Examining chemical interaction of stream and aquifer near a river barrage area by factor analysis

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Abstract: - A statistical approach has been applied in order to evaluate chemical interaction between groundwater and river water by using electrical conductivity (EC) in the Changnyeong-Haman river barrage (CHRB), Korea. The EC values in groundwater have been decreased an average of 50 μS/cm and 160 μS/cm. According to factor analysis using the EC data, the EC in groundwater has been disturbed by the CHRB construction as well as dredging of the Nakdong River during the construction work and with time ealpse the groundwater quality became stabilized. It is also demonstrated that hydrologic environment has been changed due to the CHRB construction, comparing the 1st period and 4th period. Hence, a long-term monitoring is required in order to reveal the change of hydrologic environment that can adversely affect plant growth.

Key-Words: River barrage, Stream-aquifer interaction, Electrical conductivity, Factor analysis

1. Introduction

The chemical property of groundwater depends on many factors such as the mineralogy of aquifers, the chemical compositions of the precipitation and surface water, climate, topography, and anthropogenic activities (Edmunds et al., 1982). Surface water-groundwater interaction can be revealed by using physical and chemical components between stream and aquifer. Comprehensive understanding of groundwater-surface water interactions will also identify migration of pollutants and potential impact to ecological systems within the aquatic environment (Jorge et al., 2015).

Surface water–groundwater interaction has been studied using hydrochemical and isotopic end-member mixing analysis to describe the influence of water origins (e.g., Christophersen et al., 1990; Hooper et al., 1990; Ladouche et al., 2001). The surface water–groundwater interactions in the Jialu River basin using major ion chemistry and stable isotopes were studied by investigating temporal and spatial variations in water chemistry affected by humans and by characterizing the relationship between surface water and groundwater in the shallow Quaternary aquifer (Yang et al., 2012). Pierre et al. (2012) revealed a clear evolution of river water chemical composition that could be related to the increasing amount of limestone aquifers inside the Eau Blanche River basin. Hinkle et al. (2001) collected isotopic and chemical data from shallow hyporheic zone wells and demonstrated interaction between regional ground water and river water. Dixon-Jain (2008) studied groundwater-surface water interaction and implication for nutrient transport to tropical rivers. USGS (2003) reported surface water and groundwater interaction of the Spokane River and the Spokane Valley-Rathdrum Prairie aquifer, by means of physical properties and major ions, trace elements, and stable isotopes.

This study aimed to evaluate chemical interaction between groundwater and river water by using factor analysis with electrical conductivity (EC) data in the Changnyeong-Haman river barrage (CHRB) area which is located in downstream of the Nakdong River, Korea and mostly used for agriculture. The study area (Figure 1) having an elevation of 6–10 m above mean sea level is mostly utilized by agricultural field among which rice field occupies more than 84%. Groundwater is importantly used for irrigation and its usage is dependent to the agricultural cycles of rice farming from May to August and greenhouse cultivation from December to April. The CHRB was constructed during the period from June 2011 to September 2012. By the context of the Four Major River Restoration Project (4MRRP) from 2008 until 2012, 16 river barrages have been constructed on the four major rivers (the Han, Nakdong, Geum, and Yeongsan) in South Korea.

2. Change of EC in the groundwater and river

The electrical conductivity (EC) values in groundwater have been collected at the total of 33 monitoring well (HAM-004 – 065) from Jul. 1, 2011 to Jun. 30, 2015 as well as the EC values of the Nakdong River at the Chilseo purification plant from Jul. 1, 2012 to Jun. 30, 2015 (Table 1). For the 1st period (Jul. 1, 2011 – Jun. 30, 2012), the average EC value in groundwater was 678 µS/cm with a range of 161 (at HAM- 062) to 1836 µS/cm (at HAM-047). For the 2nd period (Jul. 1, 2012 – Jun. 30, 2013), the average EC value in groundwater was 621 µS/cm with a range of 160 (at HAM- 062) to 15496 µS/cm (at HAM-047). For the 3rd period (Jul. 1, 2013 – Jun. 30, 2014), the average EC value in groundwater was 614 µS/cm with a range of 149 (at HAM- 062) to 1483 µS/cm (at HAM-047). Finally, for the 4th period (Jul. 1, 2014 – Jun. 30, 2015), the average EC value in groundwater was 615 µS/cm with a range of 149 (at HAM- 062) to 1443 µS/cm (at HAM-047).

On the other side, 2013, the average EC values in the river displayed 269 µS/cm, 263 µS/cm, and 234 µS/cm from the 2nd to 4th period, respectively. The average EC values both in the groundwater and the river decreased from Jul. 1, 2011 to Jun. 30, 2015, indicating the change of hydrologic environment due to the construction of the CHRB.

Table 1. Average electrical conductivity values from Jul. 2011 until Jun. 2015.

Wells	Average EC of GW (µS/cm)				Wells	Average EC of GW (µS/cm)			
	2011-2012	2012-2013	2013-2014	2014-2015		2011-2012	2012-2013	2013-2014	2014-2015
HAM-004EC	489	532	551	559	HAM-042EC	457	372	373	387
HAM-005EC	359	355	362	344	HAM-043EC	1547	1406	1401	1398
HAM-007EC	492	645	658	661	HAM-045EC	778	660	634	635
HAM-008EC	387	351	353	365	HAM-046EC	1027	201	185	180
HAM-010EC	1158	1260	1261	1256	HAM-047EC	1836	1549	1483	1443
HAM-011EC	1001	998	996	990	HAM-048EC	435	379	366	357
HAM-013EC	215	215	218	221	HAM-051EC	730	724	729	738
HAM-014EC	808	780	778	775	HAM-056EC	718	623	615	615
HAM-015EC	582	564	563	565	HAM-057EC	273	249	260	283
HAM-019EC	690	702	703	707	HAM-059EC	880	897	899	903
HAM-021EC	1455	1364	1335	1337	HAM-060EC	494	472	469	462
HAM-022EC	819	452	342	377	HAM-061EC	293	347	356	365
HAM-023EC	703	715	731	742	HAM-062EC	161	160	149	149

HAM-035EC	606	535	550	559	HAM-063EC	402	403	401	401
HAM-038EC	422	540	560	588	HAM-064EC	344	286	271	288
HAM-040EC	948	795	757	767	HAM-065EC	477	418	413	420
HAM-041EC	376	536	549	467					

	July 2011 – June 2012	July 2012 – June 2013	July 2013 – June 2014	July 2014 – June 2015
Maximum EC of average values	1836 (HAM-047EC)	1549 (HAM-047EC)	1483 (HAM-047EC)	1443 (HAM-047EC)
Maximum EC of average values	161 (HAM-062EC)	160 (HAM-062EC)	149 (HAM-062EC)	149 (HAM-062EC)
Mean EC of average values	678	621	614	615
Skewness EC of average values	1.289	1.177	1.100	1.073
Kurtosis EC of average values	1.574	0.889	0.655	0.558

3. Factor analysis for electrical conductivity

Factor analysis is a kind of multivariate techniques that simplify large data sets into smaller number of groups and make useful generalizations that provide meaningful insight (Lawrence and Upchurch, 1982; Suk and Lee, 1999; Shim et al., 2000; Hamm et al., 2000; Jeong, 2001; Lee and Woo, 2003). Thus, the factor analysis can identify groups of highly correlated original variables (Papatheodorou et al., 2007). In this study, R-mode factor analysis which estimates the relationships between variables by extracting eigenvalues and eigenvectors from a covariance or correlation matrix, was carried out in order to identify the EC characteristics of the groundwaters. The factors were extracted using principal component analysis using the procedure of orthogonal varimax rotation and were determined for eigenvalues higher than or equal to 1 (Davis, 2002), using SPSS ver. 23 (IBM Corporation, 2015). The R-mode factor analysis of the EC values of the 33 monitoring wells was carried out for the four periods of one year unit (Jul. 2011 – Jun. 2012, Jul. 2012 – Jun. 2013, Jul. 2013 – Jun. 2014, and Jul. 2014 – Jun. 2015). Total three factors were identified by the R-mode factor analysis.

For the first period (Jul. 2011 – Jun. 2012), Factor 1 showed higher positive loadings to HAM-005, 008, 013, 015, 040, 047, 051, and 056 (>0.70) with a negative loading to HAM-007, 010, 019, 046, 048, and 064 which accounted for 42.68% of the total variance with an eigenvalue of 14.04. This factor is related to the influence of the Nakdong River and tributaries (Fig. 1a). Factor 2 showed higher positive loadings to HAM-011, 022, and 065 (>0.70) with a negative loading to HAM-014 and 060 which accounted for 22.05% of the total variance with an eigenvalue of 7.28. This factor may be related to the influence of the agricultural activity (Fig. 1a). Factor 3 showed high positive loadings to HAM-035 (>0.70) which accounted for 9.04% of the total variance with an eigenvalue of 2.98. This factor may reflect the influence of the natural groundwater (Fig. 1a).

For the second period (Jul. 2012 – Jun. 2013), Factor 1 showed higher positive loadings to HAM-021, 022, 040, 045, 048, and 064 (>0.70) with a negative loading to HAM-004 which explained

31.62% of the total variance with an eigenvalue of 10.43. This factor may reflect the influence of the Nakdong River and tributaries (Fig. 1b). Factor 2 showed higher positive loadings to HAM-008, 013, 019, 038, and 059 (>0.70) with a negative loading to HAM-047 and 060 which accounted for 22.32% of the total variance with an eigenvalue of 7.37. This factor may reflect the influence of the agricultural activity (Fig. 1b). Factor 3 showed high positive loadings to HAM-051 (>0.70) which explained 10.82% of the total variance with an eigenvalue of 3.57. This factor may reflect the influence of the natural groundwater (Fig. 1b). The EC values and factors for the second period indicate the disturbance of groundwater quality by the construction of the CHRB.

For the third period (Jul. 2013 – Jun. 2014), Factor 1 presented higher positive loadings to HAM-004, 008, 013, 019, 038, 040, 042, 059, and 064 (>0.70) with a negative loading to HAM-005, 011, 041, 046, 047, and 060 which explained 44.29% of the total variance with an eigenvalue of 14.62 (Fig. 1c), reflecting the higher influence of the Nakdong River and tributaries than the second period. Factor 2 presented high positive loadings to HAM-014 (>0.70) with a negative loading to HAM-021 which accounted for 16.49% of the total variance with an eigenvalue of 5.44. This factor may reflect the influence of the agricultural activity (Fig. 1c). Factor 3 showed high positive loadings to HAM-007, 010, and 048 (>0.70) which explained 9.47% of the total variance with an eigenvalue of 3.13. This factor may reflect the influence of the natural groundwater (Fig. 1c). This pattern of factors designates stabilization of groundwater quality with time elapse since the completion of the CHRB construction.

Finally, for the fourth period (Jul. 2014 – Jun. 2015), Factor 1 presented higher positive loadings to HAM-013, 015, 019, 021, 035, 038, 040, 05 1, 062, and 064 (>0.70) with a negative loading to HAM-010, 011, 014, 045, and 048 which explained 43.87% of the total variance with an eigenvalue of 14.48 (Fig. 1d), reflecting the influence of the Nakdong River and tributaries. Factor 2 presented high positive loadings to HAM-007 (>0.70) which explained 15.72% of the total variance with an eigenvalue of 5.19. This factor may reflect the influence of the agricultural activity (Fig. 1d). Factor 3 showed high positive loadings to HAM-061 (>0.70) which explained 15.72% of the total variance with an eigenvalue of 3.57. This factor may reflect the influence of the natural groundwater (Fig. 1d).

According to the pattern of factors for the total periods, the EC values have been stabilized with time elapse since the completion of the CHRB construction, with indicating the effect of the water quality disturbance by the CHRB construction and dredging of the Nakdong River during the construction work.

4. Conclusions

This study interpreted the chemical interaction between the stream and aquifer by using factor analysis of electical conductivity (EC) in groundwater for the four periods with year nuit from July 2011 to June 2015, associated with the effect of the construction of Changnyeong-Haman river barrage (CHRB). Based on the factor analysis and the EC variation with time elapse, it is concluded that the EC values has been disturbed by the CHRB construction and dredging of the Nakdong River during the construction work and then the groundwater quality became stabilized. In addition, it is demonstrated that hydrologic environment has been changed due to the CHRB construction, comparing the 1st period and 4th period. Hence, a long-term monitoring of chemical constituents in groudnwater is required in order to reveal the change of hydrologic environment that can adversely affect plant growth.

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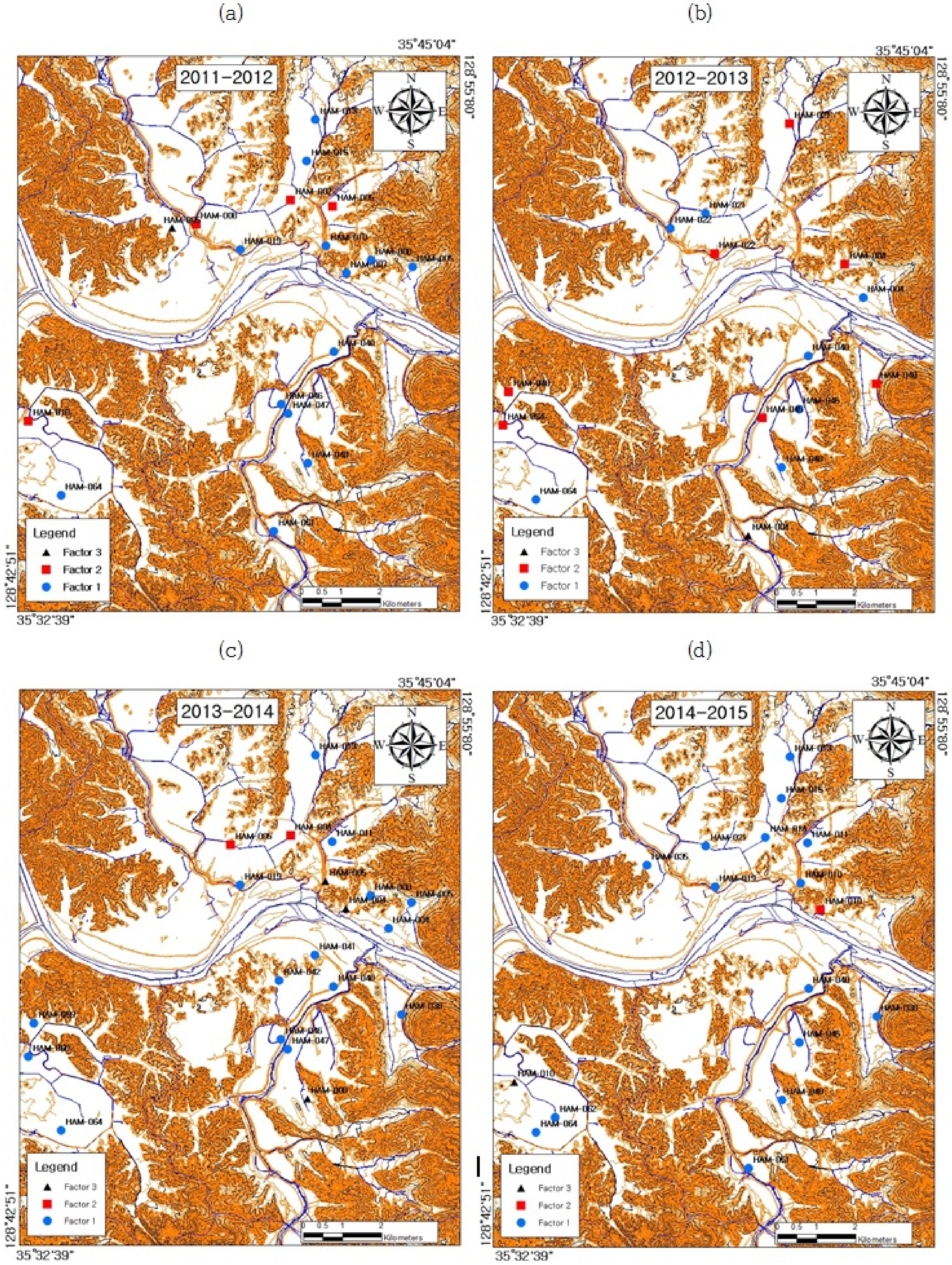

Fig. 1. Results of the factor analysis for the periods of (a) Jul. 2011 – Jun. 2012, (b) Jul. 2012 – Jun. 2013, (c) Jul. 2013 – Jun. 2014, and (d) Jul. 2014 – Jun. 2015.

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