration [9]. As the soil characterized with light textured, the sand dune area of Aomori has the greatest risk of contamination in groundwater from anthropogenic activities which may deteriorate groundwater quality and also contribute to eutrophication of Japan Sea. In order to develop the best management practices for sand dune area, well designed detail data are needed on groundwater quality. Therefore this study was initiated to assess the suitability of groundwater as irrigation in sand dune area of northwest Honshu island.

Materials and Methods

Study area

An agricultural field was selected in Tsugaru city of Aomori Prefecture (northwest Honshu island) for the purpose of this study which is located approximately at 40055′ N latitude and 140019′ E longitude with an elevation of 29 m above sea level and about 2.1 kilometers away from Japan sea (*Fig. 1*). Geology of the study area is shown in *Fig. 2* [5]. Usually the farmers of the study area cultivate the crops from April to November. Because of heavy snowfall in winter most of the fields become fallow. Wheat, radish, melon, shallot, Chinese yam, watermelon, burdock, potato, tobacco, garlic, asparagus, pumpkin, leek, and carrot are main cultivated crops of the study area. Percentage of total cultivated areas covered by different cultivated crops are shown in *Table 1*. Crop fields are irrigated by overhead sprinkler irrigation system using water of Yamada river in the study area except melon field where drip irrigation system is used. Irrigation water quality of the study area is shown in *Table 2*. The recommended fertilizer doses for this sand dune area are shown in *Table 3*. Monthly total precipitation and average temperature of the study area are shown in *Fig. 3*. The soil of this area is characterized by sand. Some physico-chemical properties of soil of the investigation field are shown in *Table 4*.

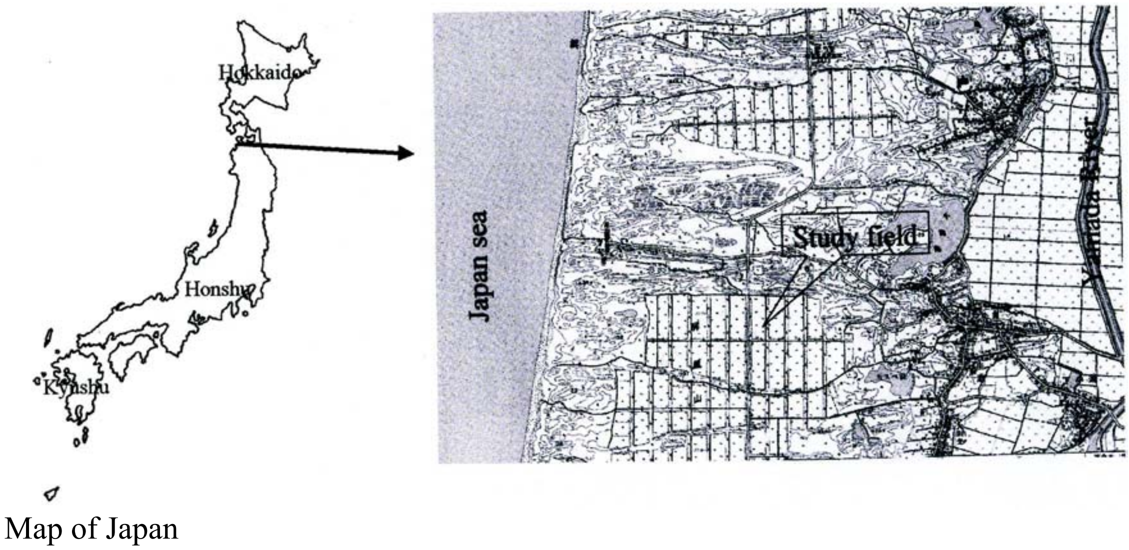

Figure 1. *Location of the study area in northwest Honshu Island.*

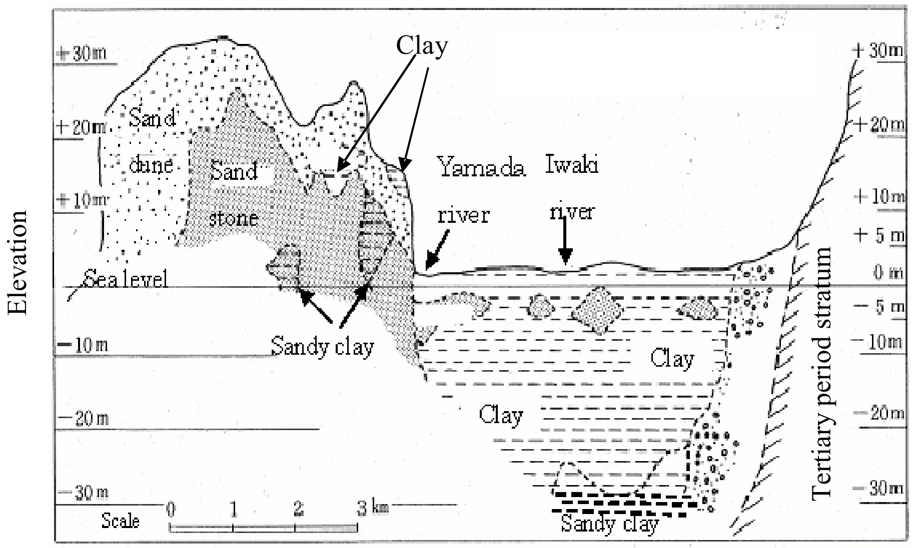

Figure 2. *Cross section of the study area showing geology [5]*

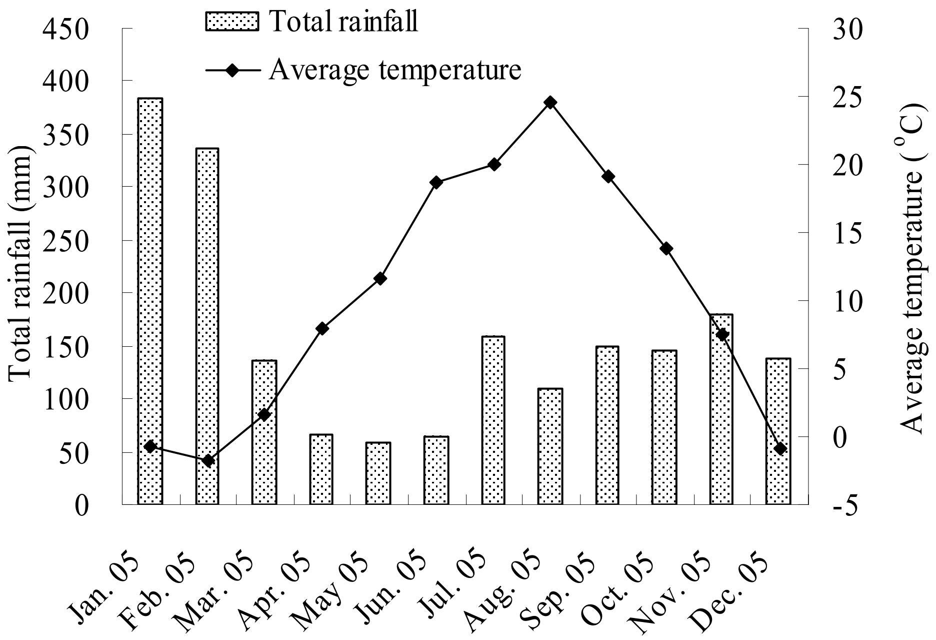

Figure 3. *Monthly total precipitation and average temperature of the study area.*

Sample collection

Three observation wells were installed in the investigated field made of polyvinyl chloride (PVC) pipe to collect the groundwater samples. In every well three plastic tubes with 5 mm diameter were installed to collect the groundwater sample from 2.0 m, 2.5 m and 3.0 m depth. The sampling was performed every month from January to November, 2005. First groundwater was pumped by syringe to rinse the pipe and syringe, and thereafter samples were collected in plastic containers. The samples were then immediately transported to the laboratory of Hirosaki University, Japan, and kept refrigerated until chemical analysis was carried out.

Table 1. *Percentage of total cultivated area covered by different crops in the study area, 1996-2005*

Crop	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
	%									
Wheat	26.1	26.3	24.9	23.3	17.8	18.0	20.0	19.3	13.9	15.7
Radish	26.2	21.1	21.4	22.0	21.2	19.5	17.6	18.7	11.1	11.1
Melon	11.3	10.4	9.1	8.2	7.8	6.4	6.3	4.6	5.7	5.0
Shallot	0.1	0.3	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.1
Chinese yam	7.6	10.2	12.0	12.3	8.7	11.9	13.9	16.0	18.4	18.8
Water melon	3.2	2.7	2.1	2.3	2.5	2.7	2.4	2.3	2.3	2.2
Burdock	5.9	5.2	5.0	6.2	5.5	5.3	5.8	7.2	7.9	8.0
Tobacco	1.9	1.7	2.1	2.2	7.9	2.1	2.6	2.5	3.0	3.2
Potato	2.4	4.0	2.6	2.6	3.2	3.9	4.2	3.0	2.7	2.9
Garlic	0.1	0.6	0.4	0.7	1.3	2.2	1.7	1.9	2.6	3.5

Asparagus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.8
Pumpkin	1.3	1.8	2.6	2.5	2.3	2.6	2.8	4.9	4.8	3.1
Leek	7.7	7.8	9.3	9.4	9.7	7.3	7.7	7.7	7.5	7.1
Carrot	1.4	0.5	0.5	0.8	1.2	1.1	1.0	1.6	1.7	1.9
Others	4.8	7.4	7.9	7.3	10.9	17.1	14.1	10.3	18.2	16.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Groundwater quality analyses

The water samples were analyzed for total dissolved solids (TDS), sodium (Na), calcium (Ca), magnesium (Mg) and phosphate phosphorus (PO_4-P). TDS was measured according to Atekwana et al. [2]. The concentrations of Na, Ca, and Mg were determined by using atomic absorption spectrophotometer (Z8200 Hitachi, Tokyo,

Table 2. *Irrigation water quality of the study area,2005*

Month	pH	EC (dS m^{-1})	DO	Fe	Na	K	Ca	Mg	SAR	Ca:Mg
			mg l^{-1}							
July,05	7.25	0.37	3.90	1.20	41.40	15.00	12.95	5.25	2.44	2.47
August,05	7.24	0.22	5.50	2.20	40.90	9.40	14.00	5.25	2.36	2.67
September,05	7.08	0.26	4.50	1.30	34.30	7.70	10.78	4.90	2.17	2.20
October,05	7.44	0.34	6.00	1.00	50.80	10.40	12.47	6.79	2.86	1.84

Table 3. *Recommended fertilizer rate for some agricultural crops in study area.*

Crops	N	P_2O_5	K2O
	kg ha^{-1}		
Wheat	140	120	100
Radish	200	220	200
Burdock	250	250	250
Melon	130	200	120
Water melon	130	200	120
Potato	170	233	170
Chinese yam	330	238	330
Leek	300	300	300

Table 4. *Physico-chemical properties of soils in study field.*

Texture	Porosity (%)	ρ_b[1] (Mg m^{-3})	ρ_p[2] (Mg m^{-3})	pH	Exchangeable Cations (meq. $100g^{-1}$ soil)			
					Na	Ca	Mg	K
Sand	44.86	1.48	2.68	6.36	0.36	3.06	0.43	0.32

[1]Bulk density; [2]Particle density.

Japan). PO_4-P was measured by using NP autoanalyzer in every month. Sodium absorption ratio (SAR) and total hardness (HT) values were computed from the estimated values of Na, Ca and Mg ion concentrations using the following formulae of Todd [15] and Sawyer and McCarty [14], respectively:

$$SAR= [Na^{+}] /\{([Ca^{2+}]+[Mg^{2+}])\}^{1/2} \quad \text{(Eq. 1)}$$

$$HT = Ca^{2+}\times 2.5+Mg^{2+}\times 4.1 \quad \text{(Eq. 2)}$$

Results and Discussion

Total dissolved solids

Total dissolved solids is the concentration of a solution as the total weight of dissolved solids which express the degree of salainity in a medium. TDS of groundwater was differed with depth (*Fig. 4*). On average the highest TDS value 215.27 mg l^{-1} was observed at 2.0 m depth followed by 2.5 m depth and the lowest value was observed 184.93 mg l^{-1} at 3.0 m depth. The value for TDS of groundwater was decreased with soil depth might be due to slow rate of vertical diffusion of solutes in groundwater. The results indicated that groundwater of the study area was fresh water since water with 0-1000 mg l^{-1} TDS values is classified as fresh water [7].

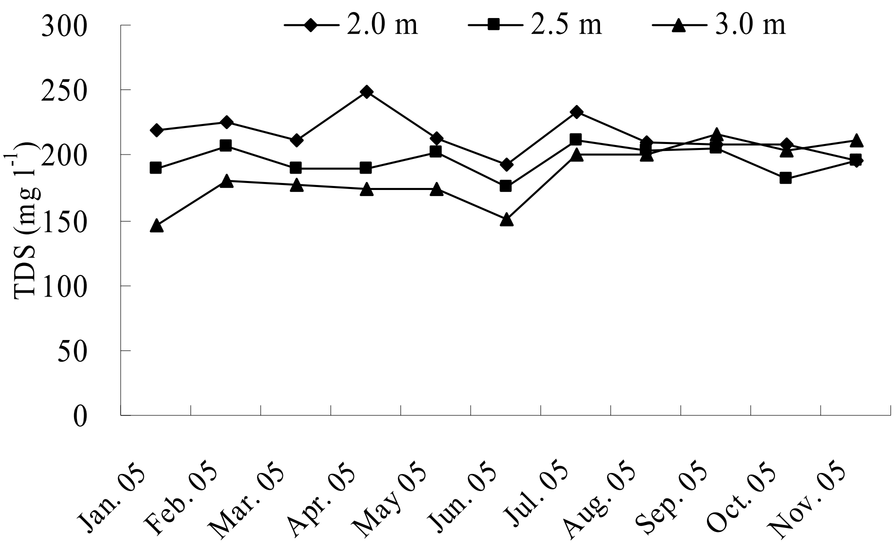

Figure 4. *Total dissolved solids in groundwater at different depth.*

Sodium

Sodium in irrigation water is of concern due to it can deteriorate soil properties and induce leaf burn in sensitive plants at high concentration [3]. Sodium concentration in

groundwater was decreasing with increasing the depth throughout the investigation period (*Fig. 5*). On average the highest sodium concentration (23.15 mg l^{-1}) was observed at 2.0 m followed by 2.5 m and the lowest (14.43 mg l^{-1}) was observed at 3.0 m. The groundwater of the study area is suitable for sprinkler irrigation since, water with <3 me l^{-1} Na has no restriction to use for sprinkler irrigation [3]. Water of Yamada river was used as a source of irrigation which contained 41.85 mg l^{-1}Na, whereas Na concentration in river water of Japan range from 6.70 to 10.60 mg l^{-1}[16]. So it can be assumed that irrigation water from Yamada River might play a vital role as a source of Na in groundwater.

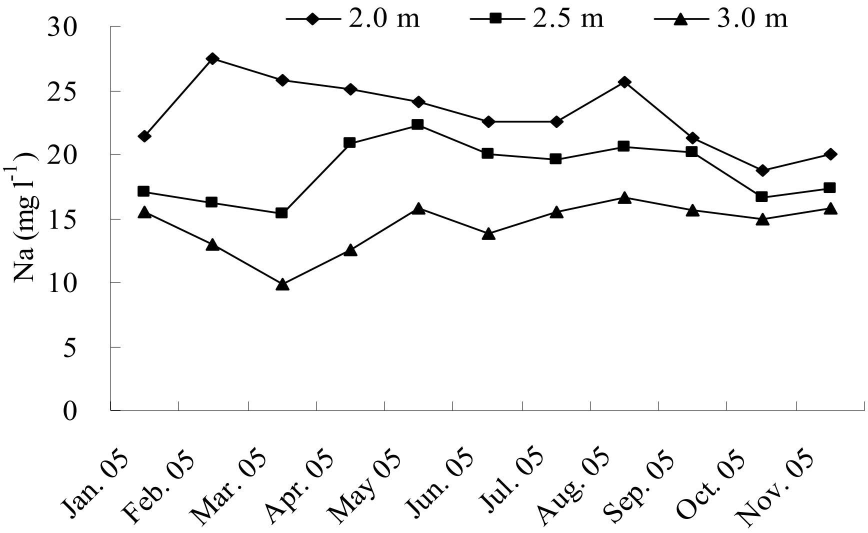

***Figure 5.** Sodium concentration in groundwater at different depth.*

Calcium

Irrigation water containing a high proportion of soluble calcium may form scale inside the irrigation component [11] and form scale like deposits on plant parts when overhead sprinkler irrigation system is used [8]. Calcium concentration was varied in groundwater with depth. The highest Ca concentration was observed at 2.0 m depth and the lowest was at 3.0 m depth throughout the investigation (*Fig. 6*). On average the highest Ca concentration (43.91 mg l^{-1}) was observed at 2.0 m whereas the lowest (15.82 mg l^{-1}) was observed at 3.0 m. Groundwater of the study area is suitable for irrigation since usual range of Ca in irrigation water is 0-20 me l^{-1} [3].

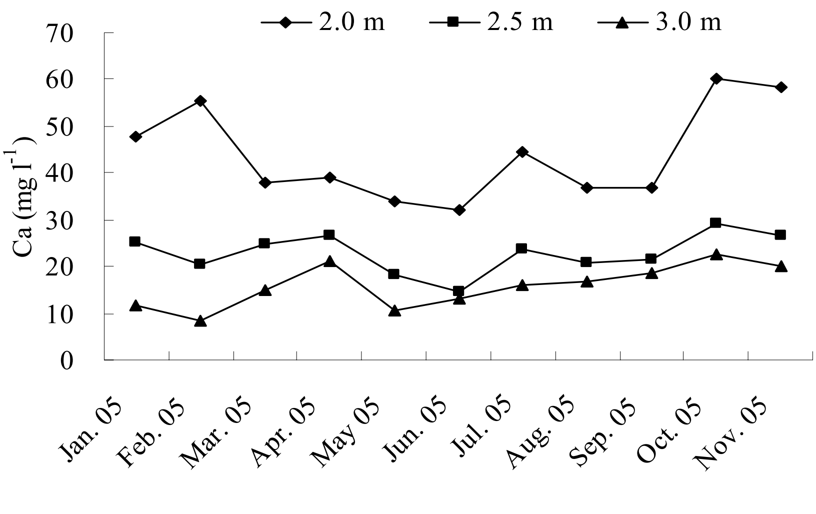

***Figure 6**. Calcium concentration in groundwater at different depth.*

Magnesium

Magnesium is a important element in groundwater which may reduce the crop yield by inducing Ca deficiency at high concentration of Mg [3]. Magnesium concentration in groundwater was varied at different depth (*Fig. 7*). The highest Mg concentration values were observed at 2.0 m depth followed by 2.5 m depth and the lowest values were observed at 3.0 m throughout the investigation period. On avergae the highest Mg concentration (11.56 mg l^{-1}) was obseved at 2.0 m and the lowest (6.83 mg l^{-1}) was obseved at 3.0 m. The usual range of Mg in irrigation water is 0-5 me l^{-1} [3]. So, It can be assumed that groundwater of the study area would be suitable for irrigation.

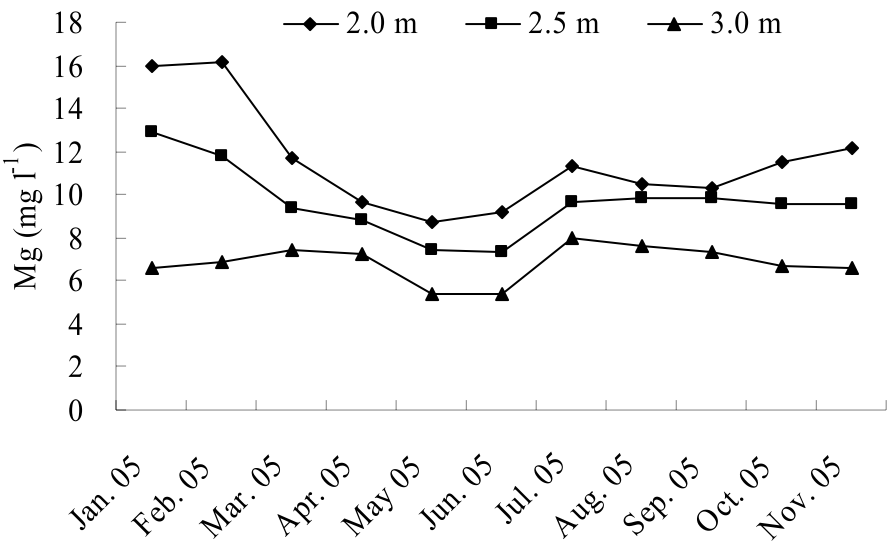

***Figure 7.** Magnesium concentration in groundwater at different depth.*

Sodium absorption ratio

Sodium absorption ratio is the measurement of sodium content relative to calcium and magnesium in soil-water medium which influences soil properties and plant growth. Sodium absorption ratio of groundwater in the study area was observed with in a range of 0.52 to 1.10 (*Fig. 8*). Therefore, the groundwater of the study area is excellent for irrigation since irrigation water with <10 SAR is classified as excellent quality [15]. On average comparatively high SAR values were observed during irrigation period (April-August) than fallow period of land. Yamada River was used as a source of irrigation which contained averagely 41.85 mg l^{-1} Na [9] whereas, Na concentration in river water of Japan range from 6.70 to 10.60 mg l^{-1} [16] and on the other hand comparatively low Ca concentration was observed during that period (*Fig. 6*). On average the highest SAR (0.84) was observed at 2.5 m depth followed 2.0 m and the lowest (0.77) was observed at 3.0 m.

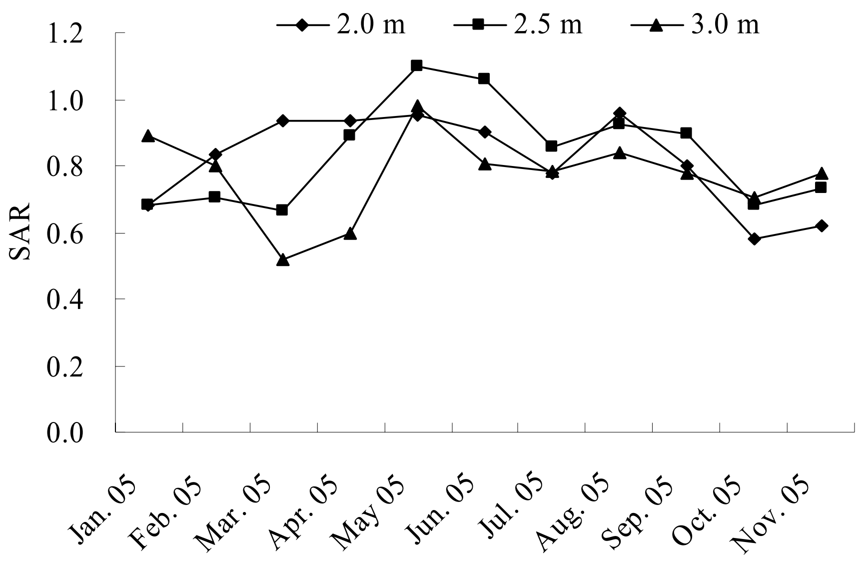

Figure 8. *Sodium absorption ratio of groundwater at different depth.*

Total hardness

Total hardness of water is a measure of dissolved Ca and Mg in water expressed as $CaCO_3$. Total hardness of groundwater in the study area was differed with depth. The highest values of total hardness were observed at 2.0 m depth followed by 2.5 m depth and the lowest values were observed at 3.0 m depth during the investigation period (*Fig. 9*). It might be due to that the highest concentrations of Ca and Mg were at 2.0 m followed by 2.5 m and the lowest were at 3.0 m (*Fig. 6* and *Fig. 7*). On average the highest HT (157.22 mg l^{-1}) was observed at 2.0 m and the lowest (67.61 mg l^{-1}) was observed at 3.0 m. Average HT of groundwater in the study area was observed 107.20 mg l^{-1}. Results indicated that groundwater of the study area can be classified as moderately hard since water with hardness of 75-150 mg $l^{-1}$is moderately hard water [14].

Ratio of calcium and magnesium

Ratio of Ca and Mg in groundwater of the study area was varied with depth. The highest values for Ca and Mg ratios were observed at 2.0 m depth during the investigation period (*Fig. 10*). On average the highest Ca and Mg ratio (3.83) was observed at 2.0 m and the lowest (2.32) was at 3.0 m. Magnesium dominated irrigation water (ratio of Ca/Mg < 1.0) may increase the potential effect of sodium and induce the Ca deficiency [3]. So the results indicated that groundwater of the study area would be suitable for irrigation since ratio of Ca and Mg in groundwater was always >1.0.

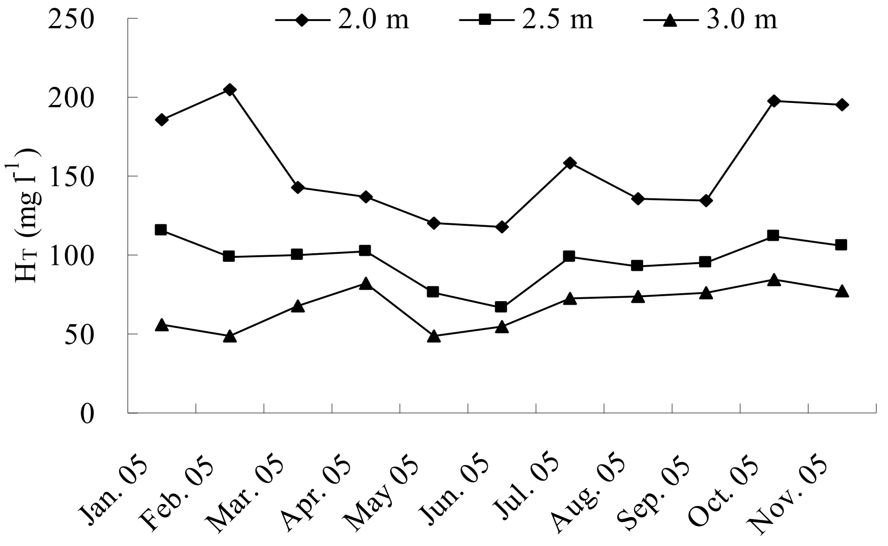

Figure 9. *Total hardness of groundwater at different depth.*

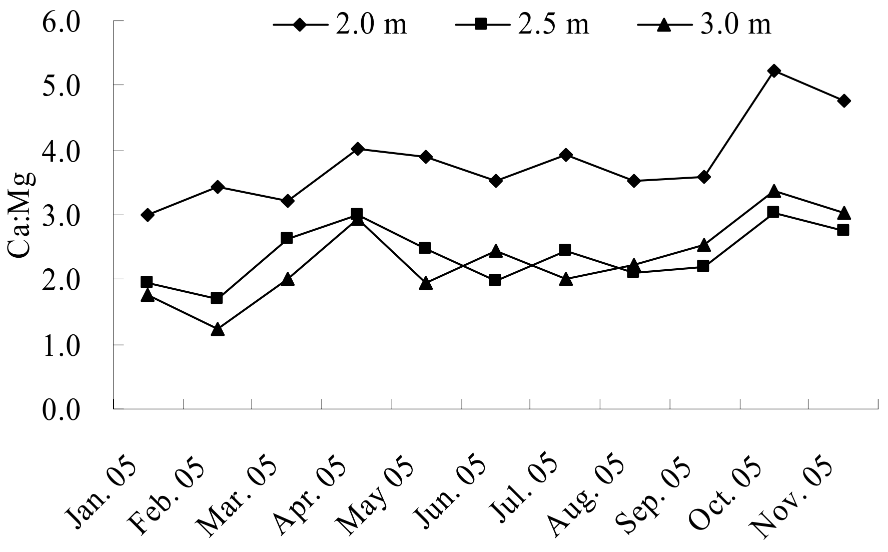

Figure 10. *Ratio of Ca and Mg in groundwater at different depth.*

Phosphate phosphorus

Phosphorus is a soluble agricultural chemical that may be moved from point of application by surface run off or move out of the soil surface layer with percolation. Phosphate phosphorus concentration in ground water of the study area was varied with depth (*Fig. 11*). In average the highest PO_4-P concentration (0.058 mg l^{-1}) was observed at 3.0 m followed by 2.5 m and the lowest (0.042 mg l^{-1}) was at 2.0 m. Our findings indicated that groundwater of the study area would be suitable for irrigation as usual range of PO_4-P concentration in irrigation water is 0-2 mg l^{-1} [3].

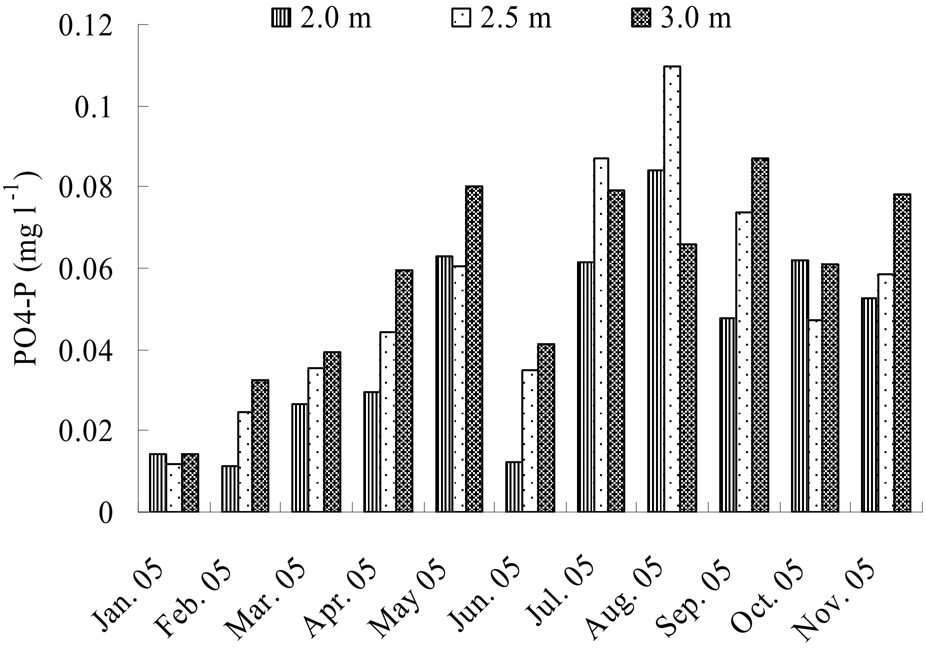

Figure 11. *Phosphate phosphorus concentration in groundwater at different depth.*

Conclusions

According to the findings of this study, TDS, concentrations of Na, Ca, and Mg and total hardness in groundwater of the study area were decreasing with depth, revealed that anthropogenic activities might play a vital role for high values at upper groundwater. Groundwater of the study area contained desirable level of TDS, Na, Ca, Mg, PO_4-P and SAR value for irrigation, indicated that there would not be any possibility of salinity and sodicity hazards from irrigation using groundwater. However, groundwater of the study area was moderately hard. Since concentration of PO_4-P was very low in groundwater, there would not be any threat to eutrophication of surrounding water bodies such as Japan Sea due to PO_4-P in groundwater.

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