

## Applications of Hydrochemical Models for the Assessment of Groundwater

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In this study, we focused on the evaluation and comparison of the physico-chemical characteristics and distribution of cations and anions in groundwater sampled from 2015 (485 samples) to 2016 (145 samples) in rural provinces of Korea. The major objectives of this study were as follows: 1) quality assessment of groundwater for special usage, such as agricultural or industrial applications; 2) the determination of groundwater types; and 3) the tracing of ion sources in groundwater. The assessment of the groundwater qualities from 2015 (n=480 samples) to 2016 (n=145 samples) for agricultural usages were conducted using SAR (Sodium Adsorption Ratio), Na(%), RSC (Residual Sodium Carbonate), PI (Permeability Index), SSP (Soluble Sodium Percent), MH (Magnesium Hazard), KR (Kelly's Ratio) and PS (Potential soil Salinity). Furthermore, the results of samples in 2015 were classified as SAR [Excellent (100%)], Sodium [(Excellent (34%), Good (55%), Permissible (9%), Doubtful (1.6%), Unsuitable (0.4%)], RSC [(Good (95.7%), Medium (3.5%), Bad (0.8%)], PI [(Excellent (40.6%), Good (59%), Unsuitable (0.4%)], SSP [(Excellent (26.3%), Good (59.8%), Fair (13.1%), Poor (0.8%)], MH [(Acceptable (94.4%), Non-Acceptable (5.6%)], and Kelly's Ratio [(Permissible (93%), Non-Permissible (7%)], PS [(Excellent to Good (98%), Good to Injurious (1.2%), and Injurious to Unsatisfactory (0.2%)]. In addition, the groundwater sampled in 2016 was classified as SAR [Excellent (100%)], Sodium [Excellent (2.1%), Good (51.1%), Permissible (39.3%), Doubtful (6.2%), Unsuitable (0.7%)], RSC [Good (100%)], PI [Excellent (100%)], SSP [Excellent (0.7%), Good (37.2%), Fair (61.4%), Poor (0.7%)], MH [Acceptable (96.6%), Non-Acceptable (3.4%)], KR [Permissible (69.7%), (Non-Permissible (30.3%)), and PS [Excellent to Good (100%)]. Evaluations based on the Wilcox diagram were classified as "excellent to good" or "good to permissible" and the water quality evaluated using the U.S. Salinity Laboratory's Diagram was classified as C1S1 (Excellent/Excellent) and C2S1 (Good/Excellent) for all samples from 2015 to 2016. Moreover, in the application of two factors of the Langelier Saturation Index (LSI) and Corrosive ratio (CR), we obtained similar results for defining the suitability of groundwater for industrial purposes.

**Key words:** Geochemical characteristics, Wilcox diagram, US salinity laboratory's diagram, Langelier saturation index, Corrosivity ratio

### 1. Introduction

Groundwater is the water present beneath Earth's surface in soil pore spaces and in the fractures in rock formations. A unit of rock or an unconsolidated deposit is called an aquifer when it can yield a usable quantity of water. Groundwater is recharged from, and eventually flows to, the surface nat-

urally; it is also often withdrawn for agricultural, municipal, and industrial uses by constructing and operating extraction wells. Typically, groundwater is thought of as water flowing through shallow aquifers, but, in a technical sense, it also includes soil moisture, permafrost, immobile water in very low permeability bedrock, and deep geothermal or oil formation water<sup>1-3</sup>. Groundwater is naturally reple-

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nished when surface water from precipitation, streams, and rivers when reaches the water table. Additionally, groundwater can be a long-term reservoir of a natural water cycle, having residence times ranging from a few days to millennia, as opposed to short-term water reservoirs like the atmosphere and fresh surface water. Therefore, in this natural process, it is well known that there are many physically and chemically phenomena initiated by the interactions between the groundwater body and soil-rock systems. As a result, the groundwater quality is a consequence of the physical and chemical state of the water as well as any alterations that may have occurred as a consequence of human activity and microbial activities in soils. Therefore, numerous studies have been carried out to assess the geochemical characteristics of groundwater affected by contamination from human influences such as sewage effluents and agricultural fertilizer, as well as other processes such as ion-exchange, evapotranspiration and water-rock interactions, which result in an increase in the ion concentration, making the water unfit for drinking and agricultural purposes<sup>4-6</sup>). In this study, many diagram models and assessment equations were applied to determine the groundwater quality for agricultural and industrial usages and to deduce water-rock interactions for the groundwater samples from 2015 to 2016. Over two years, groundwater samples were collected in the Pre-Monsoon season (PRM; June) and Post-Monsoon season (POM; July-November) to broadly cover the seasonal variations. First, the assessment of groundwater for agricultural purposes was performed using SAR (Sodium Adsorption Ratio), Na (%), RSC (Residual Sodium Carbonate), PI (Permeability Index), SSP (Soluble Sodium Percent), MH (Magnesium Hazard), KR (Kelly's Ratio) and PS (Potential soil Salinity) equations. The Wilcox diagram, based on Na (%) and electrical conductivity, as well as the U.S. salinity Laboratory's Diagram, based on SAR and electrical conductivity, are also used to evaluate water quality for agricultural usage.<sup>7-9</sup>) Additionally,

the water samples were assessed for their suitability for industrial usage by applying factors such as the LSI (Langelier Saturation Index) and CR (Corrosivity Ratio).

## 2. Material and Experimental Methods

### 2.1. Sampling preparation and measurement of on-site items

In order to obtain a representative groundwater sample for chemical analysis, it is important to remove stagnant water from the well casing and the water immediately adjacent to the well before collection of the sample. This may be achieved with one of a number of sampling devices. The most common of these devices are the bailer, submersible pump, non-contact gas bladder pump, inertia pump and suction pump. At a minimum, three well volumes should be purged, if possible. The equipment must be decontaminated prior to use and between each well. Once purging is completed and the proper sample containers have been prepared, sampling may proceed. Samples should be collected from the depth interval at which contaminants are expected, but need not be collected with the same device used for well purging. However, some sampling methods will affect the sample integrity and care should be taken when choosing the sampling device. If possible, sampling should occur progressively from the least to most contaminated well. Therefore, samples collected after pumping a significant volume of water from the well may be considered as representative of groundwater, unlike samples collected using methods designed to focus on a specific purpose. Owing to the importance of achieving "the least disturbance or change in the chemical and physical properties" of water samples, we followed the guideline for groundwater sampling and in situ measurement for on-site items. A total of 486 samples in 2015 and 145 samples in 2016 were collected in one-liter, acid-washed, well-rinsed, low-density polyethylene bottles with inside stop-

pers from bore wells and analyzed for their chemical parameters following the guidelines. The samples were collected after pumping the wells for a sufficient amount of time, approximately 15–20 min, and by subsequent filtering through 0.45 µm membranes. The analyzed parameters for the in-situ fields include the activity of hydrogen ion concentration (pH), electrical conductivity (EC), total hardness (TH), total dissolved solids (TDS) and cation groups, such as calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), sodium ( $\text{Na}^+$ ), and potassium ( $\text{K}^+$ ), and anion groups like bicarbonate ( $\text{HCO}_3^-$ ), chloride ( $\text{Cl}^-$ ), nitrate ( $\text{NO}_3^-$ ), and phosphate ( $\text{PO}_4^{3-}$ ). The pH and electrical conductivity (EC) were measured using pH and EC meters. All anions and cations were analyzed by ion chromatography (Dionex) and the analytical conditions of anion and cation for groundwater are shown in Table 1. Following the guidelines, quality controls and quality assurances were undertaken by checking every step for the guarantee of miscellaneous factors, such as the following: calibration curves, blanks, sample preservations, duplicate samples, and standards.

## 2.2. Estimations of groundwater quality for agricultural usage

Groundwater resources play a major role in ensuring livelihood security across the world, especially in economies that depends on agriculture. Many parameters are used to define irrigation water quality, to assess salinity hazards, and to determine appropriate management strategies. A complete water quality analysis will include the determination of factors such as the following: 1) the total concentration of soluble salts, 2) the rela-

tive proportion of sodium to the other cations, 3) the bicarbonate concentration relative to the concentration of calcium and magnesium, and 4) the concentration of specific elements and compounds. Therefore, the amounts and combinations of these substances define the suitability of water for irrigation and the potential for plant toxicity. In most irrigation situations, the primary water quality parameter is the salinity level, since salts can affect both the soil structure and crop yield. However, a number of trace elements are found in water that can limit its use for irrigation. From this point of view, in this study, we placed more emphasis on the suitability of groundwater for irrigation of farm fields and rice fields, because most of the sampling sites are located in the rural areas of the middle and southern provinces of Korea. As was mentioned, irrigation waters pumped from wells contain considerable chemical constituents derived from the natural soil environment and human activities that may influence crop yield and soil fertilities. The irrigation of groundwater to the rice field and farm field always introduces major nutrients and salts into the root zone. Naturally, plant roots take in water, but absorb very little salt from the soil solution. Similarly, water evaporates from the soil surface, but salts remain behind. These processes result in a gradual accumulation of salts in the root zone, affecting the plants by creating a salinity hazard, water deficiency, and toxicity. To compensate for such problems, it is necessary to obtain logical and scientific information concerning the quality of irrigation water and its effect on soils and crops. Therefore, in this study, major assessment methods for the groundwater

**Table 1.** Analytical conditions of anion and cation for groundwater

Items	Anion	Cation
Column	Ion Pac AS12A (25 cm (L.), 4 mm × 250 mm)	Ion Pac CS12A, 4 mm × 250 mm
Eluent	3.5 mM sodium carbonate + 1.0 mM sodium-bicarbonate	Methanesulfonic acid 20 mM
Velocity of eluent	1.2 mL/min.	1.0 mL/min
Injection volume	50 µL	50 µL
Detector	Electric conductivity detector	Electric conductivity detector

quality assurance were applied to obtain the following key parameters: SAR, Na (%), RSC, PI, SSP, MH, Kelly's Ratio, and PS; all equation are shown in Table 2.

#### 2.2.1. SAR (Sodium Adsorption Ratio)

The sodium adsorption ratio, also expressed as the sodium content or alkali hazard, is very important for determining the quality of water used for irrigation purposes. Higher salinity reduces the osmotic activity of plants and prevents water from reaching the branches and leaves of plants resulting in inferior production. Moreover, irrigation water with high  $\text{Na}^+$  and low  $\text{Ca}^{2+}$  content favors ion exchange by saturation of  $\text{Na}^+$ , destroying the soil structure by dispersion of clay particles, resulting in lowered production due to difficulty in cultivation.

#### 2.2.2. Na (%)

Sodium is an important ion used for the classification of irrigation water owing to its reaction with soil that reduces its permeability. The percentage of  $\text{Na}^+$  is widely used for assessing the suitability of water for irrigation purposes.  $\text{Na}^+$  is expressed as the percent of sodium or soluble-sodium percentage (Na (%)).

#### 2.2.3. RSC (Residual Sodium Carbonate)

The sum of carbonates and bicarbonates over the sum of calcium and magnesium in water influences how fit the ground-water is for irrigation purposes. An excess of sodium bicarbonate and carbonate influences the physical properties of soil by dissolution of organic matter in soil that leaves a black stain on the surface upon drying.

#### 2.2.4. PI (Permeable Index)

The permeability of soil is influenced by the sodium, calcium, magnesium and bicarbonate contents in soil, which also influences the quality of irrigation water for long term use. Doneen has evolved a criterion for assessing the suitability of

water for irrigation based on the PI.

#### 2.2.5. SSP (Soluble Sodium Percentage)

The Soluble Sodium Percentage (SSP) is also used for the assessment of irrigation water quality, as an important factor in studying the sodium hazard. SSP is defined as the ratio of sodium to the total number of cations multiplied by 100. A high sodium ( $\text{Na}^+$ ) percentage can decrease soil permeability and inhibit plant growth.

#### 2.2.6. MH (Magnesium Hazard)

The  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  ions maintain a state of equilibrium in most groundwater. In equilibrium,  $\text{Mg}^{2+}$  in water affects the soil by making it alkaline and results in a decrease of crop yield. The measure of the effect of magnesium in irrigated water is expressed as the magnesium ratio; Paliwal developed an index for calculating the magnesium hazard.

#### 2.2.7. Kelly's Ratio (KR)

Kelly's Ratio is used for the classification of water for irrigation purposes. A KI ( $>1$ ) shows an excess of sodium and KI ( $<2$ ) signifies its deficit in water. Water with low KI ( $< 1$ ) is suitable for irrigation while that with a greater ratio is unsuitable.

#### 2.2.8. PS (Potential Salinity)

Doneen pointed out that the suitability of water for irrigation is not dependent on the concentrations of soluble salts. Doneen is of the opinion that the low soluble salts get precipitated into the soil and accumulate with each successive irrigation, whereas the concentrations of highly soluble salts enhance the salinity of the soil. Potential salinity is defined as the chloride concentration plus half of the sulfate concentration.

### 2.3. Estimations of groundwater quality as an industrial usage

The stability of water is the tendency of water

**Table 2.** Equations and classifications for evaluating of groundwater<sup>10-14)</sup>

Items	Equations	Classifications	References
SAR	$[(Na^+) / \sqrt{[(Ca^{2+} + Mg^{2+}) / 2]}]$	Excellent, Good, Permissible, Doubtful	Richards (1954)
Na (%)	$[(Na^+ + K^+) / (Ca^{2+} + Mg^{2+} + K^+ + Na^+)] \times 100$	Excellent, Good, Permissible, Doubtful, Unsuitable	Wilcox (1954)
RSC	$(HCO_3^- + CO_3^{2-}) - (Ca^{2+} + Mg^{2+})$	Good, Medium, Bad	Richards (1954)
PI	$[[Na^+ + \sqrt{HCO_3^-}] / [Ca^{2+} + Mg^{2+} + Na^+]] \times 100$	Excellent, Good, Unsuitable	Doneen (1964)
SSP	$[(Na^+ + K^+) / (K^+ + Na^+ + Ca^{2+} + Mg^{2+})] \times 100$	Excellent, Good, Fair, poor	Richards (1954)
MH	$[(Mg^{2+}) / (Ca^{2+} + Mg^{2+})] \times 100$	Suitable, Unsuitable	Paliwal (1972)
Kelly's Ratio	$[(Na^+) / (Ca^{2+} + Mg^{2+})]$	Permissible, Non-Permissible	Kelly (1940)
PS	$Cl^- + \sqrt{SO_4^{2-}}$	Excellent to Good, Good to Injurious, Injurious to Unsatisfactory	Doneen (1954, 1964)

to either dissolve or deposit minerals varying with its chemical makeup. Water that tends to dissolve minerals is considered corrosive and that which tends to deposit minerals is considered scaling. Corrosive water can dissolve minerals like calcium and magnesium, as well as dissolve harmful metals such as lead and copper from plumbing utilities. Meanwhile, scaling waters deposit a film of minerals on pipe walls and may prevent corrosion of metallic surface. If the scale deposition is too rapid, it also can be harmful and can damages appliances, such as water heaters, and increase pipe friction coefficients and, in extreme cases, may clog pipes. Therefore, the water saturation index is used to assess whether water is precipitating out, dissolving or in equilibrium with calcium carbonate. Indices like LSI, and CR<sup>15)</sup> have been calculated to understand groundwater industrial suitability and each of the equations used (all units are in mg/l) are from Eqs. (1) to (2) as the LSI and CR were only applied for the samples of 2015, because there were no groundwater samples for the industrial usages in 2016.

$$\text{Langelier Saturation Index (LSI)} = \text{pHw} - \text{pHs} \quad (1)$$

$$\begin{aligned} \text{Where pHw} &= \text{measured pH, and pHs} \\ &= [9.3 + A + B] - [C + D] \end{aligned}$$

$$A = [\log_{10} (\text{TDS}) - 1] / 10$$

$$B = -13.12 \times \log_{10} (^\circ\text{C} + 273) + 34.55$$

$$C = \log_{10} [Ca^{2+} \text{ as } CaCO_3] - 0.4$$

$$D = \log_{10} [\text{Alkalinity as } CaCO_3]$$

Corrosivity Ratio (CR)

$$= \left[ \frac{Cl^-}{35.5} + \frac{SO_4^{2-}}{48} \right] \sqrt{\left[ \frac{CO_3^{2-} + HCO_3^-}{50} \right]} \quad (2)$$

### 3. Result and Discussions

#### 3.1. Chemical parameters of groundwater

The behaviors of major ions ( $Ca^{2+}$ ,  $Mg^{2+}$ ,  $Na^+$ ,  $K^+$ ,  $HCO_3^-$ ,  $SO_4^{2-}$ ,  $Cl^-$ ) and important physico-chemical parameters, such as pH, electrical conductivity (EC), total dissolved solids (TDS), and total hardness (TH), are classified as parameters for determining the suitability of a special purpose. In particular, pH and EC are regarded as important tools for the rough parameters about the general feature of groundwater. The pH is a measure of the balance between the concentration of hydrogen ions and hydroxyl ions in water. The pH of water provides vital information in many types of geochemical equilibrium or solubility calculations. Additionally, electrical conductivity is a measure of water's capacity to convey electrical current and the value of electrical conductivity may be an approximate index of the total content of a dissolved substance in water. It depends upon temperature, concentration and the types of ions present in the groundwater body. In this study, pH, electrical conduc-

tivity (EC), dissolved oxygen (DO), and oxidation-reduction potential (ORP) were measured on site. In Tables 3 and 4, the patterns of pH, EC, DO, and ORP of samples from 2015 to 2016 are recorded. In the case of the 2015 samples, the results of the on-site measurement were shown to be 6.1~8.8 for pH and 24~1,885  $\mu\text{S}/\text{cm}$  for EC, 0.3~11 mg/L for DO, and -19.4~460 mV for ORP. In Table 4, the results of on-site measurement for the 2016 samples are shown to be 5.7~8.7 for pH and 49~1,224  $\mu\text{S}/\text{cm}$  for EC, 0.5~11.8 mg/L for DO, and -53.0~456.0 mV for ORP.

### 3.2. Distribution patterns of cation and anion

Calcium and magnesium are the most abundant elements in the natural surface water and groundwater, and exist mainly as bicarbonates and, to a lesser degree, in the form of sulfates and chlorides. The higher  $\text{Ca}^{2+}$  content can cause abdominal ailments and is undesirable for domestic uses as it causes encrustation and scaling. The maximum permissible limit of  $\text{Mg}^{2+}$  concentrations in

drinking water is specified as 100 mg/l and 150 mg/l (WHO 2004)<sup>16</sup>. Sodium ranks sixth among the elements in order of abundance and is present in most natural water. Sodium is generally found in lower concentrations than  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  in freshwater. The maximum permissible limit of sodium is 200 mg/l, and groundwater with a high Na content is not suitable for agricultural use as it tends to deteriorate the soil. Potassium is a naturally occurring element, however, its concentration remains significantly lower than those of  $\text{Ca}^{2+}$ ,  $\text{Mg}^{2+}$  and  $\text{Na}^+$ . Additionally, in the case of anions, we focused on the distributions of  $\text{HCO}_3^-$ ,  $\text{SO}_4^{2-}$ , and Cl<sup>-</sup>. A higher concentration of  $\text{HCO}_3^-$  in the water points to the dominance of mineral dissolution (Stumm and Morgan 1996)<sup>17</sup>. Furthermore, sulfates are one of the major anions occurring in natural water. The upper limit for sulfate concentration for drinking water is 150 mg/l. The origin of chlorides in groundwater may be from diverse sources, such as weathering, leaching of sedimentary rocks and soils, intrusion of saltwater,

**Table 3.** pH, EC, DO, ORP values (Average) of samples (n=483, 2015)

Month	Items	pH			EC ( $\mu\text{S}/\text{cm}$ )			DO (mg/L)			ORP (mV)		
		Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.
Jun. (n=206).		7.0	6.1	8.8	181	51	959	7.2	2.2	10.9	181.6	0	301
Jul. (n=33)		7.2	6.4	8.3	180	75	447	5.6	4.6	11	166.8	30	258
Sep. (n=194)		6.9	6.1	8.4	164	24	1033	3.8	0.3	6.1	186.2	54	270
Oct. (n=33)		7.2	6.6	7.8	194	79	511	4.9	3.1	5.3	211.4	146	245
Nov. (n=17)		7.7	6.2	8.5	329	82	1885	6.2	3.2	7.9	210.7	-19	460
Total ave. (n=483)		7.0	6.1	8.8	180	24	1885	5.5	0.3	11	185.5	-19	460
Seasonal (483)	pre-monsoon	7.0	6.1	8.8	181	51	959	7.2	2.2	10.9	181.6	0.0	301
	post-monsoon	7.0	6.1	8.5	179	24	1885	4.3	0.3	11.0	188.4	-19	460

**Table 4.** pH, EC, DO, ORP values (Average) of samples (n=145, 2016)

Month	Items	pH			EC ( $\mu\text{S}/\text{cm}$ )			DO (mg/L)			ORP (mV)		
		Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.	Aver.	Min.	Max.
Jun. (n=37)		6.9	5.8	7.9	407	109	1224	4.4	0.5	10.8	187.2	-9.0	456.0
Jul. (n=28)		7.0	6.3	8.7	412	117	1108	5.4	1.8	9.4	214.5	-26.6	381.0
Sep. (n=59)		7.1	5.8	8.2	151	49	321	6.3	0.7	11.8	292.1	-53.0	697.0
Oct. (n=11)		6.3	5.7	7.1	366	337	411	5.8	2.1	11.1	296.7	102.0	653.0
Nov. (n=10)		6.8	6.3	7.6	310	103	659	4.3	1.8	10.1	15.4	13.2	17.8
Total ave. (n=145)		6.9	5.7	8.7	294	49	1224	5.5	0.5	11.8	256.1	-53.0	697.0
Seasonal (n=145)	Pre-monsoon	6.9	5.8	7.9	407	109	1224	4.4	0.5	10.8	187.2	-9.0	456.0
	Post-monsoon	7.0	5.7	8.7	250	49	1108	6.0	0.7	11.8	270.4	-53.0	697.0

windblown salt in precipitation, domestic and industrial waste discharges, municipal effluents, etc. (Karanth 1987)<sup>18)</sup>. In natural water, the concentration of Cl<sup>-</sup> bears a strong correlation with the Na<sup>+</sup> content and specific conductance. Chloride determination may serve to indicate the intrusion of waters of different compositions or to trace and measure rates and volumes of water mass movements. From Tables 5 to 8, the patterns of cations (Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup>) and anions (HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup>) are shown for samples from 2015 to 2016. In the case of the 2015 samples, the total ranges of concentrations for the cations are shown to be 2.6~229.9 mg/L for Ca<sup>2+</sup> and 0.2~62.0 mg/L for Mg<sup>2+</sup>, 0.5~178.7 mg/L for Na<sup>+</sup>, 0.0~124.4 mg/L for K<sup>+</sup>. And in the case of anions the concentrations are shown to be 9.7~962.3 mg/L for HCO<sub>3</sub><sup>-</sup> and 4.8~473.8 mg/L for CO<sub>3</sub><sup>2-</sup>, nd~98.0 mg/L for SO<sub>4</sub><sup>2-</sup>, 1.0~512.0 mg/L for Cl<sup>-</sup>. In addition, in the case of 2016 samples, the concentration ranges of cations are shown to be 5.2~124.4 mg/L for Ca<sup>2+</sup> and 1.0~25.0 mg/L for Mg<sup>2+</sup>, 4.5~112.8

mg/L for Na<sup>+</sup>, nd~38.1 mg/L for K<sup>+</sup>. And in anions the concentrations are shown to be 17.1~285.2 mg/L for HCO<sub>3</sub><sup>-</sup> and 8.4~140.4 mg/L for CO<sub>3</sub><sup>2-</sup>, nd~60.8 mg/L for SO<sub>4</sub><sup>2-</sup>, 4.0~167.0 mg/L for Cl<sup>-</sup>.

### 3.3. Assessment of groundwater for the agricultural usages

The suitability of groundwater for irrigation is contingent on the effects of the mineral constituents in the water of both the plants and soil. Salts may harm plants' growth physically, by limiting the uptake of water through modification in the osmotic processes, or chemically, by metabolic reactions, such as those caused by toxic constituents. The effects of salts on soils cause changes in soil structure, permeability, and aeration, which indirectly affect plant growth. An important factor allied to the relation of crop growth to water quality is drainage. If soil is open and well drained, crops may be grown on it with the application of generous amounts of saline water.

**Table 5.** Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup> values (Average, Minimum, Maximum) (n=483, 2015)

Month	Cations			Ca <sup>2+</sup>			Mg <sup>2+</sup>			Na <sup>+</sup>			K <sup>+</sup>			
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	
Jun. (n=206)	36.8	2.6	229.9	8.0	0.5	60.3	17.5	0.5	68.7	2.4	nd	40.9				
Jul. (n=33)	32.4	7.7	102.8	3.5	0.3	20.0	17.4	4.9	54.9	5.4	0.7	19.4				
Sep. (n=194)	32.2	3.3	189.4	6.7	0.3	62.0	16.5	0.9	178.1	2.4	0.2	23.6				
Oct. (n=33)	37.3	9.0	147.0	7.8	1.0	35.4	23.8	5.6	178.7	7.2	0.3	124.4				
Nov. (n=17)	45.1	13.3	138.8	6.7	0.2	28.3	18.9	4.8	52.0	9.2	0.4	72.9				
Total average (n=483)	35.0	2.6	229.9	7.1	0.2	62.0	17.5	0.5	178.7	3.1	nd	124.4				
Seasonal average (483)	pre-monsoon	36.8	2.6	229.9	8.0	0.5	17.5	17.5	0.5	68.7	2.4	nd	40.9			
	post-monsoon	33.6	3.3	189.4	6.4	0.2	17.6	17.6	0.9	178.8	3.7	0.2	124.4			

**Table 6.** HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup> values (Average, Minimum, Maximum) (n=483, 2015)

Month	Anions				HCO <sub>3</sub> <sup>-</sup>			CO <sub>3</sub> <sup>2-</sup>			SO <sub>4</sub> <sup>2-</sup>			Cl <sup>-</sup>		
	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	
Jun. (n=206)	92.2	2.4	875.8	45.4	1.20	431.2	19.0	nd	65.0	28.0	3.0	512.0				
Jul. (n=33)	85.8	14.6	231.6	42.2	7.21	114.0	18.6	0.5	70.2	24.0	3.0	98.0				
Sep. (n=194)	88.0	3.6	861.2	43.3	1.80	424.0	17.0	2.0	98.0	25.0	1.0	247.0				
Oct. (n=33)	163.3	24.4	1761.9	80.4	12.01	867.5	14.1	2.0	79.0	37.0	3.0	248.0				
Nov. (n=17)	141.4	9.7	962.3	69.6	4.81	473.8	19.0	4.0	33.0	44.0	3.0	271.0				
Total average (n=483)	96.7	2.4	1761.9	47.6	1.20	867.5	17.9	nd	98.0	28.0	1.0	512.0				
Seasonal average (483)	pre-monsoon	92.2	2.4	875.8	45.4	1.20	431.2	19.0	nd	65.0	28.0	3.0	512.0			
	post-monsoon	100.0	3.66	1761.9	49.2	1.80	867.5	17.0	0.56	98.0	27.0	1.00	271.0			

**Table 7.** Ca<sup>2+</sup>, Mg<sup>2+</sup>, Na<sup>+</sup>, K<sup>+</sup> values (Average) (n=145, 2016)

Month	Cations	Ca <sup>2+</sup>			Mg <sup>2+</sup>			Na <sup>+</sup>			K <sup>+</sup>		
		Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Jun. (n=37)		37.6	11.1	118.4	7.8	1.7	17.3	22.0	6.3	105.3	4.1	0.0	37.7
Jul. (n=28)		44.6	12.0	124.4	9.4	3.0	18.9	25.3	5.4	112.8	5.5	0.9	38.1
Sep. (n=59)		33.0	5.7	108.8	6.6	1.0	25.0	18.9	5.1	71.7	2.4	0.1	33.6
Oct. (n=11)		36.6	9.7	112.6	6.0	2.5	11.8	14.7	4.6	23.6	6.4	0.8	34.9
Nov. (n=10)		33.7	9.7	111.6	6.2	2.6	11.6	14.2	4.5	23.7	6.7	1.2	32.6
Total average (n=145)		36.7	5.2	124.4	7.4	1.0	25.0	20.3	4.5	112.8	4.0	nd	38.1
Seasonal average (n=145)	Pre-monsoon	37.6	11.1	118.4	7.8	1.7	17.3	22.0	6.3	105.3	4.1	nd	37.7
	Post-monsoon	36.7	5.7	124.4	7.4	1.0	25.0	20.3	4.6	112.8	3.8	0.1	38.1

**Table 8.** HCO<sub>3</sub><sup>-</sup>, CO<sub>3</sub><sup>2-</sup>, SO<sub>4</sub><sup>2-</sup>, Cl<sup>-</sup> values (Average) (n=145, 2016)

Month	Anions	HCO <sub>3</sub> <sup>-</sup>			CO <sub>3</sub> <sup>2-</sup>			SO <sub>4</sub> <sup>2-</sup>			Cl <sup>-</sup>		
		Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.	Ave.	Min.	Max.
Jun. (n=37)		98.6	31.7	285	48.6	15.6	140.4	19.4	nd	57.2	32.0	5.0	160.0
Jul. (n=28)		96.9	21.9	282.3	47.7	10.8	139.0	19.7	1.4	60.8	34.0	5.0	167.0
Sep. (n=59)		87.6	26.8	263.4	43.2	13.2	129.7	14.4	3.0	51.0	22.0	4.0	74.0
Oct. (n=11)		98.5	23.2	259.7	48.5	11.4	127.9	14.7	nd	34.0	20.0	4.0	49.0
Nov. (n=10)		82.8	17.1	263.3	40.8	8.4	129.6	14.1	3.0	30.0	19.0	4.0	47.0
Total average (n=145)		92.7	17.1	285.2	45.7	8.4	140.4	16.7	nd	60.8	27.0	4.0	167.0
Seasonal average (n=145)	Pre-monsoon	98.6	31.7	285.2	48.6	15.6	140.4	19.4	nd	57.2	32.0	5.0	160.0
	Post-monsoon	91.5	21.9	282.3	45.1	10.8	139.0	16.0	2.0	60.8	25.4	4.0	167.0

On the other hand, a poorly drained area combined with the application of good quality water may fail to produce as satisfactory a crop. The important hydrochemical parameters of groundwater used to determine its suitability for irrigation are EC, Salinity, percent sodium (Na (%)), Sodium Adsorption Ratio (SAR), RSC, Permeability Index (PI) and the Magnesium Ratio. As a result of applying the equations and classifications for evaluating of groundwater, we could obtain the following classifications.

### 3.3.1. Sodium Adsorption Ratio (SAR)

SAR is an important parameter for determining the suitability of groundwater for irrigation because it is an alkali/sodium hazard to crops (Subramani et al., 2005).<sup>19)</sup> All concentrations are expressed in meq/l. SAR can indicate the degree to which irrigation water tends to enter cation-exchange reactions in soil. Richards classified four categories based on SAR values; “excellent (<100), good (20-

40), doubtful (18-260), unsuitable (>80)”. On the basis of SAR, samples in both 2015 and 2016 can be classified as 100% excellent.

### 3.3.2. Na (%)

Sodium replacing adsorbed calcium and magnesium is a hazard, as it damages the soil structure and renders it compact and impervious. As a result, sodium concentration is important in classifying irrigation water, because it reacts with soils to reduce its permeability. Based on the Na (%) classification, 34.3% of the samples fall in excellent, 55.2% of samples fall in good and 8.2% samples fall in permissible for the samples of 2015. Of the samples from 2016, 2.1% of the samples fall in excellent, 51.7% of samples fall in good and 39.3% samples fall in permissible.

### 3.3.3. Residual Sodium Carbonate (RSC)

Residual sodium carbonate (RSC) also influences the suitability of water for use in irrigation. RSC

can be estimated by subtracting the quantity of alkaline earths ( $\text{Ca}^{2+} + \text{Mg}^{2+}$ ) from the carbonates ( $\text{CO}_3^{2-} + \text{HCO}_3^-$ ). When the sum of carbonates is in excess of calcium and magnesium, there is a possibility of the complete precipitation of  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$ . If the carbonates are less abundant than alkaline earths, it indicates that the residual sodium carbonate is zero. A high value of RSC in water leads to an increase in the adsorption of sodium in soil<sup>61</sup>). Based on the RSC, groundwater samples in 2015 were classified 'good and safe' in 85% of cases and 'medium/marginal' in 3.5%. Samples in 2016 were classified 'good and safe' for 100% of cases.

### 3.3.4. Permeability Index (PI)

Soil permeability is affected by long-term use of irrigation water with a high salt content. Permeability is influenced by the sodium, calcium, magnesium, chloride, and bicarbonate contents of the soil. Kelly has classified irrigation waters based on the PI, which indicates the suitability of groundwater for irrigation use. The groundwater may be classified into classes 1 (Excellent), 2 (Good), and 3 (Unsuitable) based on the permeability indices. Classes 1 and 2 are suitable for irrigation, with 75% or more maximum permeability, and class 3 is unsuitable, with 25% maximum permeability or less. Based on the above classification, 40.6% of the samples fall in class 1 (Excellent), 59% of samples fall in class 2 (Good) and 0.8% of samples are unsuitable for irrigation usage among the 2015 samples. Of the 2016 samples, 100% were rated excellent.

### 3.3.5. Soluble Sodium Percentage (SSP)

This is an important factor for studying sodium hazards. Sodium has the potential of reacting with soil thereby reducing its permeability and supports little or no plant growth. Based on SSP values, 27.3% of samples belong to 'Excellent' class, 59.7% of samples belong to 'Good', 13.0% samples belong to 'Fair', and 0.8% samples belong to 'Poor' in 2015.

In 2016, 0.7% of samples belong to 'Excellent' class, 37.2% of samples belong to 'Good', 61.4% samples belong to 'Fair', and 0.7% samples belong to 'Poor'.

### 3.3.6. Magnesium Hazard (MH)

Szabolcs and Darab<sup>20</sup>) proposed a magnesium hazard for assessing the suitability of water quality for irrigation. Normally, a high level of  $\text{Mg}^{2+}$  is caused by exchangeable Na in irrigated soils. An increased proportion of  $\text{Mg}^{2+}$  relative to  $\text{Ca}^{2+}$  increases sodication in soils, which causes the dispersion of clay particles, thus damaging the soil structure and decreasing the relative hydraulic conductivity of soils, as  $\text{Mg}^{2+}$  behaves like  $\text{Na}^+$ . A magnesium ratio of more than 50 is considered to be harmful and unsuitable for irrigation use. This would adversely affect the crop yield, as soils become more alkaline. Based on the above classification, 94.4% of the samples fall in 'Acceptable', 5.6% of samples fall in 'Non-Acceptable' for irrigation usage in the 2015 samples, and 96.6% of the samples fall in 'Acceptable', 3.4% of samples fall in 'Non-Acceptable' for irrigation usage in the 2016 samples.

### 3.3.7. Kelly's Ratio (KR)

Sodium measured against  $\text{Ca}^{2+}$  and  $\text{Mg}^{2+}$  was considered by Kelly and Paliwal to calculate this parameter. A Kelly's ratio of  $>1$  indicates an excess level of sodium in water, which is unsuitable, and a ratio of  $< 1$  is suitable for irrigation uses. Based on the Kelly's ratio, a majority of samples (93.2% in 'non-permissible' and 6.8% in 'permissible') are suitable for irrigation purpose in the 2015 samples and a majority of samples (69.7% in 'permissible' and 30.3% in 'Non-permissible') are suitable for irrigation purpose in 2016.

### 3.3.8. Potential Salinity (PS)

Doneen explained that the suitability of water for irrigation is not dependent on soluble salts. Owing to the low solubility salts precipitating in the soil

and accumulating with each successive irrigation, the concentration of highly soluble salts increases the soil salinity. The potential salinities of groundwater samples were classified in the following three classes: 'Excellent to Good (< 5)', 'Good to Injurious (5~10)', and 'Injurious to Unsatisfactory (> 10)'. Based on the above classification, 98.5% of the samples fall in 'Excellent to Good', 1.2% of sam-

ples fall in 'Good to Injurious' and 0.3% samples fall in 'Injurious to Unsatisfactory' in 2015, while 100.0% of the samples fall in 'Excellent to Good' in 2016. In the assessment of groundwater samples applied by 8 kinds of equations, all groundwater sampled from 2016 (n=485) to 2015 (n=145) were classified as suitable for the agricultural usage (from Table 9 to 12).

**Table 9.** Classifications of Groundwater by SAR, Na (%), RSC, PI (n=483, 2015)

	SAR				Na (%)				RSC			PI			
	10~20		Excellent (E)		Up to 20		Excellent (E)		< 1.25	Good/Safe (G)	> 75%	Excellent (E)			
Classifications	10~18		Good (G)		20~40		Good (G)		1.25~2.5	Medium/Marginal (M)	25~75%	Good (G)			
	18~26		Permissible (P)		40~60		Permissible (P)		> 2.5	Bad/Unsuitable (B)	> 25%	Unsuitable (U)			
Grade Usage	> 26		Unsuitable (U)		60~80		Doubtful (D)		-	-	-	-			
	-		-		> 80		Unsuitable (U)		-	-	-	-			
	(E)	(G)	(P)	(U)	(E)	(G)	(P)	(D)	(U)	(G)	(M)	(B)	(E)	(G)	(U)
Agriculture	17.2	0.0	0.0	0.0	5.8	9.9	0.8	0.6	0.0	16.8	0.0	0.4	6.4	10.8	0.0
Living	44.7	0.0	0.0	0.0	15.3	24.8	4.3	0.2	0.0	40.9	3.3	0.5	16.8	27.9	0.0
Drinking	37.5	0.0	0.0	0.0	13.2	19.9	3.1	0.8	0.4	37.3	0.2	0.0	17.2	19.9	0.4
Industrial	0.6	0.0	0.0	0.0	0.0	0.6	-	-	-	-	-	-	0.2	0.4	-
Total (%)	100	0.0	0.0	0.0	34.4	55.4	8.2	1.6	0.4	95.7	3.5	0.8	40.6	59.0	0.4
	483 (100%)				483 (100%)				483 (100%)			483 (100%)			

**Table 10.** Classifications of Groundwater by SSP, MH, Kelly's ratio, PS (n=483, 2015)

	SSP				MH		Kelly's Ratio		PS		
	< 20		Excellent (E)		> 50	Unsuitable (U)	> 1.0	Non-Permissible (NP)	< 5	Excellent to Good (E)	
Classifications	20~40		Good (G)		< 50	Suitable (S)	< 1.0	permissible (P)	5~10	Good to Injurious (G)	
	40~80		Fair (F)		-	-	-	-	> 10	Injurious to Unsatisfactory (I)	
Grade Usage	> 80		Poor (P)		-	-	-	-	-	-	
	(E)	(G)	(F)	(P)	(U)	(S)	(NP)	(P)	(E)	(G)	(I)
Agriculture	4.8	10.4	2.1	0.0	3.3	13.9	14.1	3.1	16.8	0.4	0.0
Living	12.8	24.8	7.0	0.0	0.4	44.3	43.3	1.4	44.5	0.2	0.0
Drinking	8.7	24.0	3.9	0.9	1.9	35.6	35.2	2.3	36.6	0.6	1.0
Industrial	1.0	0.6	-	-	-	0.6	0.6	-	0.6	-	-
Total (%)	26.3	59.8	13.0	0.9	5.6	94.4	93.2	6.8	98.5	1.2	0.3
	483 (100%)				483 (100%)		483 (100%)		483 (100%)		

**Table 11.** Classifications of Groundwater by SAR, Na (%), RSC, PI (n=145, 2016)

Classifications	SAR				Na (%)					RSC			PI		
	10~20	Excellent (E)			Up to 20		Excellent (E)			< 1.25	Good/Safe (G)		> 75%	Excellent (E)	
Classifications	10~18	Good (G)			20~40		Good (G)			1.25~2.5	Medium/Marginal (M)		25~75%	Good (G)	
	18~26	Permissible (P)			40~60		Permissible (P)			> 2.5	Bad/Unsuitable (B)		> 25%	Unsuitable (U)	
Classifications	> 26	Unsuitable (U)			60~80		Doubtful (D)			-	-		-	-	
	-	-			> 80		Unsuitable (U)			-	-		-	-	
Grade Usage	(E)	(G)	(P)	(U)	(E)	(G)	(P)	(D)	(U)	(G)	(M)	(B)	(E)	(G)	(U)
Agriculture	49	0.0	0.0	0.0	0.7	24.8	21.4	1.4	0.7	49.0	0.0	0.0	49.0	0.0	0.0
Living	4.1	0.0	0.0	0.0	0.0	3.4	0.7	0.0	0.0	4.1	0.0	0.0	4.1	0.0	0.0
Drinking	46	0.0	0.0	0.0	1.4	23.4	17.2	4.8	0.0	46.9	0.0	0.0	46.9	0.0	0.0
Total (%)	100	0.0	0.0	0.0	2.1	51.7	39.3	6.2	0.7	100	0.0	0.0	100.0	0.0	0.0
	145 (100%)				145 (100%)					145 (100%)			145 (100%)		

**Table 12.** Classifications of Groundwater by SSP, MH, Kelly's ratio, PS (n=145, 2016)

Classifications	SSP				MH		KR		PS				
	< 20	Excellent (E)			> 50	Unsuitable (U)		> 1.0	Non-Permissible (NP)		< 5	Excellent to Good (E)	
Classifications	20~40	Good (G)			< 50	Suitable (S)		< 1.0	Permissible (P)		5-10	Good to Injurious (G)	
	40~80	Fair (F)			-	-		-	-		> 10	Injurious to Unsatisfactory (I)	
Classifications	> 80	Poor (P)			-	-		-	-		-	-	
	Grade Usage	(E)	(G)	(F)	(P)	(U)	(S)	(NP)	(P)	(E)	(G)	(I)	
Agriculture	0.0	18.6	29.7	0.7	2.8	46.2	15.9	33.1	49.0	0.0	0.0		
Living	0.0	2.8	1.4	0.0	0.0	4.1	0.0	4.1	4.1	0.0	0.0		
Drinking	0.7	15.9	30.3	0.0	0.7	46.2	14.5	32.4	46.9	0.0	0.0		
Total (%)	0.7	37.2	61.4	0.7	3.4	96.6	30.3	69.7	100.0	0.0	0.0		
	145 (100%)				145 (100%)		145 (100%)		145 (100%)				

**3.4. Assessment by the SAR via Wilcox and USSL Diagrams<sup>21)</sup>**

EC and Na concentrations are important in classifying irrigation water, because high saline contents (high EC) in irrigation water leads to the formation of saline soil. The salinization of rice fields is the major cause of loss of production and has adverse effect on irrigation systems, including the water quality of stream and lake water, owing irrigation water on the rice field being drained to the stream or lake to circulate the water. There-

fore, the induction of saline water from the groundwater to the rice field should be monitored regularly, so the judgements made through multiple criteria, such as conductivity and SAR, would be a very proper tool for maintaining high productivity of rice fields, because saline conditions severely limit the choice of crops and adversely affect crop germination and yields. In this respect, it is important that all evaluations regarding irrigation water quality are linked to the evaluation of the soils to be irrigated. Above all, sodium concentration

is important in classifying irrigation water, because sodium reacts with soil to reduce its permeability. In all natural water, percent sodium is a vital parameter to evaluate its suitability for agricultural purposes; sodium combining with carbonate forms alkaline soils, while sodium combining with chloride forms saline soils. Either type of sodium-enriched soil will support little or no plant growth. High-salinity problems are encountered where irrigation activity is in poor drainage agricultural soils and also where water logging allows the water table to rise close to the root zone of plants, causing an accumulation of sodium salts in the soil solution through capillary rise following surface evaporation. The sodium or alkali hazard in the use of water for irrigation is determined by the absolute and relative concentrations of cations. The relative activity of sodium ions in the exchange reaction with soil is expressed in terms of the SAR. If a high sodium content and low calcium content are present in water used for irrigation purpose, the base-exchange complex may become saturated with sodium. This can destroy the soil structure owing to the de-flocculation (dispersion of clay particles) process. The U.S. salinity Laboratory’s Diagram uses

electrical conductivity, and SAR classifies groundwater as  $C_xS_x$ , which is a combination of electrical conductivity (C1~C4) and SAR (S1~S4) (Table 13). The plot of the analytical data on the U.S. salinity diagram, in which the EC is taken as a salinity hazard and SAR as an alkalinity hazard, for the samples of 2015 (Fig. 1) and samples of 2016 (Fig. 2), have shown “excellent to good” for the Wilcox diagram and C1S1 (Excellent /Excellent) and C2S1 (Good/ Excellent) of USSL diagram.

**3.5. Assessment of groundwater by the LSI and CR**

**3.5.1. Langelier Saturation Index (LSI)<sup>22)</sup>**

The Langelier saturation index (LSI) is used to determine the need for calcium carbonate precipitation scale control in water sources containing a TDS concentration of less than 10,000 mg/l (ASTM 1998)<sup>23)</sup>. It is the difference between the water’s measured pH (pHw) and the calculated pH when that water is in equilibrium with calcium carbonate (pHs). Scaling and corrosion are common process problems found in domestic and industrial applications, where water or wastewater is in contact with other materials. The scaling of metallic surfaces by

**Table 13.** Classification of groundwater quality based on SAR and conductivity by USSL classifications

Wilcox diagram		Classifications and Ranges		
		Classification	Range	Quality level
	Conductivity	C1	100~200	Excellent
		C2	250~750	Good
		C3	750~2250	Doubtful
		C4~C5	> 2250	Unsuitable
		<hr/>		
	SAR	S1	< 10	Excellent
		S2	10~18	Good
		S3	19~26	Doubtful/Fairly
		S4~S5	> 26	Unsuitable

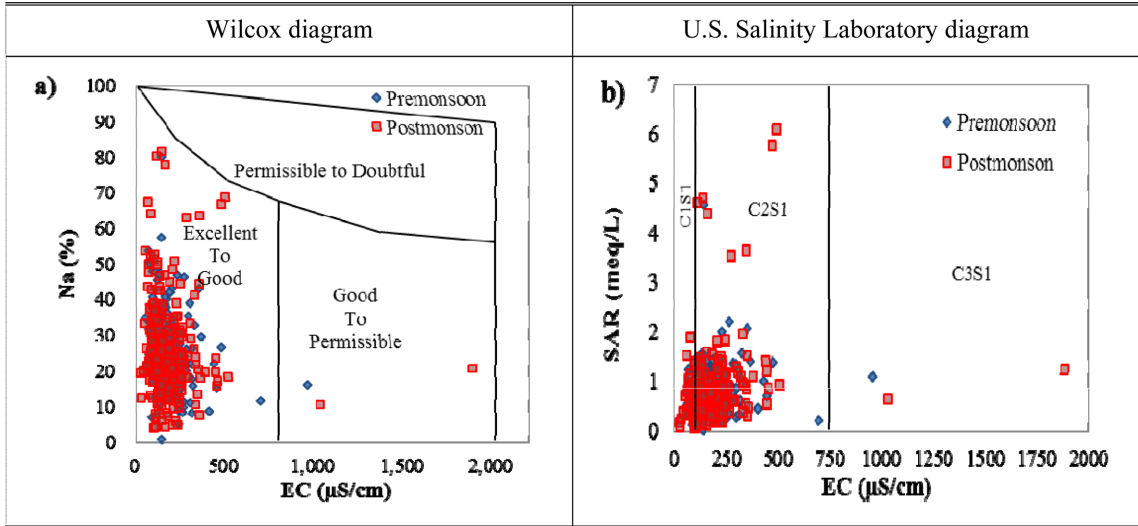


Fig. 1. Wilcox diagram (a) and U.S. Salinity Laboratory diagram (b) of groundwater (n=483, 2015).

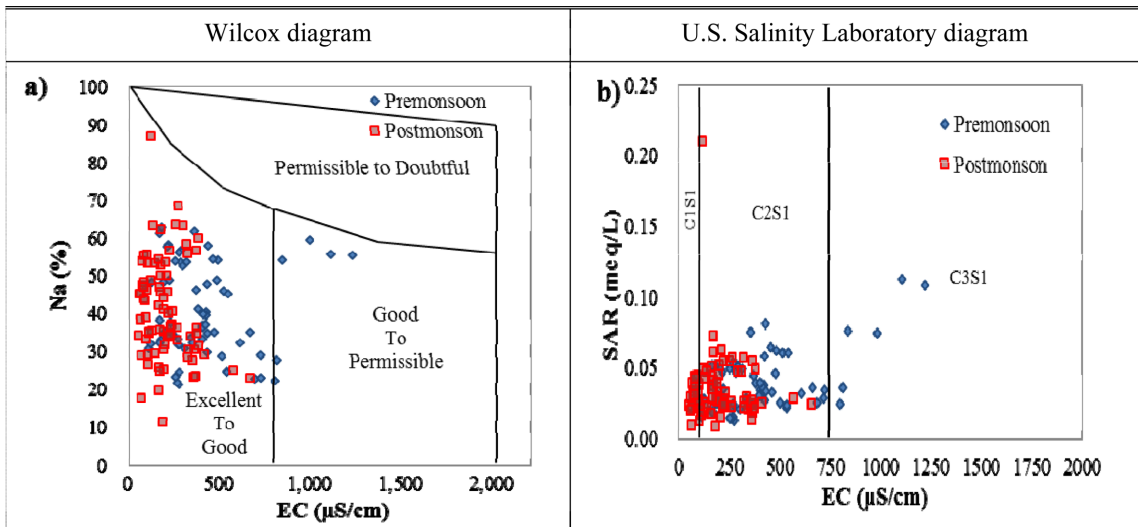


Fig. 2. Wilcox diagram (a) and U.S. Salinity Laboratory diagram (b) of groundwater (n=145, 2016).

calcium carbonate is related to the type of rocks in contact with groundwater. LSI is probably the most widely used indicator of cooling water scale potential. Positive LSI values suggest that the water is supersaturated with respect to calcium carbonate and scale formation may occur; negative values suggest that the water is unsaturated, which has a tendency to remove existing calcium carbo-

nate protective coatings in pipelines and equipment; neutral values indicate that the solution is at equilibrium providing an indication of the degree of saturation of water with respect to calcium carbonate and is neither scale forming nor scale removing. One of the major problems of high calcium water is the formation of scales in industrial boilers. The calculated results show that almost all

water samples have negative LSI values, indicating that the solution is under-saturated with calcium carbonate (i.e.  $\text{CaCO}_3$  dissolves) during both seasons, except one location where  $\text{CaCO}_3$  was deposited in the post-monsoon season. The positive LSI values indicate an encrustation tendency due to  $\text{CaCO}_3$  precipitation and, hence, a need for moderate treatment of the water to prevent scaling. The increased levels of scaling can be harmful and can cause corrosion of water pipes and a release of toxic metals into the water system. As a result of an LSI assessment, it was shown that '97.3% of samples (470 of 483 samples) were 'safe' and 2.7%

of samples (13 of 483 samples) were graded 'unsafe' for the 2015 samples in Table 14. In 2016, 97.2% of samples (141 of 145 samples) were 'safe' and 2.8% (4 of 145 samples) were unsafe, as shown in Table 15.

### 3.5.2. Corrosivity Ratio (CR)

This defines the susceptibility of groundwater to corrosion and is expressed as the ratio of alkaline earths to saline salts in groundwater. The corrosivity Ratio (CR) is defined as the corrosive tendency of groundwater due to the proportional occurrence of alkaline earths and saline salts along

**Table 14.** LSI, CR values of groundwater samples (n=483, 2015)

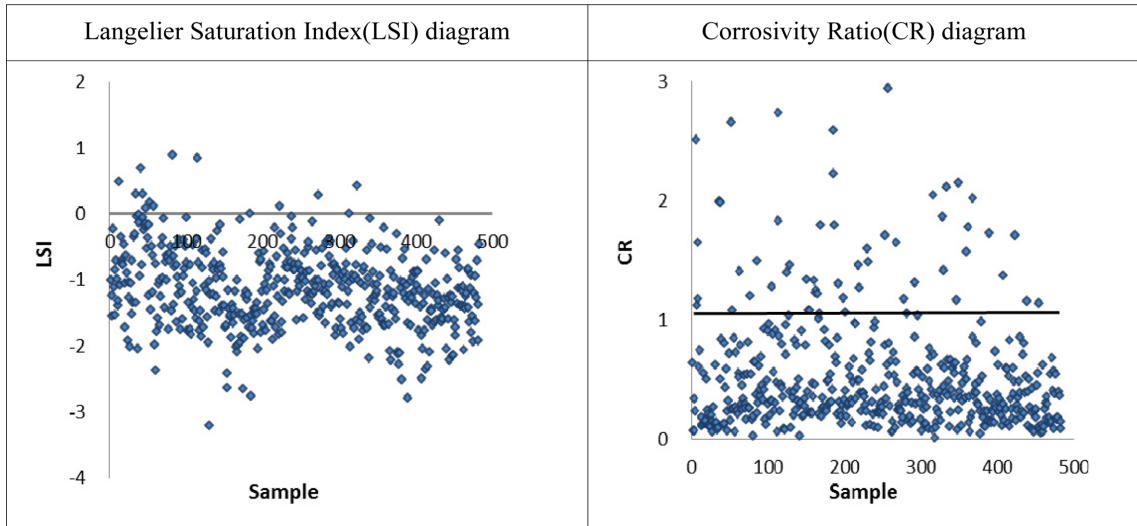
Usages	Items	Langelier Saturation Index		Corrosivity Index	
		Safe	Unsafe	Safe zone	Unsafe zone
Jun. (n=206)	Agricultural	32	3	31	4
	Living	87	1	68	20
	Drinking	81	2	70	13
	Sum.	200	6	169	37
	(%)	97.1	2.9	82.0	18.0
Jul. (n=33)	Agricultural	10	0	10	0
	Living	13	1	12	2
	Drinking	9	0	7	2
	Sum.	32	1	29	4
	(%)	97.0	3.0	87.9	12.1
Sep. (n=194)	Agricultural	32	2	32	2
	Living	91	0	80	11
	Drinking	66	0	62	4
	Industrial	3	0	2	1
	Sum.	189	2	176	18
(%)	97.4	2.6	90.7	9.7	
Oct. (n=33)	Agricultural	3	0	3	0
	Living	14	0	10	4
	Drinking	15	1	15	1
	Sum.	32	1	28	5
	(%)	97.0	3.0	84.9	15.1
Nov. (n=17)	Agricultural	1	0	1	0
	Living	8	1	7	2
	Drinking	5	2	6	1
	Sum.	14	3	14	3
	(%)	82.4	17.6	82.4	17.6
Usage (n=483)	Agricultural	78	5	77	6
	Living	213	3	177	39
	Drinking	176	5	160	21
	Industrial	3	0	2	1
	Sum.	470	13	416	67
(%)	97.3	2.7	86.1	13.9	

**Table 15.** LSI, CR values of groundwater samples (n=145, 2016)

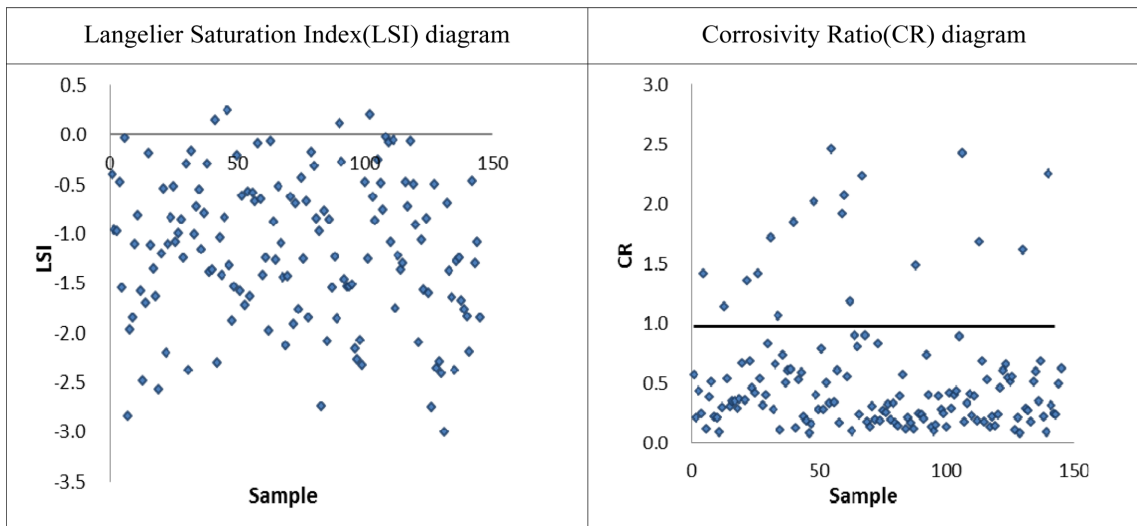
Usages	Items	Langelier Saturation Index		Corrosivity Index	
		Safe	Unsafe	Safe zone	Unsafe zone
Jun. (n=37)	Agricultural	25	0	23	2
	Living	2	0	2	0
	Drinking	10	0	6	4
	Sum.	37	0	31	6
	(%)	100	0	83.4	16.6
Jul. (n=28)	Agricultural	15	1	14	2
	Living	2	0	2	0
	Drinking	9	1	6	4
	Sum.	26	2	22	6
	(%)	92.3	0.7	78.6	21.4
Sep. (n=59)	Agricultural	21	1	21	1
	Living	2	0	1	1
	Drinking	34	0	33	2
	Sum.	57	2	55	4
	(%)	96.6	3.4	93.2	6.8
Oct. (n=11)	Agricultural	4	0	6	1
	Living	0	0	0	0
	Drinking	7	0	4	0
	Sum.	11	0	10	1
	(%)	100	0	90.9	9.1
Nov. (n=10)	Agricultural	4	0	4	1
	Living	0	0	0	0
	Drinking	6	0	5	0
	Sum.	10	0	9	0
	(%)	100	0	90	10
Usage (n=145)	Agricultural	69	2	68	6
	Living	6	0	5	1
	Drinking	66	2	54	10
	Sum.	141	4	127	18
	(%)	97.2	2.8	87.6	12.4

with sulfates in the groundwater. Corrosion causes significant losses in the hydraulic capacity of pipes and pipe fittings. Corrosion is mainly an electrolytic process that seriously damages and gradually destroys and corrodes away a metal surface. The range of corrosivity is dependent on chemical equilibrium reactions, as well as upon specific physical influences, such as temperature, pressure and velocity of flow. In addition to the lack of carbonate minerals, the intensity concentration of chlorides and sulfate minerals also cause an increase of corrosion rate. Groundwater with a corrosivity ratio of  $< 1$  is considered to be safe for transport of water in any type of pipes, whereas water with a

ratio of  $>1$  indicates a corrosive nature and hence is not to be transported through metal pipes (Mishra, 2012)<sup>24</sup>. As a result of the CR assessment, it was shown that, in 2015, 86.1% of samples (416 of 483 samples) were in the 'safe zone' and '13.9% of samples (67 of 483 samples) were graded in the 'unsafe zone', as shown in Table 14. In 2016, 87.6% of samples (127 of 145 samples) were in the 'safe zones' and 12.4% of samples (18 of 145 samples) were in the 'unsafe zone,' as shown in Table 15. In the applications of these two factors, the Langelier Saturation Index (LSI) and Corrosivity ratio (CR), to the 2015 and 2016 groundwater samples, we obtained similar patterns in the results for



**Fig. 3.** Langelier Saturation Index (LSI) and Corrosivity Ratio (CR) of groundwater (samples of 2015).



**Fig. 4.** Langelier Saturation Index (LSI) and Corrosivity Ratio (CR) of groundwater (samples of 2016).

defining the suitability of the groundwater for industrial usages.

## 5. Conclusion

This study compared the geochemical characteristics of groundwater from samples obtained in rural areas of Korea from 2015 to 2016. The major

goals of this study were classified into four categories: on-site monitoring of groundwater via instrumental and laboratory experiments, assessment of groundwater for the agricultural usages via SAR, Na (%), RSC, PI, SSP, MH, PS, and KR parameters, classification of groundwater by using Piper, Gibbs, and Chadah diagram method, and tracking of the origins of anions and cations by using rock-

dominance types. In the monitoring of the ionic properties of groundwater from 2015 to 2016, it was concluded that the concentrations of cations, such as  $\text{Ca}^{2+}$ ,  $\text{Na}^+$ ,  $\text{K}^+$ , and  $\text{Mg}^{2+}$ , and anions, such as  $\text{HCO}_3^-$ , and  $\text{Cl}^-$ , were higher in the post-monsoon season than in the pre-monsoon season, indicating groundwater quality might be influenced by chemical fertilizers and manure introduced through agricultural activities.

For the assessment of the groundwater quality in 2015, the SAR, Na (%), RSC, PI, SSP, MH, PS, and KR parameters were calculated by using the appropriate equations for each, and the results were classified as follows: 100% excellent for SAR, 55.2% good for Na (%), 95.0% good for RSC, 40.6% excellent for PI, 27.3% fair for SSP, 94.4% acceptable for MH, and 93.2% permissible for KR. Most of the groundwater samples were classified as “excellent to good” or “good to permissible” using the Wilcox diagram. For the assessment of the groundwater quality in 2016, the SAR, Na (%), RSC, PI, SSP, MH, PS, and KR were calculated by using their respective equations and the results were classified as follows: 100% excellent for SAR, 51.1% good for Na (%), 100% good for RSC, 100% excellent for PI, 61.4% fair for SSP, 96.6% acceptable for MH, and 69.7% permissible for KR. Most of the groundwater samples were classified as “excellent to good” or “good to permissible” using the Wilcox diagram. The evaluation using the U.S. Salinity Laboratory diagram also showed that most groundwater samples in 2015 and 2016 were grouped as C1S1 (Excellent/Excellent) or C2S1 (Good/Excellent). Additionally, the assessment using the LSI and CR index was 97.3% safe for the LSI and 86.1% safe zone for the CR in the 2015 samples, and 97.2% safe for the LSI and 87.6% safe zone for the CR in the 2016 samples.

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