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Article

Prioritizing countermeasures for reducing seawater-intrusion area by considering of regional characteristics using SEAWAT and a multi-criteria decision-making method

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Abstract: Coastal areas are increasingly being damaged with the expansion of seawater intrusion areas. We suggest a three-step method for reducing seawater intrusion areas by predicting future damage to groundwater being used continuously. First, the area most vulnerable to seawater intrusion damage is selected from among 25 areas on the west coast of the Republic of Korea. Having identified the Taean area as the region in question in the second step, we use RCP 4.5 and 8.5 as future sea level rise scenarios and predict the future usage of groundwater using linear-regression analysis of data for the past 10 years. Consequently, for RCP 8.5 (groundwater-usage scenario 1.0), 68.5% of the total Taean area is projected to be influenced by seawater intrusion. In the third step, the effectiveness of seawater intrusion reduction measures is analyzed considering the projected future situation and the local characteristics of the Taean area. After considering the effects of alternative locations, as well as seawater intrusion related data, alternatives were prioritized using a multi-criteria decision-making method. Consequently, 3, 5, and 4 were prioritized in the listed order, and we judged that by applying seawater intrusion area reduction measures according to this result, we will achieve the biggest effect.

Keywords: SEAWAT, Multi-criteria decision-making, Seawater intrusion, Recharge pond, Control groundwater use, Location prioritization

1. Introduction

Coastal areas have enjoyed prosperity and mass settlement owing to their transportation advantages and marine resources. The 20th century saw the development of 21 megalopolises, having populations over 8 million people, in coastal areas, and over 1/3 of the world population lives within 100 km of the coast. The International Panel on Climate Change [1] predicted that the average sea level of the world will rise by 0.26–0.82 m considering local deviation. As the area of seawater intrusion increases due to this sea level rise, seawater is polluting freshwater and crops, directly restricting human activity; secondarily, seawater intrusion also damages coastal ecosystems and restricts industrial activity. According to the Ghyben–Herzberg analysis method, 1 m of sea level rise will influence freshwater-aquifer applicability to a thickness of 40 m. According to Sherif and Singh [2], when the level of the Mediterranean Sea rises by 0.5 m, seawater intrusion will influence areas up to 9 km from the coast. Moreover, Werner and Simmons [3] showed that seawater could intrude up to 5 km from coastal areas through seawater intrusion boundary simulation. Much research is currently being conducted on such a simulation using various numerical analysis models such as MOFLOW, FEFLOW, SUTRA, SEAWAT, MOCDENS3D, and FEMWATER [4-9]. In addition,

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together with sea level rise, studies on the influence to seawater intrusion due to over-pumping of groundwater are actively proceeding [10-15].

Various attempts are being made to relieve and prevent damage from seawater intrusion. One direct method is to install freshwater-injection or seawater-pumping wells in aquifers where seawater intrusion is proceeding [16]. Another technique is seawater pumping at the wedge part of seawater intrusion at the bottom part [17, 18], which corresponds to injecting freshwater at the boundary of the seawater intrusion area [19, 20].

Thus, a great deal of research is being done to project and mitigate seawater intrusion damage on a global scale. However, to efficiently plan against seawater intrusion damage, it is necessary to select areas where such damage is actively occurring and then design a response that is suitable to the characteristics of the area. Recently, research has briskly proceeded on methods to select vulnerable areas and prioritize the optimal counterplans [21-26]. In this research, areas vulnerable to seawater intrusion are selected using multicriteria decision making (MCDM) and SEAWAT is employed to predict seawater intrusion damage under future sea level rise. We suggest a methodology to select optimal counterplans based on predicted data and local characteristics.

2. Methods

2.1. Summary of procedure

This research proceeded according to three steps, as shown Figure 1, to maximize the effectiveness of our plan. The west coast of the Republic of Korea was selected as the subject area for this research (Figure 2). As the first step, hydrological data of possible relevance to seawater intrusion was collected from local administrative districts. Various factors were assigned weighting values determined by surveys and the most vulnerable area was selected using alternative evaluation index (AEI), composite programming (CP), and the technique for order preference by similarity to an ideal solution (TOPSIS). At the second step, the future seawater intrusion scope for the selected area was analyzed. We constituted the subject area with SEAWAT, calibrated for current status and utilized sea level rise data suggested by IPCC [1] to consider the effect on the west coast. RCP 4.5 and RCP 8.5 were used as sea level rise scenarios, which projected rises of 60.5 and 81.9 cm on the west coast, respectively. Groundwater usage was analyzed in the future seawater intrusion area by considering two scenarios, one in which current growth trends are extended into the future and one where usage is reduced by 50% from current values. In the third step, we used AEI, CP, and TOPSIS to prioritize all counterplans, which were developed considering local characteristics, comprising all factors that may influence seawater intrusion.

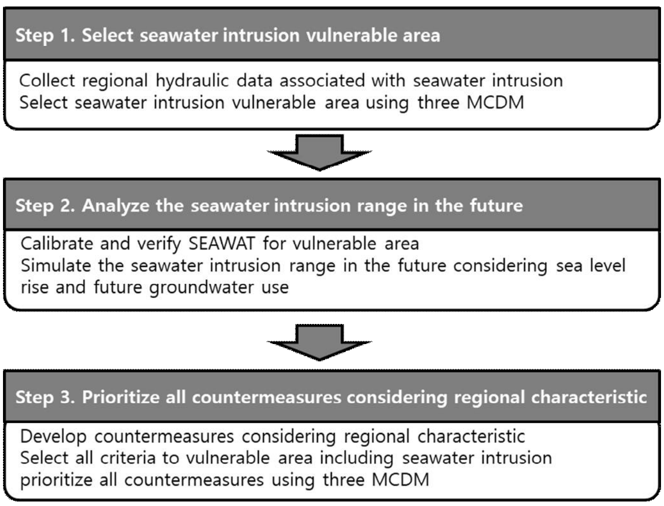

Figure 1. Procedure followed in this study

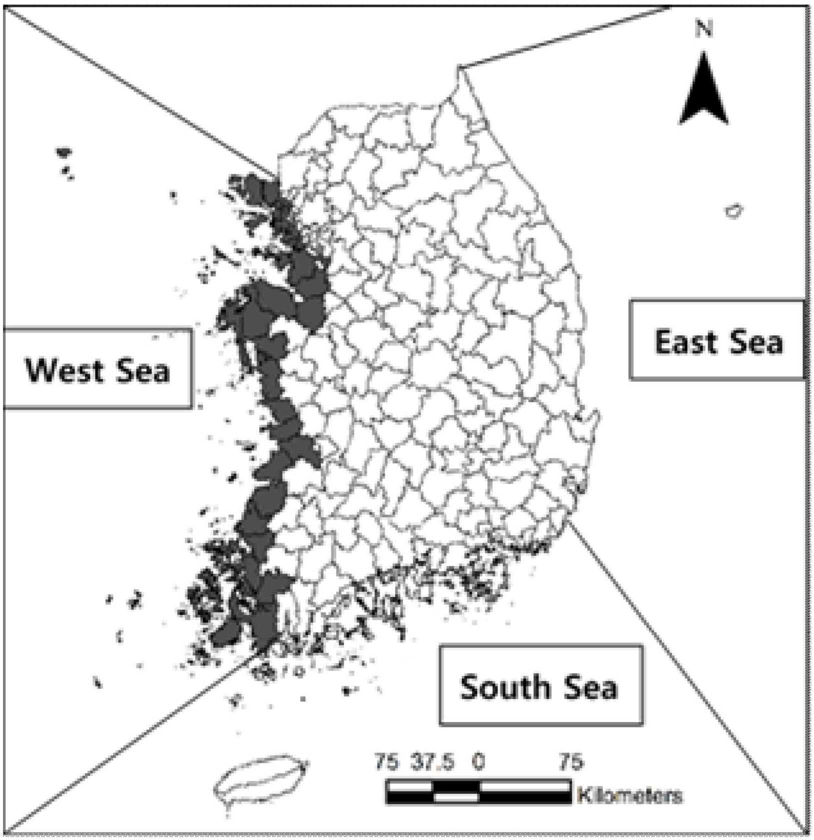

Figure 2. Study area and locations of seas

2.2 SEAWAT

To simulate variable-density groundwater flow and solute transport under transient groundwater flow, SEAWAT is coupled with MODFLOW [27] and MT3DMS [28, 29], which were designed to simulate such flows in three dimensions by considering multispecies transport. This program has been widely used to analyze seawater intrusion [30-32].

2.3 Parameter estimation package (PEST)

PEST [33-35] was used for the automatic calibration of the seawater intrusion model. The Gauss–Marquardt–Levenberg algorithm is used to estimate parameters by minimizing weighted residuals between observations and calculated equivalents.

PEST allows the modeler to optimize parameters much faster than a manual method. Furthermore, PEST allows the model to be calibrated on the basis of hydraulic conductivities, storage coefficients, and recharge [36]. Configure Layer 3, whereas the total isotropic medium and the horizontal hydraulic conductivities of K_x and K_y are assumed to be the same in each layer of the medium.

2.4 Multi-criteria decision-making (MCDM)

MCDM processes generally follow the sequence of (1) identification of final decision makers, actors (people involved in the decision-analysis process), and stakeholders (anyone involved in the decision-analysis process); (2) selecting decision-making criteria; (3) defining alternatives; (4) choosing one or more MCDM techniques; (5) weighting the criteria; (6) assessing the performance of alternatives against the criteria; (7) transforming the criteria-performance values to commensurable units, if required; (8) applying the selected MCDM techniques; and (9) making the final decision. Weighting the criteria and assessing how alternative options perform against the

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criteria are two of the most important and difficult aspects of applying the MCDM methodology, and they present potential sources of considerable uncertainty [37, 38].

2.4.1 Rescaling and alternative evaluation index (AEI)

Extreme values (minima and maxima) could potentially be unreliable outliers that distort the transformed indicator. By contrast, for indicator values lying within a very small range, the latter is widened by rescaling, thus explicitly increasing the effect on the composite indicator. Therefore, standardization is necessary when using the linear-rescaling equation.
AEI was developed by Chung and Lee [21] to prioritize alternatives for integrated watershed management using hydrological simulations and multicriteria decision-making techniques. The total score for each alternative (a_i) used in this study can be calculated according to the equation

$$AEI(I_j) = \sum_{i=1}^{n} w_j a_{ij}, \tag{1}$$

where a_{ij} are the values of the criteria, and w_j are their weighting values ($\sum_{j=1}^{m} w_j = 1$). The role of the decision makers is to select each indicator.

2.4.2 Composite programming (CP)

CP, a multilevel/multiobjective programming method, is an empirical technique used to resolve geological-exploration problems [39].
Once the relevant indicators, associated boundary values (ideal and worst values), actual values, and weights have been determined, the next step is to normalize the basic values (transforming them into the range of 0–1), thereby avoiding differences in units. Given the ideal value ($f_{i,j}^{ideal}$) and the worst value ($f_{i,j}^{worst}$), the normalized value of an actual indicator ($f_{i,j}(a)$) of an alternative (a) can be calculated. The next step is to calculate second-level composite distances for each second-level group of basic indicators using the following equation:

$$L_j(a) = \left(\sum_{i=1}^{N_j} w_{ij} \left(\frac{f_{i,j}^{ideal} - f_{i,j}(a)}{f_{i,j}^{ideal} - f_{i,j}^{worst}} \right)^{b_j} \right)^{1/b_j}. \tag{2}$$

Here i is the sequential number given to a basic indicator, j is the sequential number of a certain group of basic indicators, $L_j(a)$ is the distance from the ideal point in the second-level j group, N_j is the number of basic indicators in a second-level j group, w_{ij} is the weight expressing the relative importance of the N_j basic indicators in group j (the sum of weights in any group being equal to one), and b_j is the balancing factor (which is equal to or greater than 1) among indicators within group j. The consecutive computations of higher-level composite indices are made in the same manner until a final composite distance for a system is obtained.

2.4.3 Technique for order preference by similarity to an ideal solution (TOPSIS)

The TOPSIS method developed by Hwang and Yoon [40] is a practical technique for ranking and selecting externally determined alternatives through distance measurements. The basic principle of TOPSIS is that the chosen alternative should have the shortest distance from the positive ideal solution and the farthest distance from the negative ideal solution [41, 42]. TOPSIS

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procedure [43], $A_1, A_2, \cdots$, and A_m are m possible alternatives from which decision makers must choose. $C_1, C_2, \cdots, C_n$ are the criteria with which alternative performance is measured. We constructed a decision matrix, $X = [x_{ij}]_{n \times m}$, where x_{ij} is the rating of alternative A_i with respect to criterion C_j. w_j is the weight of criterion C_j and the weighting values sum to 1.

The positive ideal solution (PIS) and the negative ideal solution (NIS) are respectively determined as follows:

$$V^+ = \{v_1^+, v_2^+, \cdots, v_m^+\}, v_i^+ = max_j v_{ij}; \tag{3}$$

$$V^- = \{v_1^-, v_2^-, \cdots, v_m^-\}, v_i^- = min_j v_{ij}. \tag{4}$$

The separation distances between each alternative and the PIS and between each alternative and the NIS are respectively defined as

$$d_j^+ = \left\{\sum_{i=1}^{n} \left(v_{ij} - v_i^+\right)^2\right\}^{\frac{1}{2}}; \tag{5}$$

$$d_j^- = \left\{\sum_{i=1}^{n} \left(v_{ij} - v_i^-\right)^2\right\}^{\frac{1}{2}}. \tag{6}$$

Therefore, the closeness coefficient for each alternative (j) can be defined as

$$C_j^* = \frac{d_j^-}{d_j^+ + d_j^-}. \tag{7}$$

3. Area vulnerable to seawater intrusion

3.1 Description of the west coast

Korea is surrounded by 3 sea sides, so it has long coastline and various coastal topography is developed. The West Sea is consisted of the coast from Incheon City to Yeongam Gun, the South Sea is consisted of the coast from Haenam Gun to Ulsan City and the East Sea is consisted of the coast from Gyeongju City to Gosung Gun. From recent data, the length of coastline is observed as West Coast: 4,900km, South Coast: 3,300km and East Coast: 600km in South Korea[44]. West Coast has very indented coastline and there are many gulf, peninsula, cape and islands, and especially in coastline of Dadohae area and Taean Peninsula, the shape is very indented and typical rias coast has been developed.

In this research, I performed selection of the most vulnerable area targeting West Coast where the coastline is long, terrain gradient is gradual and tidal range is severe, among the area being influenced by sea water penetration influence among Korean sea. Performed analysis targeting 25 administrative districts and the name of area applicable to each number was written in Figure. 3.

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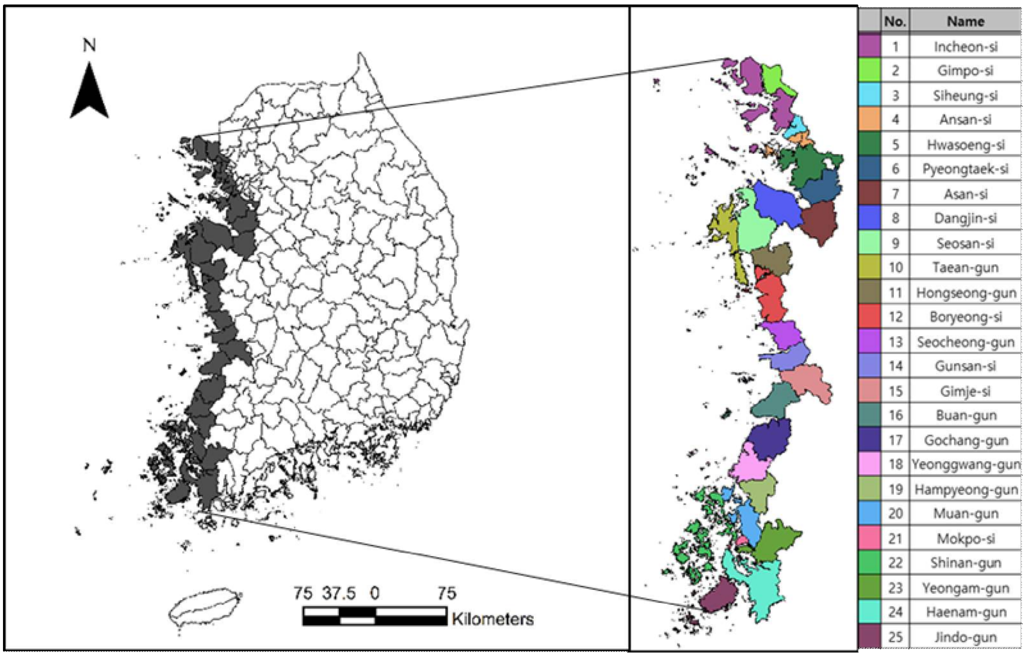

Figure 3. Administrative districts on the west coast of the Republic of Korea

3.2 Establishing criteria and determining weighting values

Twenty five research areas on the west coast were considered in terms of vulnerability to seawater intrusion. Data concerning factors directly related to the spread of the seawater intrusion area were collected and weighting values of each factor were determined by 19 groundwater resource experts according to the Delphi method, by which surveys were conducted three times and feedback was conducted twice. To show the spread of seawater intrusion areas, the trends of each factor were obtained by linear regression of 15 years of data (2001–2015). A total of four factors describing how seawater intrusion may influence coastal aquifers were selected. Fluctuation of groundwater level prevents seawater from spreading from coastal aquifers to inland areas. As groundwater level declines, aquifers become vulnerable to seawater intrusion damage. Seawater penetrates directly into coastal aquifers over the seawater intrusion area. As the sea level increases, the seawater intrusion areas spread. Groundwater usage causes lowering of groundwater level in coastal areas, leading to the expansion of seawater intrusion areas. The groundwater recharge amount describes the rate at which the freshwater level is replenished in coastal aquifers. To determine the groundwater level, groundwater usage, and groundwater recharge amount, data from the National Groundwater Information Center (GIMS) was used. The groundwater recharge amount was calculated using the SCS-CN method based on the rainfall amount in each area. For seawater level, the data were acquired from the Korea Hydrographic and Oceanographic Agency (KHOA). The weighting values for each factor showed the groundwater level trend has a maximum value of 0.31, whereas the seawater level trend had a maximum value of 0.3. Groundwater usage was 0.21 and groundwater recharge amount was 0.18. Explanations and weighting values of each factor are presented in Table 1.

Table 1. Description of indicators and their weights

Indicators	Description	Unit	Weights
GWLT	Groundwater level trend	cm/year	0.31
SWLT	Seawater level trend	cm/year	0.3
GWUT	Groundwater usage trend	m^3/year	0.21
RecT	Recharge trend	m^3/year	0.18

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3.3 Determining seawater intrusion into vulnerable areas

The area most vulnerable to seawater intrusion was determined according to four factors, which were ranked by applying the weighting values calculated using AEI, CP, and TOPSIS. The most vulnerable area to seawater intrusion was found to be No. 10, Taean Gun, which took 1^{st} place under all three methods. Taean Gun shows an overwhelming trend of increasing sea level compared with other areas and the groundwater level shows a descending trend. No. 17, Gochang Gun, took 2^{nd} place according to AEI and CP but 4^{th} place according to TOPSIS; its recharge amount showed a sharply descending trend and its sea level is increasing. No. 2, the Gimpo area, took the 2^{nd} place in TOPSIS, 4^{th} place in AEI, and 3^{rd} place in CP, and it showed the greatest descending trend for groundwater level while sea level showed a slightly increasing trend.

Table 2. All derived performance values for four criteria and vulnerability rankings determine by the AEI, CP, and TOPSIS methods

No.	GWLT	SWLT	GWUT	RecT	AEI		CP		TOPSIS	
	cm/year	cm/year	m^3/year	m^3/year	AEI	Ranking	L	Ranking	C*	Ranking
1	−0.008	0.443	−2999	−492212	0.363	21	0.433	19	0.466	13
2	−0.049	0.638	708	88806	0.552	4	0.626	3	0.614	2
3	0.011	1.001	−215	432934	0.383	20	0.388	22	0.405	19
4	−0.006	1.001	709	−826050	0.506	9	0.515	12	0.540	6
4	−0.006	1.001	709	−826050	0.506	9	0.515	12	0.540	6
5	0.010	0.602	1653	583820	0.386	18	0.397	20	0.392	20
6	−0.012	0.749	1143	−915396	0.514	8	0.531	11	0.553	5
7	−0.003	0.749	933	326288	0.429	16	0.440	18	0.462	15
8	0.010	0.749	4228	305726	0.467	14	0.495	16	0.434	17
9	0.003	0.988	3711	−509927	0.533	7	0.543	9	0.512	9
10	−0.002	3.049	2156	205594	0.659	1	0.702	1	0.614	1
11	0.059	0.817	1842	372782	0.281	24	0.343	24	0.249	26
12	0.000	0.817	4992	−46892	0.535	6	0.564	6	0.504	10
13	0.025	−0.504	2101	162252	0.276	25	0.342	25	0.292	24
14	0.010	1.019	3546	161898	0.482	12	0.496	15	0.452	16
15	−0.002	0.767	4964	998992	0.489	11	0.542	10	0.468	12
16	−0.014	0.515	3108	1655165	0.429	15	0.502	14	0.462	14
17	0.003	0.829	3408	−2400092	0.597	2	0.636	2	0.571	4
18	−0.013	1.647	2028	297674	0.561	3	0.573	5	0.576	3
19	0.019	0.613	1486	−51379	0.384	19	0.389	21	0.374	21
20	0.026	0.613	1716	998199	0.325	23	0.343	23	0.306	23
21	−0.038	−0.421	197	11512	0.422	17	0.544	8	0.524	8
22	0.026	−0.421	5156	10211	0.356	22	0.467	17	0.335	22
23	0.030	−0.421	1562	46668	0.262	26	0.317	26	0.272	25
24	0.009	0.717	6341	1222414	0.474	13	0.559	7	0.425	18
25	−0.001	0.717	5696	177098	0.535	5	0.580	4	0.499	11

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4. SEAWAT formulation

4.1 Modeling area

There are seven rivers in the Taean area, and they are all of small size and managed by the local government. The modeling area has a mild climate due to the influence of the sea, with an average annual temperature of 11.8°C and average annual precipitation of 1,270 mm, which is slightly higher than Korea's average of 1,245 mm. Summer precipitation (June–September) is 848 mm, which is 67% of the Korean average. The Taean area is a peninsula connected to Seosan City to the east and surrounded by the sea on every other side. It has a rias (heavily indented) coast. Baekhwa Mountain (height: 284.7 m) is located at the center of Taean Gun, with veins spread in all directions; however, most of the area is low-lying ground, with 95.4% of the land below 80 m above sea level. An alluvium layer consisting of mostly sand and silt with a flat overall topography is distributed throughout the area. The coast is used primarily as beaches because sandy beaches are formed due to wave erosion. Due to the irregularity of the coast, many areas of reclaimed land have been developed. Forests (41.94%) and bare ground and marsh (34.13%) account for most of the land use, and towns occupy 24.78 km^2, i.e., 4.99%, of the total area.

There are seven observation holes in the research area. From 2006–2010, calibration was performed using average annual data from OW1–OW7. OW1 and OW2, which have no missing values and good quality of data, were used for verification based on monthly average observation data from 2011 to 2015.

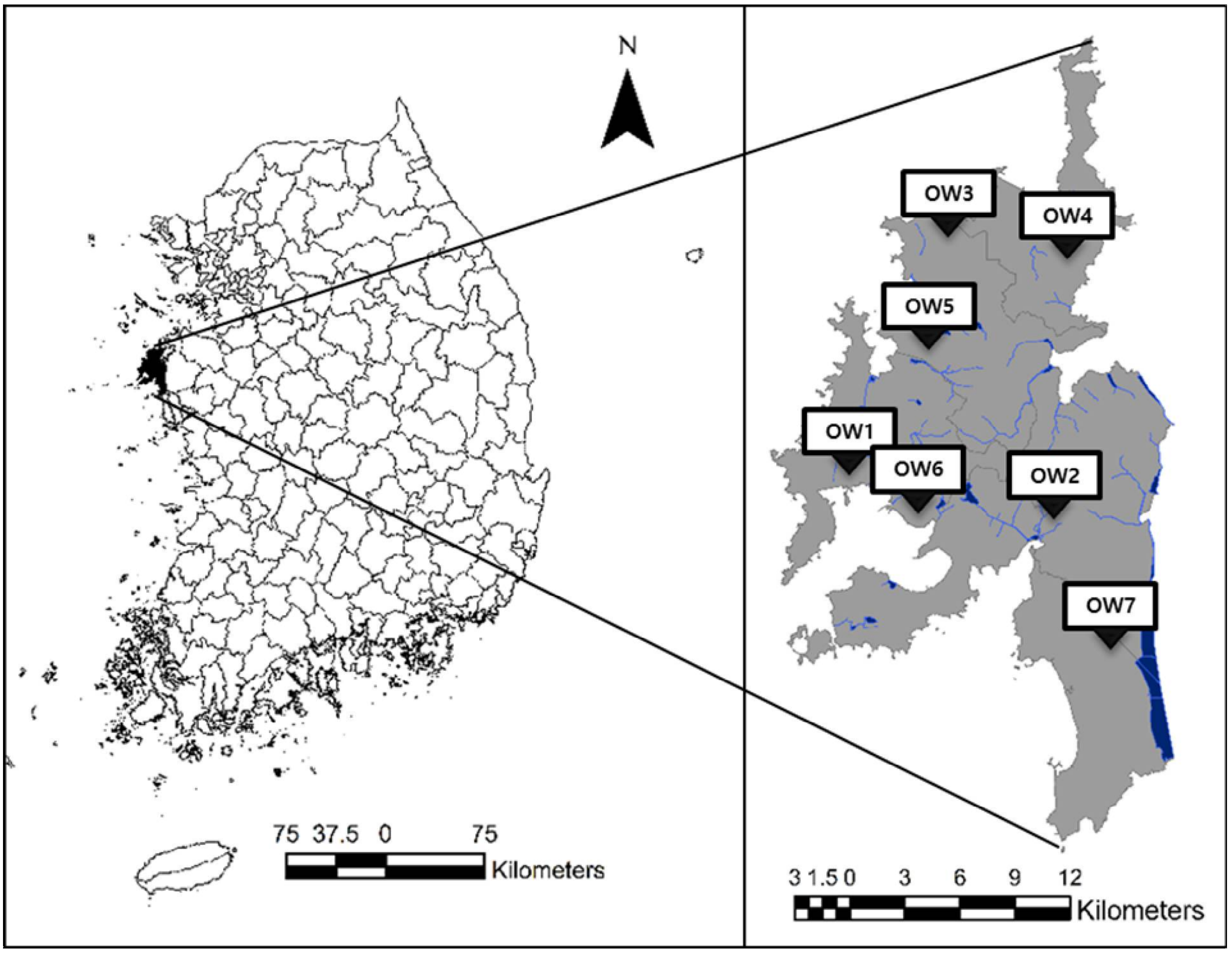

Figure 4. Modeling area and location of observation well

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4.2 Configuration

Configuration of the model comprised a calibration stage, a verification stage, and an application of predicted future scenarios stage. To increase modeling reliability, calibration was performed using the PEST module within SEAWAT based on groundwater level data for the past 10 years, salt concentrations, EC, and sea level observation data. Using several years' worth of data, the hydraulic conductivity and storage coefficient (which reflects geological features through the PEST package in a steady state) were determined, whereas we determined the rest of the variables (recharge, initial head, pumping rate, etc.) through direct input under the transient state. During the verification stage, we improved the reliability of our model by comparing with data obtained over 5 years of monthly average observations at OW1 and OW2. Figure 5 shows the configuration process of SEAWAT modeling.

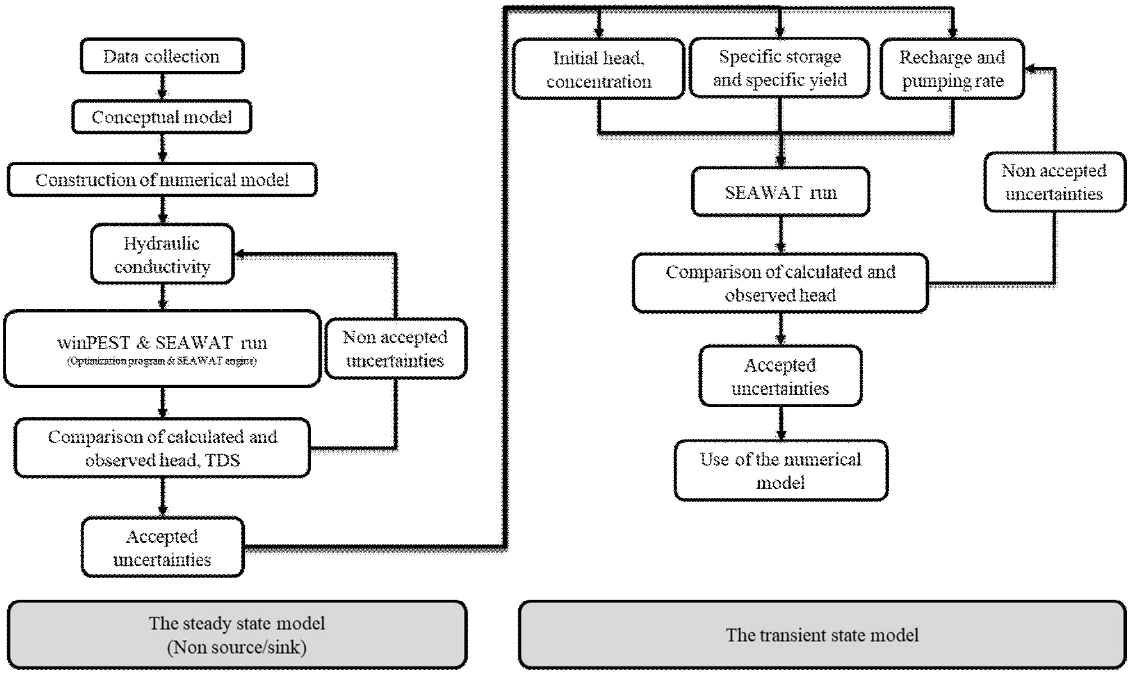

Figure 5. SEAWAT model configuration

4.3 Calibration and validation

Based on the calibration, the RMSE values, which compare observations and calculation results at the seven observation wells under a steady state from 2006 to 2010, were 0.083 m for head and 111.23 mg/L for TDS. Based on this result, from the transient state at which the calibration of the rest of the input variables was completed, the head RMSE for OW1 and OW2 was 0.135 m and that for TDS was 246.81 mg/L. Very reliable modeling was configured and, based on this, the future RCP 4.5 and RCP 8.5 sea level rise scenarios were applied to the scenario with restricted groundwater usage and additional installation of a recharge area. Figure 6 shows the dispersions of the calculated and observed values for the seven observation wells, and Figure 7 graphs the observed and calculated results from OW1 and OW2 during the verification stage from 2011 to 2015.

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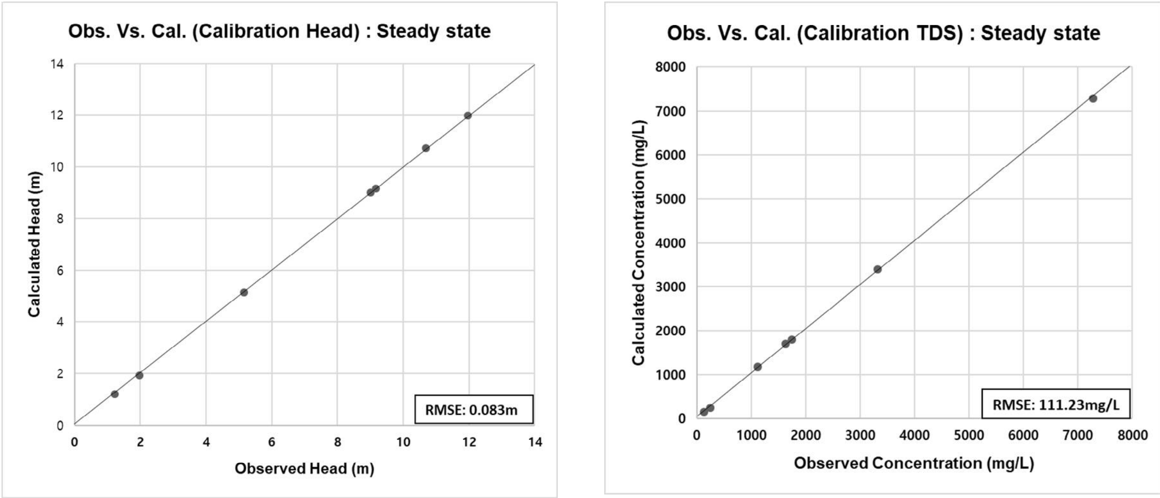
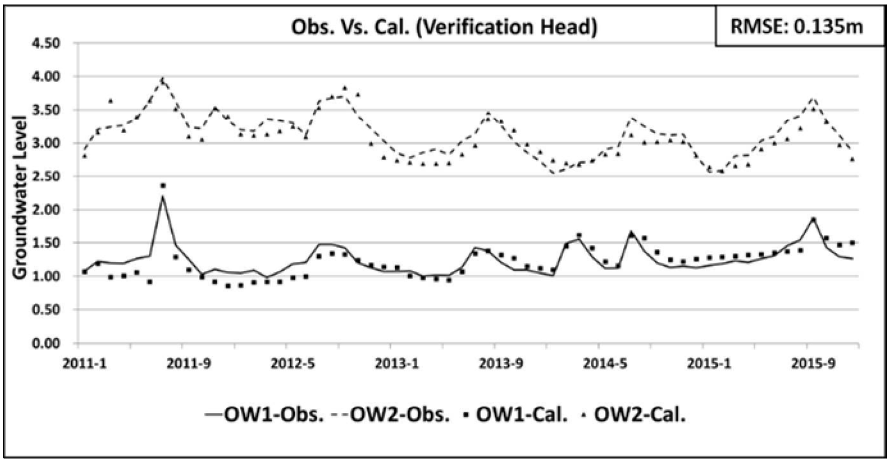
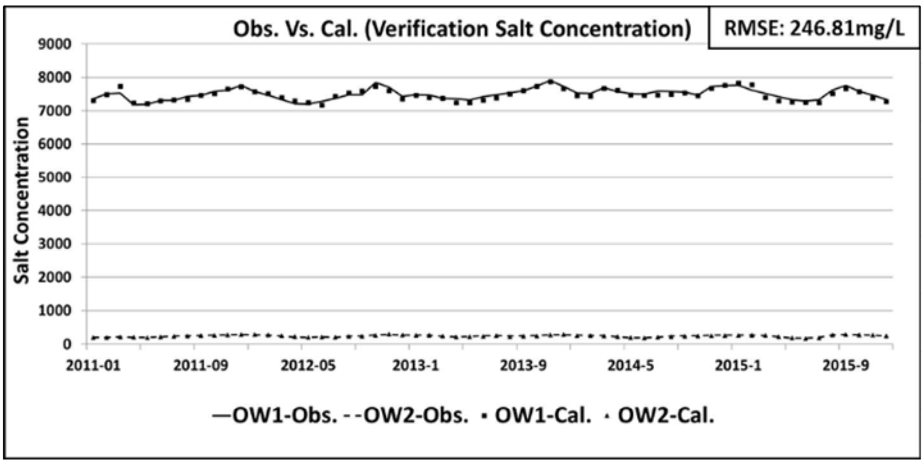


(a) Head (b) TDS

Figure 6. Scatter plots of calculated and observed values in the calibration stage



(a) Head



(b) TDS

Figure 7. Comparison between calculated and observed values in the verification stage

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5. Results

5.1 Analysis of the seawater intrusion area

5.1.1 Application of future sea level rise (RCP 4.5 and RCP 8.5) and groundwater use scenarios

To predict the scope of seawater intrusion in the research area, climate change predictions made by IPCC [1] were applied. Of these, RCP 4.5, the mid level greenhouse gas emission scenario, and RCP 8.5, the high level greenhouse gas emission scenario, were used. RCP 4.5 showed a sea level rise of 60.5 cm by 2099 compared to 2015, whereas RCP 8.5 showed a sea level rise of 81.9 cm. Figure 8 shows the sea level rise from 2016 to 2099 in the Taean area.

The groundwater usage from 2016 to 2099 was determined by the linear-regression method. The incline of the first linear-regression equation was 1,037,220. Linear regression 1.0 showed the case using the present trend and Linear regression 0.5 showed the case of a use reduction of 50% from the current trend in Figure 8. Consequently, in 2099, Linear regression 1.0 showed a ground water usage result of 132,668,635 m^3, which is 2.91 fold greater than that in 2015. Linear regression 0.5 showed 89,105,395 m^3 of groundwater usage, which is 1.96 fold greater than that in 2015. Figure 9 shows the linear-regression analysis result for future usage of groundwater.

In analyzing the seawater intrusion area, it was determined as average TDS to −10 m with Gl.m. As it borders surface of the sea, as the depth is deep, TDS may have its own TDS of seawater, it does not influence to nearby human life. Gl.m −10 m describes direct damage due to seawater intrusion, inhibiting the ability to cultivate crops or construct buildings. Considering TDS, regions with an average TDS over 10,000 mg/L at a depth of 10 m from the surface are judged to be salt water [45] and the area from the coastline to the boundary of the 10,000mg/L area was calculated.

Modeling showed that the current seawater intrusion area as of 2015 is 76.89 km^2, occupying 19.93% of the total area of Taean. Wider areas of seawater intrusion occur around small sized rivers compared to ordinary coastline areas. In the No. 5 Geunheung district, 37.33% of the area was influenced by seawater intrusion. The area of seawater intrusion in Taean was 18.13 km^2 whereas that in Nam was 14.76 km^2. The ratio of the seawater intrusion area to the total area was 24.34% for Nam and 20.70% for Taean.

Modeling until the year 2099 showed that increased groundwater usage has a more significant effect upon seawater intrusion area than sea level rise under both RCP 4.5 and RCP 8.5. For RCP 4.5, the seawater intrusion area varied by 92.24 km^2 between the different groundwater use scenarios and this value was 99.91 km^2 for RCP 8.5. On the other hand, for groundwater use scenario 0.5, the intrusion area differed by 31.27 km^2 between sea level rise scenarios and by 38.94 km^2 for scenario 1.0. From the local characteristic where everywhere except for east side is adjacent to sea, there is a high ratio of depending on groundwater and in case the development on groundwater will be started continuously, it is expected that 42.60% will be seawater intrusion area from RCP 4.5 scenario and 68.50% from RCP 8.5 scenario. Table 3 compares seawater intrusion areas in 2015 and 2099 under various scenarios. Figure 10 shows seawater intrusion areas for each scenario.

Table 3. 2015 vs. 2099 Seawater intrusion area

No.		1	2	3	4	5	6	Sum
Name		Wonbuk	Iwon	Taean	Sowon	Geunheung	Nam	
Area	km^2	74.2	40.94	87.62	69.4	52.96	60.63	385.75
2015 Seawater intrusion area	km^2	9.12	2.86	18.13	12.25	19.77	14.76	76.89
	%	27.10	12.90	42.26	32.75	43.89	33.44	34.13
2099 Seawater intrusion area RCP 4.5 GWU 0.5	km^2	18.04	10.97	25.38	22.58	30.62	25.45	133.05
	%	53.63	49.51	59.15	60.38	67.96	57.69	59.06
2099 Seawater intrusion area RCP 8.5 GWU 0.5	km^2	22.84	14.89	30.43	27.88	36.69	31.59	164.32
	%	67.87	67.19	70.92	74.57	81.42	71.59	72.93
2099 Seawater intrusion area RCP 4.5 GWU 1.0	km^2	33.65	22.16	42.91	37.39	45.06	44.12	225.29
	%	100.00	100.00	100.00	100.00	100.00	100.00	100.00
2099 Seawater intrusion area RCP 8.5 GWU 1.0	km^2	41.55	26.88	52.94	43.09	48.17	51.62	264.23
	%	123.48	121.29	123.36	115.23	106.90	116.99	117.28

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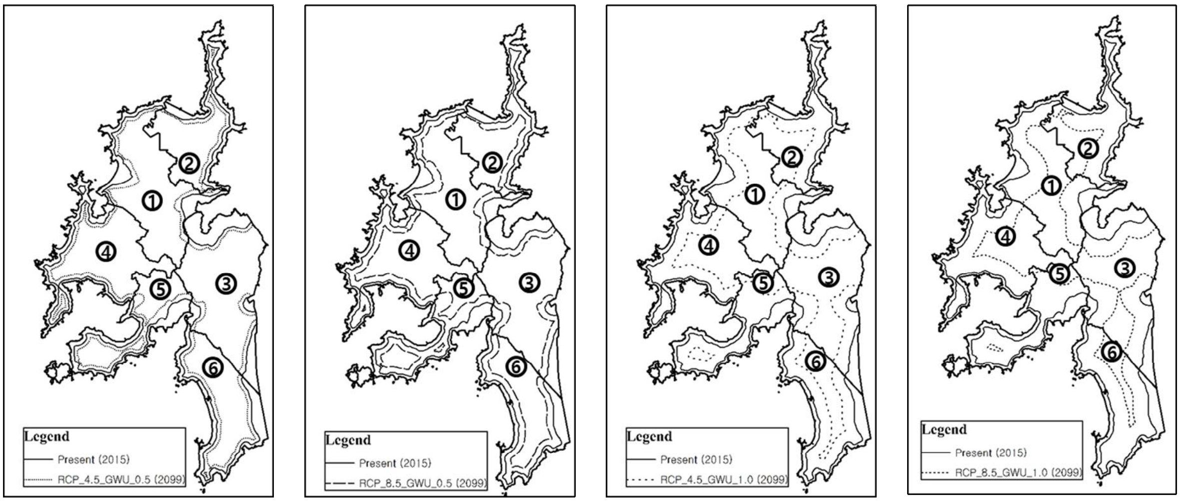

(a) RCP 4.5, GWU 0.5 (b) RCP 8.5, GWU 0.5 (c) RCP 4.5, GWU 1.0 (d) RCP 8.5, GWU 1.0

Figure 8. TDS 10,000 mg/L zones in the study area

5.1.2 Application of feasible alternatives

Most methods that have been proposed to reduce seawater intrusion areas involve controlling the inflow of seawater by injecting freshwater or by directly pumping seawater. These methods have excellent effects but can only be applied according to the geological structure or status of the underground aquifer. Our research area has a surface layer comprising silt and clay and there are weathered rock and bed rock layers lower down; therefore, the method of injecting freshwater or pumping seawater is of limited utility. Thus, in this research, we applied construction of a recharge area and restriction of groundwater usage as methods to reduce the seawater intrusion area. These methods are more passive than freshwater injection or seawater pumping but more economical considering the resources that would be available due to the uncertainty of the geological structure. The method of constructing recharge areas plays a very positive role in terms of creating new water resources with consideration of local characteristics depending on groundwater. Restriction of groundwater usage, meanwhile, can be done by limiting the usage to 50% of the average usage during periods of water shortage rather than by limiting the whole usage in a year. Dependence on groundwater can be reduced by expanding water-supply facilities.

In our model, the recharge area is located surrounding housing and farmland outside of the seawater intrusion area. It should be preferentially located where it can be easily utilized as a water-supply source and constructed at a high altitude compared to the surrounding area to maximize the recharge of freshwater. The size of each recharge area is 100 m × 100 m × 1 m and three recharge areas are installed per location. The effect was maximized by permeability coefficient by substituting power part strata. Figure 12 shows location of recharge amount per each. Restriction of groundwater usage was performed by allowing 50% of the average usage to be pumped from September to February, which is the period of relative water shortage during a year. Construction of a recharge area and restriction of groundwater usage were both applied and the seawater intrusion area reduction effect was analyzed.

The results of the analysis showed that restriction of groundwater usage was more effective than construction of a recharge area. Construction of a recharge area resulted in an 11.95% intrusion area reduction from the future scenario, but restriction of groundwater usage resulted in a 14.55% reduction. This shows the effect of reducing the amount of outflow from an underground aquifer. Construction of a recharge area seems less effective than restricting groundwater usage, but it nevertheless reduces the intrusion area by 17.58% in the future scenario. In contrast, the No. 2 Iwon area shows an average 5.5% reduction effect from the future scenario, meaning that the effect of the recharge area was smaller because the No. 1 stratum has a relatively thin surface and the weathered

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rock and bed rock layers with low water permeability are thick. When limiting groundwater usage, the intrusion area in No. 3 Taean area was reduced by an average 22.56% reduction effect from the future scenario. In contrast, No. 2 Iwon, which has less groundwater usage, shows a 7.27% reduction and No. 5 Geunheung shows 3.27% reduction. The difference in the intrusion area reduction effects between No. 2 and No. 5, between which there are no significant differences in groundwater usage, was due to differences in the locations of wells. In the No. 2 area, many wells are found throughout the land, but in the No. 5 area, the wells are found near small sized rivers. When both recharge area construction and restriction of groundwater use were implemented, there was an average 33.28% intrusion area reduction between districts in the future scenario and a 45.54% reduction for Taean in particular. No. 2 Iwon and No. 5 Geunheung, which have relatively low reduction efficiencies, showed reductions of 18.86% and 22.2%, respectively. Table 4 shows the results of applying the seawater intrusion reduction scenario.

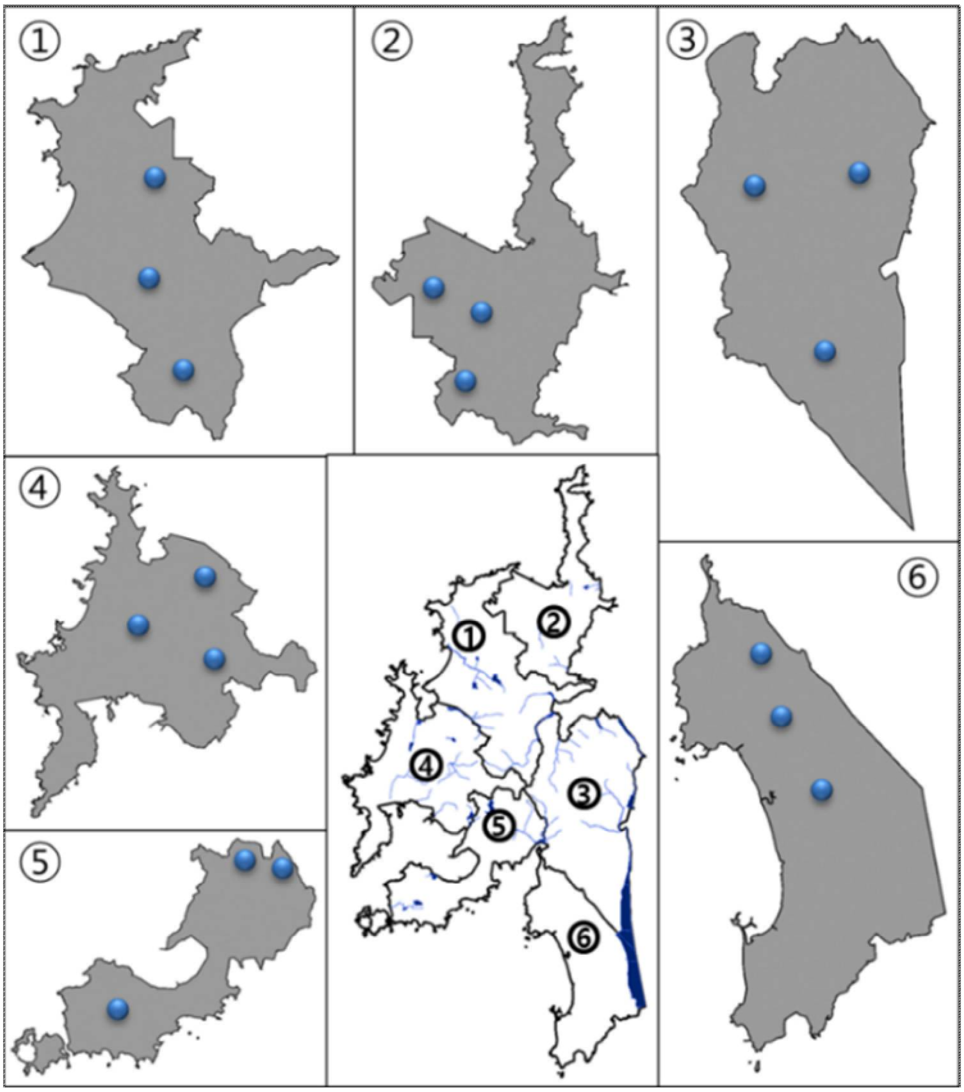

Figure 9. Locations of recharge ponds in each area

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Table 4. Results of applied seawater intrusion area reduction scenarios

Recharge pond								
No.		1	2	3	4	5	6	Sum
RCP4.5 GWU0.5	**Area (km2)**	16.99	10.45	21.24	19.12	26.58	23.53	117.90
	Reduction rate(%)	5.84	4.77	16.31	15.32	13.22	7.57	11.39
RCP8.5 GWU0.5	**Area (km2)**	21.52	14.13	25.29	23.71	31.61	29.10	145.36
	Reduction rate(%)	5.77	5.09	16.88	14.97	13.84	7.89	11.54
RCP4.5 GWU1.0	**Area (km2)**	31.35	20.85	35.08	31.37	38.72	40.49	197.85
	Reduction rate(%)	6.84	5.92	18.24	16.12	14.06	8.24	12.18
RCP8.5 GWU1.0	**Area (km2)**	38.37	25.21	42.94	35.83	41.08	46.98	230.40
	Reduction rate(%)	7.64	6.22	18.89	16.84	14.72	8.99	12.80
Groundwater use control								
No.		1	2	3	4	5	6	Sum
RCP4.5 GWU0.5	**Area (km2)**	15.81	10.26	19.92	17.95	29.72	21.21	114.87
	Reduction rate(%)	12.39	6.44	21.51	20.52	2.94	16.69	13.67
RCP8.5 GWU0.5	**Area (km2)**	19.91	13.89	23.97	22.11	35.63	26.35	141.87
	Reduction rate(%)	12.81	6.68	21.22	20.71	2.89	16.57	13.66
RCP4.5 GWU1.0	**Area (km2)**	29.23	20.44	32.81	29.51	43.50	36.13	191.62
	Reduction rate(%)	13.14	7.74	23.53	21.09	3.46	18.11	14.94
RCP8.5 GWU1.0	**Area (km2)**	35.83	24.66	40.24	33.24	46.35	41.81	222.15
	Reduction rate(%)	13.75	8.23	23.98	22.85	3.77	18.99	15.93
Recharge pond + groundwater use control								
No.		1	2	3	4	5	6	Sum
RCP4.5 GWU0.5	**Area (km2)**	13.57	9.02	14.10	12.91	24.13	17.79	91.53
	Reduction rate(%)	24.81	17.76	44.44	42.84	21.19	30.10	31.21
RCP8.5 GWU0.5	**Area (km2)**	17.07	12.23	16.76	15.89	28.66	21.83	112.45
	Reduction rate(%)	25.23	17.84	44.91	43.03	21.87	30.88	31.56
RCP4.5 GWU1.0	**Area (km2)**	24.53	17.75	23.19	20.62	34.85	29.96	150.90
	Reduction rate(%)	27.10	19.89	45.97	44.85	22.65	32.09	33.02
RCP8.5 GWU1.0	**Area (km2)**	30.27	21.51	28.14	23.56	37.05	34.57	175.10
	Reduction rate(%)	27.15	19.96	46.84	45.33	23.09	33.02	33.73

5.2 Prioritization of countermeasures

5.2.1 Establishing criteria and determining weighting values

Implementation of both recharge area construction and groundwater usage reduction in all areas would be the best countermeasure, but to minimize seawater intrusion area using limited resources, decisions should be made to apply certain techniques based on data related to seawater intrusion. To this end, options were prioritized using AEI, CP, and TOPSIS. Before prioritizing, various data related to seawater intrusion were collected and factors were determined and weighted by surveys with the Delphi method. The subjects of the survey were 28 water resource experts and the factor determination survey was performed via one survey with open-ended questions and two surveys to determine weighting values. After performing each survey, opinion exchange between surveyors took place via feedback. Finally, nine factors affecting mitigation options were determined; population, population density, groundwater usage, groundwater dependence ratio, recharge amount, groundwater usage per unit area, current seawater intrusion area ratio, future seawater intrusion area ratio, and average seawater intrusion area reduction ratio according to construction of recharge areas and restriction of groundwater usage. Other factors that were not included were the area, agricultural groundwater use ratio, living groundwater use ratio, RCP 4.5, RCP 8.5, and groundwater use scenarios 1.0 and 0.5, result of each effect analysis according to construction of recharge area, result of each effect analysis according to restriction of groundwater use, and the result of each effect analysis applying construction of recharge area and restriction of groundwater use; these factors were excluded because the representativeness for each factor is low and there is high redundancy between them.

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The most important index according to the calculated weighting value was the result of applying the seawater intrusion area reduction scenario, with a weight of 0.163. Future seawater intrusion area had a weight of 0.148 and current seawater intrusion area had a weight of 0.134. Indices that received relatively lower weighting values included population, population density, and recharge amount; these values were 0.057, 0.066, and 0.079, respectively. Population and population density are directly damaged and influenced by intrusion area, but even if population is small, seawater intrusion damage may occur to the surrounding environment rather than to people directly, causing secondary damage. Expert opinion was that groundwater usage, rather than recharge amount, was more closely related to seawater intrusion. Table 5 presents each index and the results of weighting-value calculation. Table 6 shows the performance values of the nine factors.

Table 5. Descriptions of indicators and their weights

Indicators	Description (Unit)	Weights
P	Population (persons)	0.057
PD	Population density (persons/km^2)	0.066
GWU	Amount of groundwater usage (10^6 m^3)	0.107
GWUA	Amount of groundwater usage per area (10^3 m^3/year/km^2)	0.118
RGWD	Ratio of groundwater dependence (%)	0.128
Rec	Amount of recharge (10^3 m^3)	0.079
PSWI	Ratio of present (2015) seawater intrusion area (%)	0.134
FSWI	Ratio of future (2099) scenarios' seawater intrusion area (%)	0.148
FSWIR	Ratio of future (2099) scenarios' seawater intrusion reduction area (%)	0.163

Table 6. Derived performance values for the nine factors

Indicators	Unit	No.					
		1	2	3	4	5	6
P	persons	4974	2454	26793	6205	6057	4491
PD	persons/km^2	67.0	59.9	305.8	89.4	114.4	74.1
GWU	10^6 m^3	4.50	3.46	10.69	6.74	3.41	5.06
GWUA	10^3 m^3/year/km^2	60.32	84.50	120.10	97.75	64.01	83.73
RGWD	%	0.39	0.56	0.33	0.50	0.34	0.25
Rec	10^3 m^3	11025	6085	13020	10312	7869	9009
PSWI	%	12.29	6.98	20.70	17.64	37.34	24.34
FSWI	%	39.11	45.73	43.27	47.17	75.78	63.00
FSWIR	%	26.07	18.86	45.54	44.01	22.20	31.52

5.2.2 Prioritizing countermeasures

Table 7 presents the weighting value application results for each factor according to the AEI, CP, and TOPSIS methods. All methods suggest that applying countermeasures to the Taean area is the first priority owing to the excellent effect of its seawater intrusion area reduction countermeasures. It acquired an outstandingly high score compared to other areas due to its high usage of groundwater. Following this, No. 5 Geunheung area took 2nd place according to the CP and TOPSIS methods and 3rd place according to AEI. It was determined to be urgent to apply seawater intrusion reduction countermeasures to No. 5 Geunheung because the occupation ratios of current

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and future seawater intrusion areas were outstandingly high. Subsequently, No. 4 Sowon area took 2nd place according to the AEI method and 3rd place according to CP and TOPSIS. The Sowon area has relatively high groundwater usage and intrusion reduction countermeasures there showed the second best effect after Taean.

Table 7. Final ranking of the AEI, CP, and TOPSIS methods

Countermeasures	No.	AEI		CP		TOPSIS	
		WSM	Ranking	L	Ranking	C*	Ranking
CM1	1	0.162	6	0.213	6	0.227	5
CM2	2	0.276	5	0.472	4	0.106	6
CM3	3	0.619	1	0.746	1	0.680	1
CM4	4	0.489	2	0.560	3	0.438	3
CM5	5	0.443	3	0.601	2	0.476	2
CM6	6	0.402	4	0.457	5	0.421	4

6. Conclusions

As the rise in sea level accelerates due to global warming, coastal areas are being damaged by expanding seawater intrusion areas. To prevent this, research into the causal factors influencing expansion of seawater-intrusion areas and countermeasures against it via seawater intrusion boundary simulation are well underway. Toward this end, active countermeasures, such as injection of freshwater and pumping of seawater, are being tried to reduce the seawater intrusion area and optimize its location. Considering local characteristics, these methods can be applied very restrictively. Injection of freshwater into existing aquifers and pumping of seawater require much effort to understand the characteristics of aquifers and investigate seawater intrusion boundaries.

Thus, in this research, suggested methodology to approach in three-step composition for the method to utilize as seawater intrusion prevention countermeasure using construction of recharge area and restriction of groundwater usage currently being used in the area and prioritize for each countermeasures, among Low Impact Development methods which are much used in the downtown area.

First, we identify the most vulnerable areas using hydrological data related to seawater intrusion. Then, we applied sea level increase scenarios RCP 4.5 and RCP 8.5 to predict future seawater intrusion areas and future groundwater use trends determined via linear-regression analysis. As a third step, we predicted the results of applying various seawater intrusion area reduction countermeasures considering local characteristics. We collected data related to seawater intrusion and prioritized alternatives using MCDM. This prioritization was done by conducting a survey of 28 experts and determining weighting values for each factor via feedback. For this research, the west coast of the Republic of Korea was taken as a subject and we determined the area with the highest priority for receiving countermeasures (Table 7).

In view of local characteristics in this research, only recharge area construction and groundwater usage restrictions were considered as countermeasures, but other alternatives should be considered in the future. Moreover, in terms of recharge area construction, applicable locations are limited but more precise alternatives should be prioritized by departmentalizing the research subject area and calculating the optimal location and size. For groundwater usage restriction, it is expected that if we departmentalize the location and time stages in greater detail and prepare precise restriction plans, we could more effectively prioritize countermeasures against seawater intrusion.

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References

1. IPCC. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change;* Thomas, F.S., Dahe, Q., Gian-Kasper, P., Melinda, M.B.T., Simon, K.A., Judith, B., Alexander, N., Yu, X., Vincent, B., Pauline, M.M., Cambridge University Press, Cambridge, United Kingdom, and New York, NY, USA, 2013.
2. Sherif, M.M. and Singh, V.P. Effect of climate change on seawater intrusion in coastal aquifers. *Hydrological Process* 1999, 13, 1277-1287.
3. Werner, A.D. and Simmons, C.T. Impact of sea-level rise on seawater intrusion in coastal aquifers. *Ground Water* 2009, 47, 197-204.
4. Carneiro, J.F., Boughriba, M., Correia, A., Zarhloule, Y., Rimi, A. and El Houadi, B. Evaluation of climate change effects in a coastal aquifer in Morocco using a density-dependent numerical model. *Environmental Earth Science* 2010, 61(2), 241-252.
5. Oude Essink, G.H.P., Van Baaren, E.S. and De Louw, P.G.B. Effects of climate change on coastal groundwater systems: a modeling study in the Netherlands. *Water Resource Research* 2010, 46, W00F04.
6. Michael, H.A., Russoniello, C.J. and Byron, L.A. Global assessment of vulnerability to sea-level rise in topography-limited and recharge-limited coastal groundwater systems. *Water Resource Research* 2013, 49(4), 2228-2240.
7. Green, N.R. and MacQuarrie, K.T.B. An evaluation of the relative importance of the effects of climate change and groundwater extraction on seawater intrusion in coastal aquifers in Atlantic Canada. *Hydrogeology Journal* 2014, 22(3), 609-623.
8. Koussis, A.D., Mazi, K., Riou, F. and Destouni, G. A correction for Dupuit-Forchheimer interface flow models of seawater intrusion in unconfined coastal aquifers. *Journal of Hydrology* 2015, 525, 277-285.
9. Morgan, L.K., Bakker, M. and Werner, A.D. Occurrence of seawater intrusion overshoot. *Water Resource Research* 2015, 51(4), 1989-1999.
10. Bobba, A.G. Numerical modelling of salt-water intrusion due to human activities and sea-level change in the Godavari Delta, India. *Hydrological Science Journal* 2002, 47, S67-S80.
11. Loáiciga, H.A., Pingel, T.J. and Garcia, E.S. Seawater intrusion by sea-level rise: scenarios for the 21st century. *Groundwater* 2012, 50, 37-47.
12. Carretero, S., Rapaglia, J., Bokuniewicz, H. and Kruse, E. Impact of sea-level rise on saltwater intrusion length into the coastal aquifer, Partido de La Costa, Argentina. *Cont. Shelf Res* 2013, 61-62, 62-70.
13. Langevin, C.D. and Zygnerski, M. Effect of sea-level rise on salt water intrusion near a coastal well field in Southeastern Florida. *Groundwater* 2013, 51, 781-803.
14. Rasmussen, P., Sonnenborg, T.O., Goncear, G. and Hinsby, K. Assessing impacts of climate change, sea level rise, and drainage canals on saltwater intrusion to coastal aquifer. *Hydrology and Earth System Science* 2013, 17, 421-443.
15. Sefelnasr, A. and Sherif, M. Impacts of seawater rise on seawater intrusion in the Nile Delta aquifer. Egypt. *Groundwater* 2014, 52, 264-276.
16. Abarca, E., Vázquez-Suñé, E., Carrera, J., Capino, B., Gámez, D. and Batlle, F. Optimal design of measures to correct seawater intrusion. *Water Resource Research* 2006, 42. http://dx.doi.org/10.1029/2005WR004524.
17. Sriapai, T., Walsri, C., Phueakphum, D. and Fuenkajorn, K. Physical model simulations of seawater intrusion in unconfined aquifer. *Songklanakarin Journal of Science and Technology* 2012, 34, 679-687.
18. Pool, M. and Carrera, J. Dynamics of negative hydraulic barriers to prevent seawater intrusion. *Hydrogeology Journal* 2010, 18, 95-105.
19. Botero-Acosta, A. and Donado, L.D. Laboratory scale simulation of hydraulic barriers to seawater intrusion in confined coastal aquifers considering the effects of stratification. *Process and Environment Science* 2015, 25, 36-43.
20. Luyun, R., Momii, K. and Nakagawa, K. Effects of recharge wells and flow barriers on seawater intrusion. *Ground Water* 2011, 49, 239-249.

21. Chung, E.S. and Lee, K.S. Prioritization of water management for sustainability using hydrologic simulation model and multi-criteria decision making techniques. *Journal of Environmental Management* 2009, 90(3), 1502-1511.
22. Chung, E.S., Hong, W.P., Lee, K.S. and Burian, S.J. Integrated use of a continuous simulation model and multi-attribute decision making for ranking urban watershed management alternatives. *Water Resources Management* 2011, 25(2), 641-659.
23. Yang, J.S., Kim, S.U., Chung, E.S. and Kim, T.W. Prioritization of water management under climate change and urbanization using multi-criteria decision making methods. *Hydrology and Earth System Science* 2012, 16(3), 801-814.
24. Kim, Y., Chung, E.S., Jeon, S. and Kim, S.U. Prioritizing the best sites for treated wastewater use in an urban watershed using Fuzzy TOPSIS. *Resources, Conservation and Recycling* 2013, 73, 23-32.
25. Kang, B.S., Lee, J.H., Chung, E.S., Kim, D.S. and Kim, Y.D. A sensitivity analysis approach of multi-attribute decision making technique to rank flood mitigation projects. *KSCE Journal of Civil Engineering* 2013, 17(6), 1529-1539.
26. Kim, Y. and Chung, E.S. Robust prioritization of climate change adaptation using the VIKOR method with objective weights. *Journal of the American Water Resources Association* (JAWRA) 2015, 1-16. 10.1111/jawr.12291
27. Harbaugh, A.W. *MODFLOW-2005, the U.S. Geological Survey Modular Ground-Water Model-the Ground-Water Flow process.* U.S. Geological Survey Techniques and Method 6-A16, 2005.
28. Zheng, C. and Wang, K. *A modular three dimensional multispecies transport model for simulation of advection, dispersion and chemical reactions of contaminants in groundwater systems.* Contract Rep. SERD99-1, U.S. Army Corps of Engineers, Vicksburg, MS, 1999.
29. Zheng, C. *MT3DMS v5.2 supplemental user's guide*. Technical Rep., U.S. Army Engineer Research and Development Center, Dept. of Geological Sciences, Univ. of Alabama, Tuscaloosa, AL 2006.
30. Shoemaker, W.B. Important observations and parameters for a saltwater intrusion model. *Ground Water* 2004, 42(5), 829-840.
31. Dausman, A.M. and Langevin, C.D. *Movement of the saltwater interface in the surficial aquifer system in response to hydrologic stresses and water-management practices, Broward County, Florida.* U.S. Geological Survey Scientific Investigations Report 2004-5256. Reston, Virginia: USGS, 2005.
32. Hughes, J.D., Langevin, C.D. and Brakefield-Goswami, L. Effect of hypersaline cooling canals on aquifer salinization. *Hydrogeology Journal* 2010, 18(1), 147-160. 10.1007/s10040-009-0511-6
33. ASTM. Standard practices for evaluating environmental fate models of chemicals. Annual Book of ASTM standards. *Am. Soc. For Testing and Materials*, Philadelphia. PA.E978-84, 1984.
34. Doherty, J., Brebber, L. and Whyte, P. *PEST-Model-independent parameter estimation.* User's manual Watermark Computing. Australia, 1994.
35. Oreskes, N., Shrader, F.K. and Belitz, K. Verification, validation, and confirmation of numerical models. *Earth Sciences* 1994, 263(5147), 641-646.
36. WinPest. *User's Manual: Non-linear Parameter Estimation and Predictive Analysis Program.* [S.l.]: Watermark Numerical Computing & Waterloo Hydrogeologic, Print, 1999.
37. Roy B., Slowinski, R. and Treichel, W. Multi-criteria programming of water supply systems for rural areas. *Water Resour. Bull* 1992, 28, 129-140.
38. Larichev, O.I. and Moshkovich, H.M. ZAPROS-LM: A method and system for ordering multiattribute alternatives. *Eur J Oper Res* 1995, 82, 503-521.
39. Bardossy, A. and Bogardi, I. Network design for the spatial estimation of environmental variables. *Applied Mathematics and Computation* 1983, 12, 339-369.
40. Hwang, C.L. and Yoon, K. *Multiple Attributes Decision Making Methods and Applications*; Springer; Heidelberg, Germany, 1981.
41. Sheldon, M.B. and Kailash, C.K. An algorithm for solving multicriterion linear programming problems with examples. *Operational Reserch Quarterly* 1973, 24(1), 65-77.
42. Milan, Z. A concept of compromise solutions and the method of the displaced ideal. *Computers and Operations Research* 1974, 1, 479-496.
43. Ye, F. and Li, Y. An extended TOPSIS model based on the possibility theory under fuzzy environment. *Knowl. Based Syst* 2014, 67, 263-269.

44. Ministry of Oceans and Fisheries. *Coast condition survey report-West coast*, Ministry of Oceans and Fisheries 2003.
45. Freeze, R.A. and Cherry, J.A. *Groundwater*. Prentice, HallEnglewood Cliffs 1974.