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Modeling of Ground Water Salinity on the Caspian Southern Coasts

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Abstract Water salinity is one of the main restrictive factors in water exploiting. Also, unsuitable management and exploitation of water resources has led to an increase of surface and groundwater salinity. Thus, in view of human needs to water resources, it is necessary to study and define water salinity factors in order to weaken these factors. This research has been conducted to investigate the factors of groundwater salinity and also, to provide a model for estimating groundwater salinity on the Caspian southern coasts. Data included in the model are: water qualitative examinations in the area, annual precipitation and evaporation, water table depth, surface water salinity, aquifer formation (Transmissivity) and distance from Caspian Sea. Surface and groundwater salinity was estimated by sampling in different sites on the Caspian southern coasts. Then, Multivariate Regression method was used by using SPSS software. In this stage, groundwater EC has been used as a variable for water salinity or dependent variable and groundwater salinity factors have been used as independent variables. A linear model and a non-linear model were presented. The models efficiency was evaluated by applying them in the sites that their data were not used for presenting the models. Finally, groundwater EC average map was provided by using the presented non-linear model and Geographic Information System in the Eastern part of Mazandaran province. In view of salinity hazard increases in the coastal terrains and agricultural areas, the places with high hazard salinity must be defined and managed to decrease water resources salinity.

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1 Introduction

Groundwater is one of the most important water resources and its qualitative study is very important for water resources protection and planning. Unfortunately, water resources quality is in danger, because of unsuitable exploitations and increase of human activities in recent decades. The growth process of urban societies throughout the world has increased and is predicated that it will increase up to 60% in the year 2030 (McGee 2001). Cosmopolitan area growth and population increase have been accompanied by landuse changes and agricultural areas development, thus, its undesired effects are as follow: groundwater discharge reduction, surface flow increase and water quality decrease (Hirsch et al. 1990; Burns et al. 2005). The increase of water salinity leads to botanical and animal species changes and decrease of agricultural productions in the Mazandaran Province coasts. Water salinity changes occur in two dimensions: local and temporal. Salinity, local changes is more important and occurred more than temporal changes in the study area, due to the increase of water salinity and decreases of productive agricultural terrains and food production. Water provision is very important, especially for agriculture and drinking in the study area. Extensive rice fields and gardens are located in the Caspian Southern coasts. Agriculture needs proper water in terms of quantity and quality. So, it is necessary to define the reasons of water quality decreasing in order to minimize its hazards and damages. The water table depth is less than 10 m on the Caspian southern coasts and these water resources are exposed to salinity. In northern Iran, there are widespread water resources (surface and groundwater) but most of them have been contaminated by salinity and traditional contaminants. On Caspian southern coasts the development of surface and ground water salinity is due to low water table depth (<10 m) and evaporation on static water resources. Side by side the growth of Tamarix on the banks of water resources is aggravating the situation. On Gorgan Gulf coasts (east of Mazandaran Province), there is an extensive rangeland of Tamarix species and it is reported that ground water salinity is more than 6,000 μmhos/cm. In the past, different models have been developed to study the influence of climate changes on ground water (Brunner and Kinzelbach 2005). Studies have shown that the impact of climate change on ground water is site-specific (Brouyere et al. 2004). Prohaska and Stevanovic (1993) and Zhang et al. (1996) presented two models to simulate ground water discharge, using different methods such as regression analysis. Different models are there to estimate the salinity status of world groundwater and surface water (Zhang 2001). Hall et al. (2001) presented a model to manage the danger of salinity in Thailand. Coppola et al. (2005) found that Artificial Neural Network (ANN) technology can serve as a powerful and accurate prediction and management tool, minimizing degradation of ground water quality to the extent possible by identifying appropriate pumping policies under variable and/or changing climate conditions. Abdelrhem et al. (2008) applied MODFLOW and MODOFIC packages to make simulation and optimization respectively the area in the West of Libya, where they studied water table changes. Their results have shown clear changing of water table 8 m, 11.93 m, and 14.43 m respectively. Nichols and Verry (2001), developed regression equations related to yearly groundwater recharge, stream flow to seasonal precipitation amounts in North Central Minnesota. The objectives of present research were to define the effective factors on groundwater salinity and modeling of groundwater salinity and also, to simulate groundwater average EC (Electrical Conductivity) for providing groundwater salinity map, using Geographic Information System (GIS) on the Gorgan Gulf Southern coasts.

2 Research Methodology

Mazandaran province is located in southern Caspian coasts and central regions of Alborz highlands in northern Iran. The study area is located in between 50° 30′ and 53° 50′ E longitude and 35° 55′ and 36° 45 N latitude (Fig. 1). This province is the second Province in terms of rice production and is one of the main agricultural regions in Iran. Study area is located in the North of Mazandaran Province that includes productive agricultural terrains. Southern Caspian coasts include the plains made of Quarternary sediments, but different geologic formation and elevation and along with slope changes is observed in the central regions of Alborz. In this research, 36 sites were selected to sample and to study environmental conditions and finally to present model. Twenty eight sites or samples were applied to present the models and eight sites were applied to validate the models efficiency (Figs. 1 and 2). All of the study wells (groundwater sampling) are shallow and were drilled to

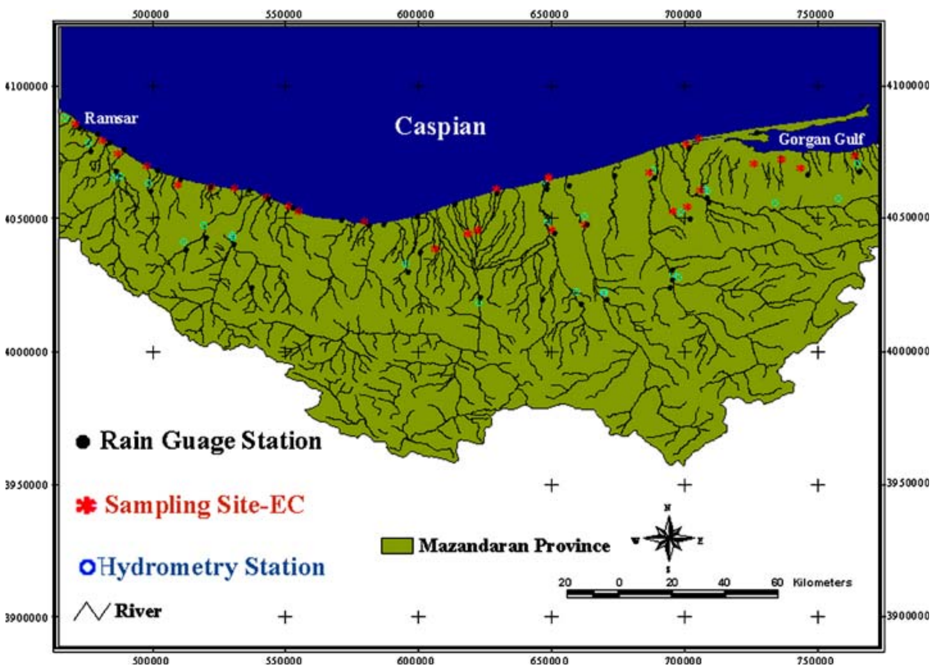

Fig. 1 Study area and location of sampling stations in the Caspian southern coasts

Fig. 2 The location of study area on the Caspian Southern coasts in Northern Iran

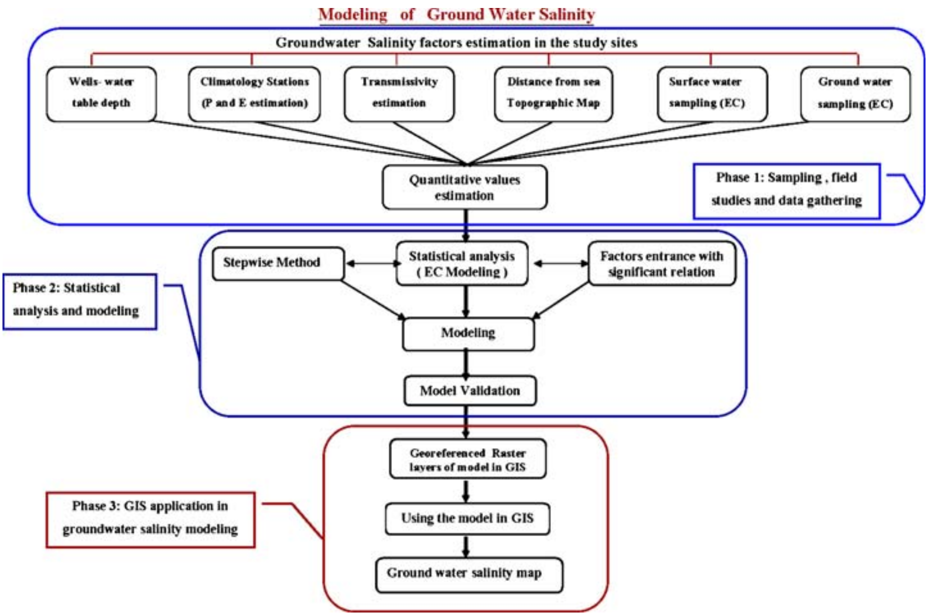

Fig. 3 Chart of study stages and methodology

study groundwater quantity and quality in unconfined aquifer (alluvial formation-TAMAB or Water Resources Research Organization of Iran, 2007b). Farmers use groundwater by digging shallow wells just in drought periods. Therefore, well pumping and the interference of fresh and salty water is not a serious problem. Study area included alluvial plains that are located in the outlet of watersheds and mostly water table depth is less than 10 m in the study area. In the South study area, Central Alborz Highlands and Karst, aquifers are located (Fig. 1). Chart of study stages and methodology is shown in Fig. 3. Multivariate Regression method was applied to present a linear model, using SPSS software. Average EC of ground water was selected as dependent variable. Annual rainfall, water table depth, Transmissivity of aquifer formation (T), Distance from Caspian Sea, annual average evaporation and average EC of surface water were studied as independent variables. Quantitative data of Transmissivity (T), water table, precipitation, evaporation and surface water average EC were provided by TAMAB (2007a) and Climatology Organization of Iran (Table 1). Thirty-six sites were selected to sample and study surface and groundwater EC and environmental conditions. Twenty-eight sites or samples were

Table 1 Factors of ground water salinity in 28 sampling stations

EC gw (μmhos/cm)	Annual rainfall (mm)	Annual evaporation (mm)	Water table depth (m)	Distance from Caspian (m)	Transmissivity of aquifer formation (T) (m^2/day)	EC sw (μmhos/cm)
198	1,188	1,000	3	1,550	500	429.2
580	1,130	1,000	3	1,870	1,500	419.8
403	1,209	1,000	3	3,450	500	265.6
500	1,329	900	3	1,640	1,500	370.8
550	1,483	800	10	4,137	1,125	326.3
710	1,411	800	5	2,325	1,125	386
490	1,137	800	2.1	1,217	1,500	470.8
820	1,090	800	1.3	1,604	1,500	624.1
380	1,413	800	11	1,312	1,500	656
1,500	1,413	800	2.05	1,326	750	656
540	1,025	900	5	909	1,500	588.2
680	799	900	11	15,760	750	544.3
1,100	900	950	2	14,320	2,000	606.4
940	900	950	3.28	13,850	2,000	606.4
630	1,153	1,000	2.7	962	175	745.8
946	638	1,000	1.38	20,473	500	788.7
1,400	904	1,000	3.48	687	100	792.2
1,400	709	1,000	4.97	20,956	750	792.2
1,150	800	1,000	9.39	27,822	1,500	521.6
1,150	743	1,000	7.13	25,987	750	521.6
930	743	1,000	8.35	26,029	1,500	521.6
930	705	1,000	14.71	21,425	1,500	486.6
1,700	680	1,000	2	3,069	100	610
4,200	680	1,000	1.73	1,884	100	610
6,400	629	1,000	1.5	6,668	175	900
780	629	1,000	1.92	5,035	175	365.6
630	629	1,000	13.39	7,571	750	365.6
887	510	1,100	3	3,704	750	521.6

applied to present the models and eight sites were applied to validate the models efficiency. Regression analysis was done to manifest a linear model to estimate average EC of ground water. Stepwise multivariate regression analysis was done by using SPSS software. In the next step, efficiency of the presented linear model for simulation of EC of ground water was investigated. In this stage, the presented model was applied for simulating the sites of salinity (EC) that was not used for presenting the model. The linear model needs surface water EC as an input, but these data are not available for entire of Mazandaran province. Therefore, in the present investigation the linear model can not be used to provide ground water salinity map by using Geographic Information System. In addition, a new linear model would not be considered as significant ($R^2 < 0.5$) if surface water salinity parameter is eliminated from list of independent parameters. Thus, a non-linear model has been presented by using Multivariate Regression method and the factors are Transmissivity of aquifer formation (T) and distance from Caspian Sea. Efficiency of the presented non-linear model for estimation EC of ground water was investigated and confirmed. Finally, the developed non-linear model and GIS were used to provide ground water salinity map by using two raster layers: average Transmissivity of aquifer formation (T) and distance from Caspian Sea.

3 Results

Most of data were collected from TAMAB (2007a, b), Surveying and Climatology Organizations. Multivariate regression method was used to present two models for simulation of ground water salinity (EC). Correlation between the water salinity factors and ground water average EC were observed in Tables 2 and 3. As Table 4 showed, the presented linear model was significant ($R^2 = 0.56$). Regression analysis manifested a linear model for simulation of ground water average EC (Eq. 1):

$$\log \mathrm{EC_{Gw}} = 1.018 \log \mathrm{EC_{Sw}} - 0.339 \log \mathrm{T} + 0.21 \log \mathrm{L_s} + 0.403 \qquad (1)$$

That $\mathrm{EC_{Gw}}$ is ground water average EC (μmhos/cm), $\mathrm{EC_{Sw}}$ is surface water average EC (μmhos/cm), T is Transmissivity (m^2/day) and $\mathrm{L_s}$ is distance from Caspian Sea (m). As mentioned earlier, the linear model can not be used to provide ground water salinity map because the data of surface water EC ($\mathrm{EC_{Sw}}$) is not available in some study area. Thus, regression analysis manifested a non-linear model to simulate ground water salinity (Eq. 2):

$$\log \mathrm{EC}\, gw = 45.212\, (LogT)^{-6} - 3.61 \frac{1}{LogLs} + 3.789 \qquad (2)$$

That $\overline{EC}_{\mathrm{gw}}$ is ground water average EC (μmhos/cm) and Ls is distance from Caspian Sea (m). The presented model was applied for investigation of efficiency in simulated ground water salinity. As Table 5 showed, the presented linear model was significant ($R^2 = 0.501$). Thus, in order to manifestation of the model (sites uniform distribution in study area) it was used to estimate ground water salinity in the

Table 2 The results of multivariate regression analysis (linear model, $R^2 = 0.56$)

Model	Sum of squares	*df*	Mean square	*F*	Sig.
Regression	1.525	3	0.5048	10.45	0.00
Residual	1.168	24	0.0486		
Total	2.693	27			

Table 3 Pearson correlation between ground water EC and their effective factors

	EC	(P) rainfall	Evaporation	Water table depth	Distance from sea	Transmissivity	Surface EC
EC	1	0.024	0.247	−0.289	0.261	−0.526	0.573
(P) rainfall	0.024	1	−0.350	0.077	−0.165	0.189	0.351
Evaporation	0.247	−0.350	1	−0.124	0.345	−0.497	0.189
Water table depth	−0.289	0.077	−0.124	1	0.321	0.341	−0.294
Distance from sea	0.261	−0.165	0.345	0.321	1	0.182	0.056
Transmissivity	−0.526	0.189	−0.497	0.341	0.182	1	−0.296
Surface EC	0.573	0.351	0.189	−0.294	0.056	−0.296	1

Table 4 Correlation between ground water EC and their effective factors

	Precipitation	Water table	Transmissivity of aquifer formation (T)	Distance from Caspian	Evaporation	Surface water EC
Ground water EC	0.024	–0.289	–0.526	0.261	0.247	0.573

Table 5 The results of regression analysis (non-linear model, $R^2 = 0.501$)

Model	Sum of squares	*df*	Mean square	*F*	Sig.
Regression	2	2	0.67	12.527	0.00
Residual	1.345	25	0.0538		
Total	2.693	27			

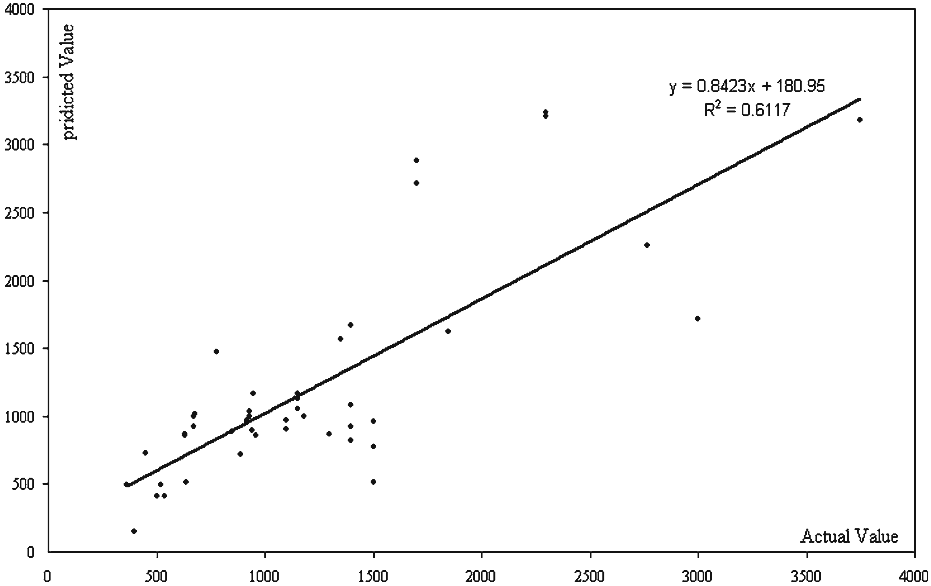

Fig. 4 Comparison between estimated ground water $\overline{EC}$ by using non-linear model with reported actual EC (the sampling stations were not used for manifestation the non-linear model)

unused sites. Also, the evaluated results of the efficiency of the linear and non-linear models have been given in Fig. 4 and Table 6 respectively. Comparison between the models estimated values and recorded values by TAMAB (2007b) confirmed that non-linear model efficiency is proper for simulating ground water salinity on the Caspian southern coasts.

Finally, the presented non-linear model and GIS were used to provide ground water salinity map by using two raster layers: average Transmissivity of aquifer formation (T) and distance from Caspian Sea on the Gorgan Gulf southern coasts (In this area ground water salinity is very high, range = 100–6,000 μmhos/cm. Ground water salinity map is displayed in Fig. 5.

Table 6 Comparison between estimated ground water $\overline{EC}$ using linear model with reported actual $\overline{EC}$ (the samlping stations were not used for manifestation the linear model)

X sample	Y sample	$\overline{EC}_{Sw}$	T	Ls	$\overline{EC}_{Gw\ Estimated}$	$\overline{EC}_{Gw\ Observed}$
642,800	4,062,450	792.2	100	658	1,852.6	1,850
656,555	4,061,099	656.02	100	4,830	2,323	2,300
692,950	4,058,760	370.8	100	17,792	1,709.6	1,800
688,100	4,074,500	770.18	100	1,457	2,127	2,768
521,000	4,059,800	386	500	2,815	700	450
626,250	4,048,550	745.8	2,000	10,584	2,468	960
628,350	4,051,300	745.8	1,500	8,242	1,183	1,400
657,500	4,056,800	656	1,000	9,166	1,217	1,300

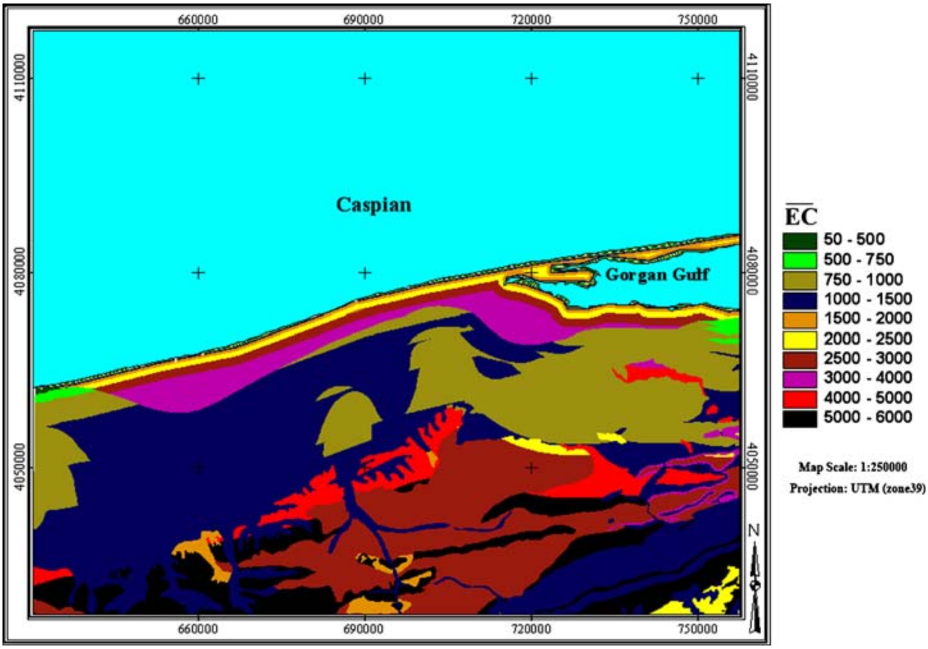

Fig. 5 The map of average ground water salinity (μmhos/cm) in eastern coasts of Mazandaran. This map has been provided by using non-linear model and Geographic Information System

4 Discussion and Conclusions

This research was done by using extensive data about aquifer characteristics, climatology, and topography and so on. The results of the study showed that surface water quality is the most important factor on ground water salinity (Table 3). followed by aquifer formation(T).Also, the rate of rainfall has an inverse relationship with ground water salinity. In study area, an increase in ground water salinity was observed from the West to the East of Mazandaran Province (Rainfall decreases from 1,200 mm to 600 mm in the west to east of this area). In the western Mazandaran Province (Gorgan Gulf coasts), it has been reported $\overline{EC}$ gw = 5,400 μmhos/cm by TAMAB showing groundwater endangers salinity increases. Stepwise method was used to present the models. In this method, the parameters or factors do not have a significant relationship with dependent variable (groundwater salinity) and will not enter the model and they will be eliminated. Thus, some independent variables in regression analysis (stepwise method) have not been entered in the presented models. On the Mazandaran coasts, there are some wells on sandy coasts (water table depth is <2 m) and their water comprises a proper quality. Also, it is observed $\overline{EC}$ > 2,000 μmhos/cm in the regions with clay soil and far from Caspian Sea (water table depth >5 m). These evidences show the presented models efficiency and accuracy. The linear model has capability to simulate groundwater salinity. However, is in need of surface water salinity. Moreover, sampling and estimating surface water salinity for the total study area is costly and time consuming. Also, a new linear model would not be significant ($R^2 < 0.5$) if surface water salinity parameter is eliminated from list of independent parameters. Therefore, a non-linear model has been presented that simulates ground water salinity by only using two parameters: Transmissivity of aquifer formation and distance from sea. Both of these factors were studied in the total surface of Mazandaran Province. But, it should be noted that non-linear model error in simulating groundwater salinity in maximum and minimum values, is more than the linear model. The non-linear model application for simulating ground water $\overline{EC}$ is more than the linear model because this model just needs two factors (T and Ls) and there are their quantitative values in entire study area (source: TAMAB). But the non-linear model has less accuracy than the linear model for estimation the maximum and minimum values of ground water EC in study area. The presented non-linear model can be applied for simulation ground water average EC in Caspian southern coasts (the sites have not been studied). The presented model and other groundwater models can be used for future planning of sustainable groundwater development and management of groundwater resources (Yasmin 2008). Furthermore, there is a relationship between water EC and TDS (Total Dissolved Salts, TDS = 0.6 EC). Therefore, these models can be applied for simulating ground water TDS or to classify ground water in terms of qualitative in the Caspian southern coasts.

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References

Abdelrhem IM, Rashid Kh, Ismail A (2008) Integrated groundwater management for great man-made river project in Libya. Eur J Sci Res 22(4):562–569. ISSN: 1450-216X. http://www.eurojournals.com/ejsr.htm

Brouyere S, Carabin G, Dassargues A (2004) Climate change impacts on groundwater reserves: modeled deficits in a chalky aquifer. Geer basin, Belgium. Hydrogeol J 12(2):123–134. doi:10.1007/s10040-003-0293

Brunner P, Kinzelbach W (2005) Groundwater modeling in remote Chinese basin—how can models be improved in areas where data are scarce? European Geosciences Union 2005

Burns D, Vitvar T, McDonnell J, Hassett J, Duncan J, Kendall C (2005) Effects of suburban development on runoff generation in the Croton River basin, New York, USA. J Hydrol 311: 266–281. doi:10.1016/J.jhydrol.2005.01.022.0022-1694. www.sciencedirect.com

Coppola EA, McLane CF, Poulton MM, Szidarovszky F, Magelky RD (2005) Predicting conductance due to upcoming using neural networks. Journal of Ground Water 43(6):827–836

Hall N, Greiner R, Yangvanit S (2001) Modeling salinity management at from and catchment level in NSW and Thailand and Modsim 2001. Australian National University, Canberra

Hirsch RM, Walker JF, Day JC, Kallio R (1990) The influence of man on hydrologic systems. In: Wolman MG, Riggs HC (eds) Surface water hydrology, vols 0–1. Geological Society of America, Boulder, pp 329–359

McGee T (2001) Urbanization takes on new dimensions in Asia's population giants. Popul Today 29:1–2. POPLINE Document Number: 161361

Nichols DS, Verry ES (2001) Stream flow and groundwater recharge from small forested watershed in north central Minnesota. J Hydrol 89–103. PII: soo22-1694(01)00337-7

Prohaska S, Stevanovic Z (1993) The development of the autocross-regression model for karst spring flow simulation. Theory Appl Karst 6:151–155

TAMAB (2007a) Data and studies of the Mazandaran province aquifers, 12-Organization of Iran

TAMAB (2007b) Data and studies of study wells, Water Resources Research Organization of Iran

Yasmin R (2008) Groundwater modeling of the north-eastern part of Barind Tract its sustainable development and management, Bangladesh. Asian J Inf Technol 7(5):218–225. ISSN: 1682-3915

Zhang M (2001) Information-statistics evaluation on the effects of ground water buried depth to upper soil and groundwater salinity. In: China postdoctoral proceeding. Science Press, Beijing, pp 221–224

Zhang YK, Bai EW, Libra R, Rowden R, Huaibai L (1996) Simulation of spring discharge from a limestone aquifer in Iowa, USA. Hydrogeol J 4(1):41–54