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ASSESSMENT OF GROUNDWATER QUALITY FOR IRRIGATION PURPOSES: A CASE STUDY OF SUWANNAPHUM DISTRICT, ROI-ET, THAILAND

* Rawintra Eamrat[1], Sukanya Lapkratok[2], Sukanya Mingyai[3] and Bijay Man Shakya[4,5]

[1] Faculty of Science, Ramkhamheng University, Thailand; [2] Faculty of Science and Liberal Arts, Rajamangala University of Technology Isan, Thailand; [3] Faculty of Agricultural Product Innovation and Technology, Srinakharinwirot University, Ongkharak, Thailand; [4] Interdisciplinary Centre for River Basin Environment, University of Yamanashi, Japan; [5] Smartphones For Water Nepal, Nepal

*Corresponding Author, Received: 01 March 2022, Revised: 05 May 2022, Accepted: 02 Aug. 2022

ABSTRACT: Groundwater was used to increase water usage and solve the problem of an inadequate irrigation system in Suwannaphum district, Roi-Et, Thailand. Groundwater from shallow wells and deep ponds was used in this area. This study aims to determine groundwater quality for irrigation concerning its physicochemical properties and then classify it for irrigation purposes. The hydrochemical parameters, namely pH, Electrical conductivity (EC), Total dissolved solids (TDS), Sodium adsorption rate (SAR), Sodium percentage (Na%), Kelly's index (KI), Residual sodium carbonate (RSD), and Magnesium hazard (MH) were calculated and discussed thoroughly in US Salinity, Wilcox and Gibbs diagrams. The abundance of cation and anion are $Na^{+}>Ca^{2+}>Mg^{2+}>K^{+}=Cl^{-}>HCO_3^{2-}$. Most of the groundwater samples are suitable for irrigation. The majority of groundwater samples are subject to medium salinity with low alkalinity (US Salinity diagram), while the Wilcox diagram classified the water as excellent to doubtful for irrigation. However, groundwater samples from shallow wells in the area of Ban Nong I Khem and Ban Tang Mung were found to have high EC, TDS, and ion values greater than those recommended by the irrigation guidelines. The halite dissolution caused sodium and chloride element in groundwater. Moreover, agricultural activities (use of geochemical) can help increase the value of sodium in the study area. Therefore, problematic and require high salt toleration of crops and special irrigation management methods.

Keywords: Irrigation; Water quality; Groundwater; Agriculture

1. INTRODUCTION

Groundwater is one of the main water resources throughout the world because it supplies water for domestic, industrial, and agricultural uses. Recently, groundwater resources have become one of the main water resources in Thailand, especially in rural areas and in those areas not served by a public water supply. There are six groundwater basins in Thailand located in North, East, Northeast, South, Upper Central, and Lower Central Thailand. Thailand has 738,406 groundwater wells and 1,405,401 dug wells, but they are not located in all parts of Thailand [1]. In this study, we investigated an area in Roi-Ed province, Thailand, which is a part of Tung Kura Roi Hai. This particular area suffers from serious problems with water management because of a lack of irrigation systems and long droughts during the long summer season. Thus, the management of irrigation water is an important factor for agriculture and cultivation.

Groundwater was used to solve these problems and to enhance the water supply to try to compensate for the shortage of surface water, low rainfall quantities, lack of irrigation systems, and the limitation of a public irrigation water supply. However, the quality of the groundwater that can be obtained from this study area is still unclear. Contamination of groundwater can affect human health, animals, aquatic plants, crops, and soil compositions [2]. The quality of groundwater varies from place to place and also depends on the nature of recharging water, hydro-geochemical process, surface water, sub-surface water, precipitation, and land cover [2]-[4]. In addition, changes in groundwater recharge and water table raising in the saline area can cause waterlogging and salinization, especially in the northeast region [1].

There are various research studies about groundwater assessment and hydrochemical characterization. Peiye Li et al. [5] assess the hydrochemical of groundwater for irrigation proposes around Hua country in China and found that natural processes (cation exchange, weathering of rock, and evaporation) are dominant factors for groundwater chemistry. This groundwater is suitable for agriculture with sodium hazards but is recommended to mix with low salinity water before use. Sarikhani et al. [6] determined the hydrochemical characteristics of groundwater and found that the halite dissolution causes sodium and chloride elements in groundwater. Furthermore, high sodium content and dissolved ions from irrigation can affect soil physical properties, yield, and crop production. High TDS and EC can affect plant roots to absorb water (salinity hazard) due to high salt concentration in soil [7]-[10]. Therefore, an assessment of the quality of irrigation water from the groundwater is essential for the successful management of water resources.

Thus, this study aims to determine and classify the quality of the irrigation groundwater in terms of its physicochemical properties. The information obtained from this research should play an important role in the supply of alternative irrigation water for agriculture.

2. RESEARCH SIGNIFICANCE

This study found that the groundwater samples are suitable for irrigation, but high levels of EC, TDS, and Na^+ are major factors in water quality. The abundance of cation and anion are $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^{2-}$. Therefore, salt-tolerant crops or permeable soil with salinity should be controlled.

3. RESEARCH METHODOLOGY

3.1 Study Area

This study was conducted in Suwannaphum district, Roi-Ed province, located between 15.5602 to 15.6047 latitude and between 103.6970 to 103.8075 longitude. It is at an altitude of 120 – 160 meters above mean sea level and a part of Tung Kura Rong Hai, which is a key player in the global food supply chain of jasmine rice production in Thailand. The average rainfall is 1369 mm/y. The base rock is composed of a crystalline salt rock which is found in the Korat plateau. The soil composition in this district consists of sandy loam, with a mixture of soil and sand with sodium and silica.

3.2 Sample collection and groundwater analysis

Twenty-six groundwater samples were collected from shallow wells from four study areas in the Suwannaphum district which were obtained from Ban Nong I Khem, Ban Tang Mung, Ban Lao Khao, and Rajamangala University of Technology Isan (RMUTI). Groundwater is used from shallow depths of 10-15 m and groundwater from deep ponds within the depth of 15-20 m (as shown in Fig. 1).

Fig. 1. Groundwater sampling station

In addition, a total of six samples were collected from deep ponds. The geographical positions and other location details of the samples are presented in Fig. 2 and Table 2.

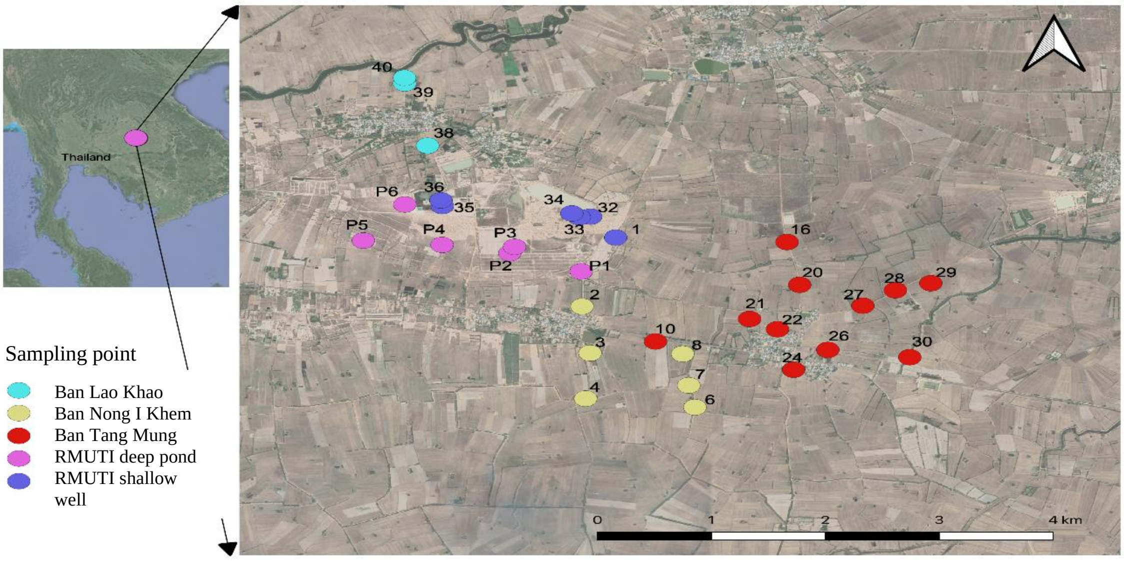

Fig. 2 Map of groundwater sampling points from shallow wells and deep ponds

The pH, dissolved oxygen (DO), electrical conductivity (EC), and total dissolved solids (TDS) were measured immediately after field sampling with a digital meter. Then the collected samples were kept in iceboxes and stored in a freezer at 4 ℃ before being analyzed in the laboratory. Chemical characteristics such as bicarbonate (HCO_3^-), calcium (Ca^{2+}), manganese (Mg^{2+}), and chloride (Cl^-) were analyzed by the titrimetric method. Sodium (Na^+) and potassium (K^+) were estimated by a flame photometer. Furthermore, sodium percentage (%Na), sodium adsorption ratio (SAR), magnesium hazard ratio (MH), residual sodium carbonate (RSC), and magnesium and Kelly's index (KI) were calculated based on a physicochemical analysis. An analysis of the correlations of the irrigation water quality was determined by plotting in the Wilcox, US Salinity Laboratory (USSL) and Gibbs diagrams.

Mathematical calculations for irrigation water quality were shown in Eq.1-5 [8]

3.2.1 Sodium Adsorption Ratio (SAR)

$$SAR = \frac{Na^+}{\sqrt{(Ca^{2+} + Mg^{2+})/2}} \qquad (1)$$

3.2.2 Sodium percentage (Na%)

$$\%Na = \frac{(Na^+ + K^+)}{(Ca^{2+} + Mg^{2+} + Na^+ + K^+)} x100 \qquad (2)$$

3.2.3 Magnesium Hazard ratio (MH)

$$MH = \frac{Mg^{2+}}{(Ca^{2+} + Mg^{2+})} x100 \qquad (3)$$

3.2.4 Residual Sodium Carbonate (RSC)

$$RSC = (CO_3^{2-} + HCO_3^-) - (Ca^{2+} + Mg^{2+}) \qquad (4)$$

3.2.5 Kelly's index (KI)

$$KI = \frac{Na^+}{Ca^{2+} + Mg^{2+}} \qquad (5)$$

4. RESULTS AND DISCUSSION

The quality of irrigation water is important for agriculture because it is related to the yield, quality of crops, soil structure, and environmental protection. The groundwater results and classification of the groundwater for irrigation purposes are summarized in Table 1 and Table 2. The details for each parameter are discussed below.

4.1 pH indicator

The pH of the groundwater ranges from 6.34 – 8.27, as summarized in Table 1. This indicates that this water is slightly acidic to slightly basic which is within the irrigation water guideline (6.0 – 8.5) [7]. pH in water can be control by cation (Na^+, Mg^{2+}, Ca^{2+}) and anion (HCO_3^-) [12]. The highest pH in this study was found in the RMUTI area (deep pond) at 8.16, which is slightly alkaline.

Table 1 Groundwater results

parameters	Normal ranking for irrigation [7]	Shallow good samples				Deep pond samples			
		Min.	Max.	Mean	S.D.	Min.	Max.	Mean	S.D.
pH	6.0 – 8.5	6.72	8.16	7.56	0.35	6.34	8.27	7.51	0.68
EC (uS/cm)	0-3000	99.80	8330	2872.96	2842.69	64.1	91.1	78.18	12.16
TDS (mg/l)	0-1000	59.4	7580	2227.56	2431.28	50	80	61.37	9.96
Ca^{2+} (meq/l)	0 – 20	0.44	26.95	7.23	7.24	0.13	0.56	0.27	0.16
Mg^{2+}(meq/l)	0-5	0.36	7.09	2.74	2.01	0.09	0.26	0.17	0.06
Na^+ (meq/l)	0-40	0.99	45.17	11.67	14.18	0.13	0.45	0.24	0.13
K^+ (meq/l)	0 – 0.052	0.038	0.22	0.091	0.07	0.026	0.077	0.0039	0.002
Cl^- (meq/l)	0-30	0.29	78.87	20.43	23.08	0.25	0.79	0.43	0.19
HCO_3^- (meq/l)	0 - 10	0.8	4	1.57	0.65	0.1	0.4	0.18	0.12

4.2 Electrical conductivity (EC) and Total dissolved solids (TDS)

EC is the parameter used to assess the quality of irrigation water which is related to the salinity hazard. EC represents the inorganic solids (minerals, salts, cations, and anions) and ionization that is dissolved in the water [11]. EC and TDS values are by changes in the EC value which leads to changes in TDS.

In this study, EC was found in a wide range of 64.10 – 8,330 µS/cm and TDS values were found in the range of 50 – 7,580 mg/l. There is a high value of EC above 3000 µS/cm and TDS above 1000 mg/l

[7] found in Ban Nong I Khem and Ban Tang Mung, which can be classified as a permissible or fair class, and their uses can affect yield and crop production. High EC or high salinity in water can result in saline soil which inhibits the growth of plants [13]. However, most groundwater can be classified as good to permissible due to this area being located on salt soil with halite, so salt accumulation level in groundwater tends to be high. Salinity occurs due to the weathering of rocks and halite dissolving in water [13]. Therefore, the high salinity or the high EC and TDS of more than 3000 µS/cm and 1000 mg/l from some areas in Ban Nong I Khem and Ban Tang Mung were classified as unsuitable for normal irrigation and suitable only for crops with a high tolerance of salt.

4.3 Ion concentration

The major ion in this groundwater in both of shallow well and deep pond samples is $Na^{+} > Ca^{2+} > Mg^{2+} > K^{+} = Cl^{-} > HCO_3^{2-}$. Na^{+} (0.13-45.17 meq/l), Ca^{2+} (0.13 – 26.95 meq/l) and Mg^{2+} (0.09 – 7.09 meq/l) are dominant cation and Cl^{-} is dominant anion (0.25 – 78.87 meq/l) as shown in Table 1. High concentrations of Ca^{2+}, Mg^{2+}, Na^{+}, $K^{+,}$ and Cl^{-} were found in Ban Nong I Khem and Ban Tank Mung. Sodium is important for the growth of some plants, while a high concentration can cause toxic for plants such as possible defoliation, leaf burn, and poor soil properties [7]. Calcium is found in natural waters and lime, while a high concentration can cause tightening of soils [14]. More magnesium in groundwater will affect crop production due to increase in soil alkalinity. However, the average concentrations of these major ions were found below the recommended parameters for irrigation. Therefore, the water is suitable for irrigation purposes but recommended to mix water of low salinity before use it.

4.4 Sodium adsorption rate (SAR)

The SAR is the parameter that relates to sodium hazards and use to predict the potential of sodium accumulation in soil [12]. The classification of irrigation water based on the SAR range can be classified into 4 classes [13], [15]. The SAR values for the groundwater range from 0.31 – 10, which could be classified as excellent and suitable for irrigation, except for 7.4% of the samples in Ban Tang Mung were classified as good (Table 2). High SAR or an excess of sodium can break down the soil structure, which becomes compact, forms a crust structure when dry, and reduces soil permeability [5], [10], [15]. Chaudhara et al. [13] support that high SAR from irrigation water cause damage to soil structure by poor air movement properties rate and become low infiltration. Further information on the SAR values for the groundwater can be obtained from plots on the US salinity diagram (USSD) shown in Fig 3. This shows that 100% of the deep pond samples fall within the C1-S1, which means low salinity and low sodium type of water which is suitable for irrigation. The samples from shallow wells were classified into the groups of medium-high salinity and low-medium alkalinity hazards (C2-S1, C3-S1, C4-S2, C4-S3 groups). This irrigation water accepted for salt-tolerant crops or permeable soil with salinity should be controlled [10, 12]. The high value of EC makes the water unsuitable for irrigation. Moreover, the excessive SAR value required special soil management, such as organic matter addition and good drainage [8].

4.5 Percentage of Sodium (Na%)

Sodium percentage (Na%) was proposed by Wilcox. The percentage of sodium is related to the salinity hazard as it can react with soil and result in poor internal drainage and reduced soil permeability [5], [7], [9]. It can inhibit water supply for crops which reduces yield productivity. High Na^{+} combined with chloride (Cl^{-}) leads to saline soil, while combined with carbonate leads to alkaline soil formations [14]. The percentages of Na% from the groundwater samples ranged from 27% – 52%, as summarized in Table 2. 62.5% of the total samples are classified as ‘Good’ for irrigation, while the remaining 37.5% fall within the “Permissible” range for irrigation. To obtain more detail, plots were made on a Wilcox diagram to confirm the irrigation classifications, as shown in Fig. 4. The majority of the groundwater was within the “Excellent to Good” and “Good to Doubtful” categories. However, 28.4% of the shallow well samples were in the “unsuitable” category, which was found in Ban Nong I Khem (50% of the total samples) and Ban Tank Mung (63.60% of the total samples). Therefore, the groundwater from these sources is not suitable for irrigation purposes due to the high EC, which makes the water unsuitable for irrigation. The unsuitability is the result of the dissolution of minerals and halite as this area is located on the salt rock, which is a major cause of high EC (salinity hazard) and percentage of sodium. When high sodium concentration, Na^+ can absorb by clay particles and displacing Ca^{2+} and Mg^{2+}, which can reduce soil permeability and poor internal drainage [14]-[17]. Moreover, agricultural activities (use of geochemical) can increase the value of sodium [13]-[14]. However, all of the groundwater in this study was suitable for irrigation purposes, but some area recommends mixing with low salinity water before use.

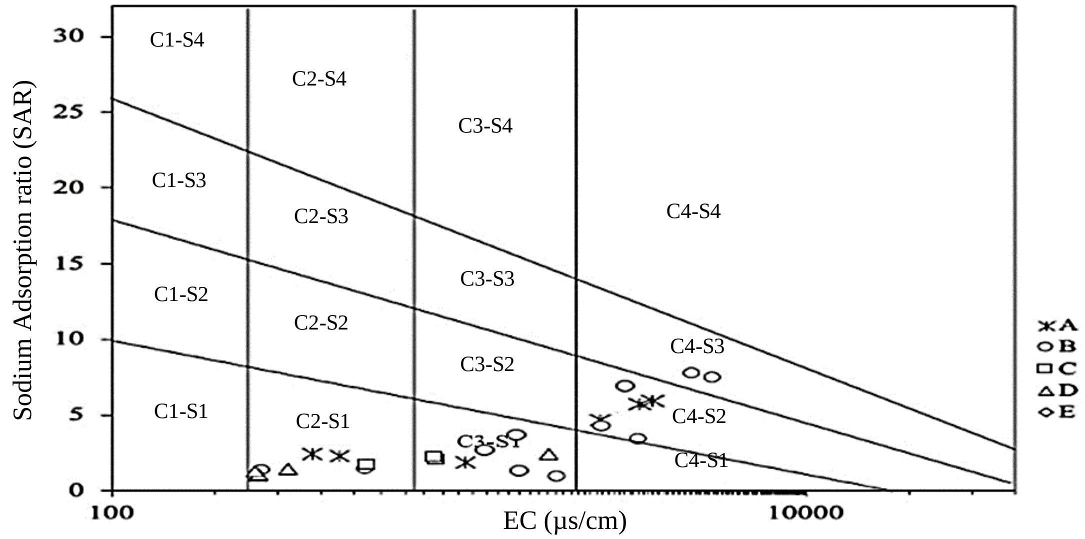

Fig. 3 US Salinity classification (EC values lower than 100 µS/cm were not shown in this graph)

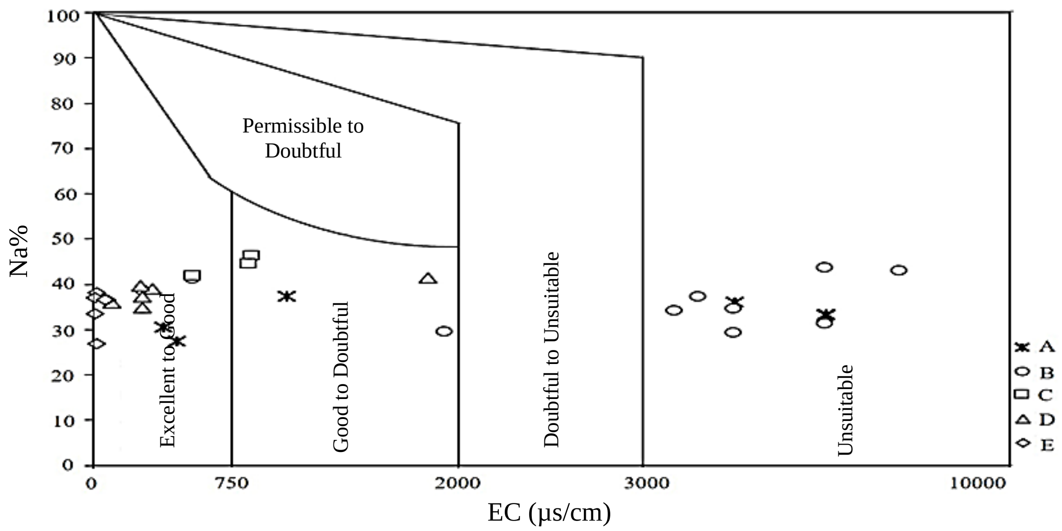

Fig. 4 Wilcox diagram showing the classification of irrigation groundwater

4.6 Kelly's Index (KI)

Kelly's Index or Kelly's ratio is one of the parameters used to determine the quality of irrigation water. If the KI value (meq/l) is more than 1, this indicates a high sodium concentration which is unsuitable for irrigation due to high alkalinity [9], [13]. The KI values of all the samples from all shallow wells and deep ponds were observed to be in the range of 0.39 – 0.87 meq/l and 0.37 – 0.62 meq/l (Table 2). is in the safe category and suitable for irrigation.

4.7 Residual sodium carbonate (RSC)

Residual sodium carbonate (RSC) is an important parameter of irrigation water which is determined by the hazard impacts of carbonate and bicarbonate [6]. The high amount of carbonate and bicarbonate can affect irrigation water quality by can causing the soil to become more concentrated due to Ca^{2+} and Mg^{2+} precipitation. In this study, most of the RSC from all the samples were safe for irrigation as they were in the range of -36.56 meq/l to 0.72 meq/l. These levels show that the groundwater was of good water with RSC at less than 1.25 meq/l. Our calculations values reveal that 78.13% of all the samples showed negative values. The negative RSC value indicates that more Ca^{2+} and Mg^{2+} were dissolved in the groundwater than carbonate and bicarbonate [16]. If high RSC in water for irrigation can cause poisoning of agriculture products, reduce crop productivity, increase soil salinity and destroy soil structure [17].

Table 2 Irrigation water quality parameters of groundwater bank in each area

ID	No.	Latitude	Longitude	Area Name	%Na	SAR	MH	RSC	KI
A1	2	15.57207663	103.71480316	Ban Nong I	37	1.87	41.87	-	0.60
A2	3	15.56660440	103.71545727	Khem	27	2.27	48.78	-	0.39
A3	4	15.56126250	103.71508649	(Shallow well)	36	4.18	50	-	0.57
A4	6	15.56024812	103.72403603		44	7.57	43.90	-	0.79
A5	7	15.56281646	103.72352627		46	7.36	45.17	-	0.85
A6	8	15.56650929	103.72303545		31	2.39	48.25	-	0.45
B1	10	15.56796267	103.72081257	Ban Tang	49	8.04	46.02	-	0.97
B2	16	15.57962778	103.73158330	Mung	30	0.92	44.26	-	0.43
B3	20	15.57460776	103.73261524	(Shallow well)	50	10	39.30	-	1.02
B4	21	15.57060325	103.72851393		35	3.78	47.61	-	0.53
B5	22	15.56939702	103.73079521		34	1.38	44.01	-	0.55
B6	24	15.56464798	103.73211938		29	3.25	51.93	-	0.42
B7	26	15.56697868	103.73491557		41	1.46	31.55	-	0.71
B8	27	15.57216333	103.73778333		52	10	38.91	-	1.11
B9	28	15.57397629	103.74044836		37	3.43	48.54	-	0.61
B10	29	15.57480289	103.74334694		39	1.38	44.53	-	0.65
B11	30	15.56611565	103.74162282		42	5.88	41.47	-	0.73
C1	38	15.59094167	103.70215560	Ban Lao Khao	42	1.72	32.86	-	0.74
C2	39	15.59824167	103.70028610	(Shallow well)	46	2.08	33.38	-	0.87
C3	40	15.59889167	103.70027220		45	2.20	48.20	-	0.81
D1	1	15.58015000	103.71755000	RMUTI	42	2.39	47.33	-	0.72
D2	32	15.58260901	103.71549623	(Shallow well)	35	1.04	23.81	0.54	0.54
D3	33	15.58255254	103.71456781		37	1.11	22.85	-	0.60
D4	34	15.58298822	103.71396602		36	0.71	44.86	0.22	0.56
D5	35	15.58384717	103.70335781		39	1.41	40.73	0.02	0.64
D6	36	15.58452074	103.70325266		40	1.26	44.32	0.72	0.66
E1	P1	15.57617400	103.71473500	RMUTI	37	0.68	37.99	-	0.59
E2	P2	15.57833333	103.70888889	(deep pond)	38	0.53	48.24	0.39	0.62

ID	No.	Latitude	Longitude	Area Name	%Na	SAR	MH	RSC	KI
E3	P3	15.57907400	103.70928200		27	0.31	48.02	-	0.37
E4	P4	15.57929400	103.70334500		37	0.40	44.36	0.07	0.59
E5	P5	15.57980200	103.69690300		37	0.72	26.71	0.06	0.58
E6	P6	15.58403300	103.70029000		34	0.37	35.29	-	0.51

4.8 Magnesium hazard indicator (MH)

The magnesium hazard ratio (MH) affects soil structure and crop production when it is equal to or higher than 50. The values of MH from the samples were in the range of 22.85 - 51. These are suitable for irrigation purposes. However, there are 3.85% of total shallow wells samples at Ban Tang Mung were over 50, which not suitable for irrigation based on the MH ratio. Excessive magnesium concentration led to the deterioration of the soil structure and decreased soil productivity. Moreover, a high amount of magnesium in groundwater responds to soil alkalinity, reduces soil infiltration capability, and hurts crops and soil becoming more alkalinity [15]. Considering the irrigation water based on Mg/Ca ratio found that the majority of all samples belong to the safe and moderate class with Mg/Ca ratio lower than 3.0 [13].

4.9 Gibbs groundwater chemistry

Gibbs's diagram recognized the relationship between aquifer lithology and groundwater chemistry. There are two diagrams; one show the ratio of TDS and $Na^+/(Na^+ + Ca^{2+})$ (Fig. 5) and other one about TDS and $Cl^-/(Cl^- + HCO_3^-)$ (Fig. 6).

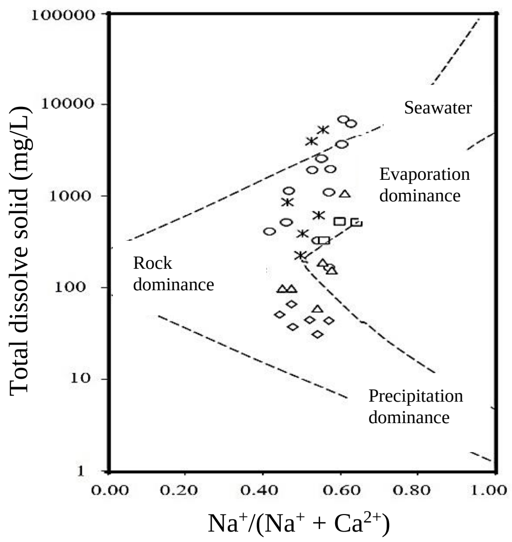

Fig 5. Gibbs variation diagrams ($Na^+ + Ca^{2+}$)

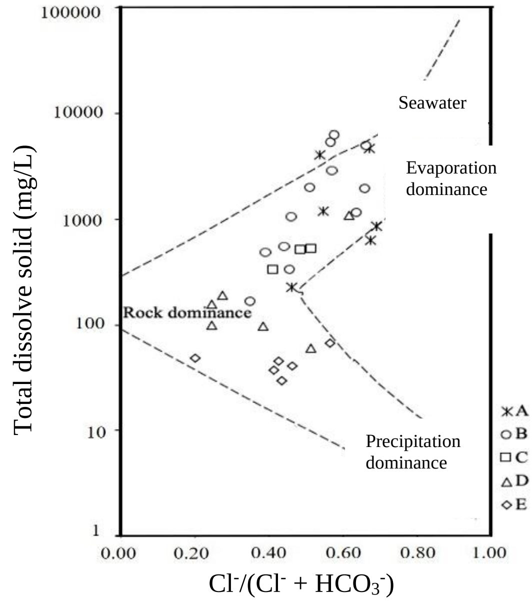

Fig 6. Gibbs variation diagrams ($Cl^- + HCO_3^-$)

This diagram represents three mechanisms dominance, evaporation dominance, rock dominance, and precipitation dominance [5]. In this study, most of the ground samples are plotted in the rock dominance and evaporation dominance, as shown in Fig. 5 and 6. Halite mineral was the controlled groundwater chemistry. Salinity increased by Na^+ and Cl^- which was related to an increase in TDS.

5. CONCLUSION

The groundwater quality based on its physicochemical properties was investigated. The abundance of cation and anion were $Na^+ > Ca^{2+} > Mg^{2+} > K^+ = Cl^- > HCO_3^-$. The groundwater from this area from both deep ponds and shallow wells was suitable for irrigation, but high levels of EC, TDS, and Na^+, which are major factors in water quality for irrigation purposes, especially in the areas of Ban Nong I Khem and Ban Tang Mung. The plots of US Salinity showed a high salinity hazard and a low-medium alkalinity hazard which is accepted for salt-tolerant crops or permeable soil with salinity should be controlled. Moreover, the Wilcox diagram shows that the majority of the groundwater was within the “Excellent to Good” and “Good to Doubtful” categories. The geology of the area also causes a deterioration in the groundwater quality. The unsuitability is the result of the dissolution of minerals as this area is located on a salt rock. The natural processes such as weathering of rock and the evaporation process are the main groundwater chemistry in this area. Human interference, river water leakage, and fertilizer application are becoming increasingly in groundwater chemistry dominance in this area. Therefore, groundwater from this area was suitable for irrigation and salt-tolerant crops, or permeable soil with salinity should be controlled.

6. ACKNOWLEDGMENTS

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