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Management of seawater intrusion in coastal aquifers for developing of well discharging, Case study: Amol- Babol aquifer

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Abstract: As result of density difference between seawater and fresh water in coastal aquifers, a transition zone between two fluids is formed. A wedge of saltwater can be entered in coastal areas to the aquifer. Seawater intrusion rate and extent of transition zone depends on several factors including: changes in sea level, aquifer characteristics, hydrologic conditions of upstream, discharging from the aquifer, tidal and seasonal fluctuations of sea water. In this paper height of interface between seawater and freshwater in Mazandaran coastal aquifers is calculated by relationships that have been used in previous researches. According to the available information, the development of exploitation of three zones (Alashroud to Haraz, Haraz to Babolroud and Babolroud to Talar river in Amol- Babol aquifer in south of Caspian Sea) for distances less than 2000 m to sea is possible in the Haraz to Alash river. The total amount of water from this study that can be discharged in the three regions is 505 million cubic meters. According to statistics, 458 million cubic meters of these three areas are allowed to be discharged. Therefore, taking into account the withdrawal of unallowable wells, it can be assumed that the saltwater intrusion has more than 2000 meters to the coast. The results of this study are based on the hydrodynamic parameters of the aquifer for the past 9 years and seawater intrusion may be aggravated by climate change and hydrodynamic parameters change of in this aquifer. Therefore, it is necessary to carefully study hydrodynamic parameters of this aquifer.

Keywords: Seawater intrusion, Water resources management, Groundwater, Saline, Interface line from sea level.

1. Introduction:

Ground water aquifers are an important resource in coastal regions because these serve as major sources for freshwater supply in many countries around the world, especially in arid and semi-arid zones. In many coastal areas, high rates of urbanization and increased agriculture have arises the demand for groundwater (Bear et al. 1999). Several wells have been drilled to supply increasing water demand .The increase in water withdrawals from the wells have caused unacceptable drawdowns and deterioration of the quality of water pumped by some of the wells. Fresh groundwater in the coastal aquifer is drained seas or lakes under natural conditions and the interface line between fresh and salt water occurs. Heavy exploitation of coastal aquifers has effect on the hydraulic gradient. Changes of hydraulic gradient in groundwater aquifer are caused advance of salt water far away the sea at the coast. This phenomenon is called seawater intrusion. Two researchers named Ghybn and Herzberg separately studied fresh underground water flow to the oceans along the coasts of Europe**.** They found that anywhere from a coastal aquifer, If depth of interface between fresh and saltwater is measured from sea level, (h_s), then level of fresh ground water from sea level, (h_f), will be 1/40 (h_s) in that point (Ghyben 1889) and (Gorelick 1983). Since these studies were started by two scientists this phenomenon is mentioned with regard to "Ghyben - Herzberg" that will be explained. Many reviews on the types of groundwater management models and their applications are made by (Yeh 1986) and

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(Loaiciga 2000). The management models applications in saltwater intrusion, is relatively recent, (Zhi-yao et al. 2008), (Xiang-ju et al. 2012), (Sharif 2012) and (Strack 1976). Most of these problems have been investigated in a more complex setting involving various management objectives. Concerning saltwater intrusion into wells, it is often addressed in an indirect manner such as constraining drawdown at control points, or minimizing the intruded saltwater volume. These studies were conducted to maintain aquifer levels and prevent the saltwater intrusion so that undesirable economic consequences and legal violations are prevented.

Perpendicular section is considered on the seaside in an aquifer (Fig. 1). Hydrostatic pressure at point A is:

$$P_A = \rho_s g h_s \quad (1)$$

That ρ_s is density of salt water, h_s is height of point A from sea level, and g is acceleration of gravity. Similarly, the hydrostatic pressure at point B that has the same depth to point A equals:

$$P_B = \rho_f g h_f + \rho_f g h_s \quad (2)$$

ρ_f is density of fresh water, h_f is freshwater height above sea level in the aquifer layer. Now, if the above two equations equal then Ghybn–Herzberg relationship would obtain as follows (see Fig. 1, 2 and 3):

$$h_s = \frac{\rho_f}{\rho_s - \rho_f} h_f \quad (3)$$

If in equation (3) the density of the salt water is 1.025 $\frac{g}{m^3}$ and fresh water density is 1$\frac{g}{m^3}$ then equation (4) is calculated as follows:

$$h_s = 40 h_f \quad (4)$$

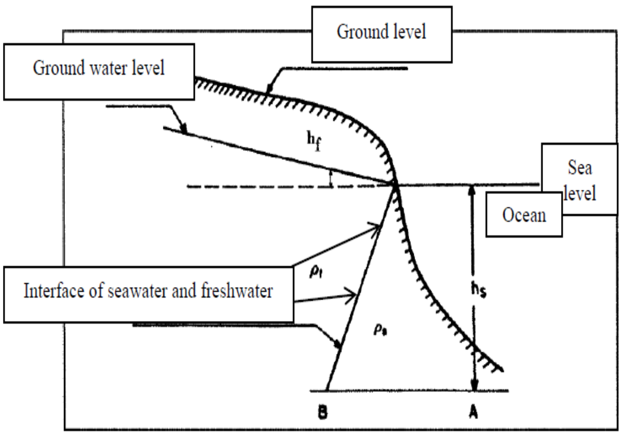

Fig.1. Ghyben – Herzberg relationship parameters

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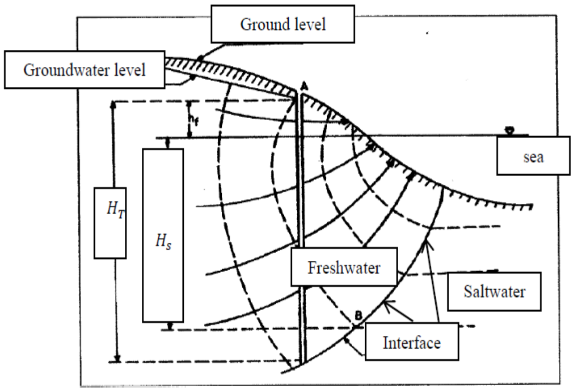


Fig.2. Ghyben – Herzberg relationship parameters. H_T is exact depth of interface and H_s is depth of interface based on Ghyben- Herzberg relationship that is lesser than H_T.

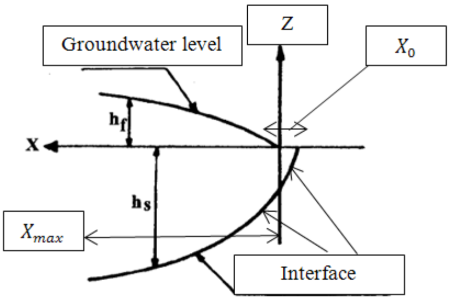
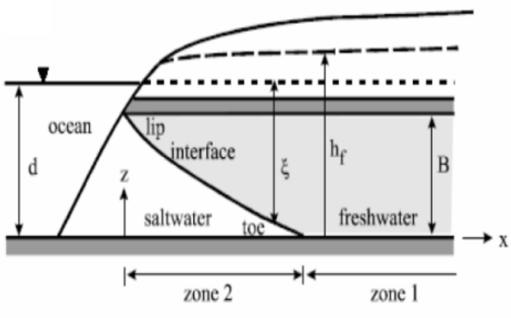


Fig.3. Ghyben – Herzberg relationship parameters.

Thus it is seen that the influence of saline water into coastal freshwater aquifer depends on h_f the height of ground water level above the sea level. True picture of the quality of sea water intrusion are shown in Figure 2 by using flow lines and potential lines. (Strack, 1976) derived a single potential theory such that a single governing equation could be applies to both the saltwater and the freshwater zones (Fatemi 2008). Figures 4(a) and (b) give a definition sketch in the vertical cross-section of a confined and an unconfined aquifer, respectively. Distinction has been made between two zones -a freshwater only zone (zone 1), and a freshwater-saltwater coexisting zone (zone 2). (Strack, 1976) demonstrated that for a homogeneous aquifer of constant thickness, a potential Φ which is continuous across the two zones.



(a)

Fig.4. Definition sketch of saltwater intrusion in (a) a confined aquifer, and (b) anunconfined aquifer

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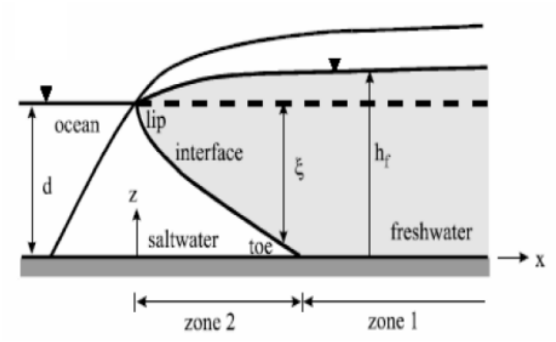

(b)

1-1 Research goals

Identifying features of rural housing in west Zagros region according to different cases of Oramanat region is our goal but selection of different cases should be done in a way that these samples can be generalized to various types of residential buildings in west Zagros region. On the basis of different types, essential documents for typology of rural housing in Oramanat have been prepared. In this paper height of interface between seawater and freshwater in Amol- Babol coastal aquifer is calculated by relationships that have been used in previous researches. *According to the available information, the development of exploitation of three zones (Alashroud to Haraz, Haraz to Babolroud and Babolroud to Talar river in Amol- Babol aquifer in south of Caspian Sea) for distances less than 2000 m to sea is possible in the Haraz to Alash river.*

1-2 Research questions

Considering that the purpose of this paper is to investigate in the management of seawater intrusion for optimal exploitation of three zones (Alashroud to Haraz, Haraz to Babolroud and Babolroud to Talar river in Amol- Babol aquifer in south of Caspian Sea) for distances less than 2000 m to sea will be possible.
:

- What are the characteristics of seawater intrusion in Babol– Amol aquifer?
- What are effective factors in the formation of seawater intrusion in Babol– Amol aquifer?
- How much can we discharge frome coastal wells in Babol– Amol aquifer to prevent of seawater intrusion in this zone?

1-3 Research method

The thickness of the fresh and seawater interface depends on a few factors such as the freshwater flows, tidal fluctuations and exploitation of groundwater aquifers. Interface can be measured with samples from various depths in a well drilled near the beach and chemical analysis of them. Electrical conductivity in depth and the depth of the water are plotted on the coordinate system. If electrical conductivity changes in depth. Verruijt showed surface groundwater and surface interface between fresh and seawater in homogeneous aquifer are parabolic.

Height of groundwater level to sea level is h_f (see fig (1) and (2)).

$$h_f = \sqrt{\frac{2\beta qx}{k(1+\beta)}} \qquad (5)$$

Height of surface interface between fresh and seawater to sea level is $\mathbf{h_s}$ (see fig (1), (2) and (3).

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$$h_s = -\sqrt{\frac{2qx}{\beta k(1+\beta)} + \frac{1-\beta}{1+\beta}\,\frac{q^2}{\beta^2 k^2}} \qquad (6)$$

$$x_0 = \frac{Q}{2\beta K} \qquad (7)$$

Where x is the distance from the point to the seaside and the land direction is positive. h_s is height of interface surface from the sea level that is positive upward. h_f is height of groundwater surface to sea level. q is amount of freshwater discharge per length unit to the sea. β equals $\frac{\rho_s-\rho_f}{\rho_f}$ and K is permeability coefficient.

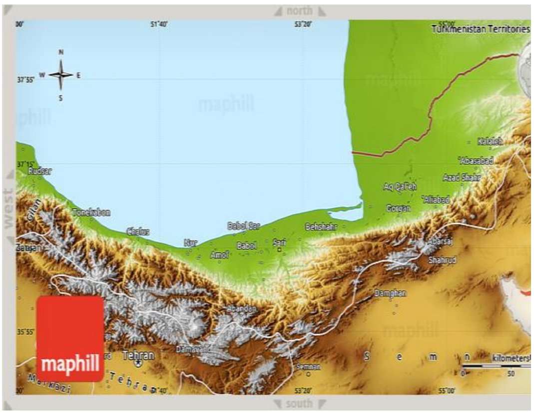

Fig (5). Mazandaran aquifers in south of Caspian Sea [11].

1-1-3. Hydrodynamic coefficients of the coastal aquifer

For determination of hydrodynamic coefficients in the five kilometers strip of seaside are used from the pumping wells data in the area and calculated hydrodynamic coefficients of them. Transmissivity coefficients from pumping tests are presented.

2-1-3. Density of freshwater and seawater

Coastal aquifer water density is considered equal to 1($\frac{g}{cm^3}$) in all prepared reports. Density of seawater is considered equal to 1.0185 ($\frac{g}{cm^3}$) in Mazandaran Sea.

2. A. Hydraulic Gradient in Coastal Aquifer

Hydraulic gradient in coastal aquifer is calculated using groundwater levels Measurement in observation wells and nivellement of wells relative to sea level.

Hydraulic gradient is calculated at some sections that do not have the annual statistics of observation wells by using of hydraulic gradient curves obtained for the 9-years average of the other sections.

3. Interaction of seawater and freshwater in Mazandaran Aquifers

Variation of transmissivity coefficients is 540 to 150 (m^2/day) from Ramsar (section A) to Daryakenar (section Q). Changes in aquifer thickness are from 67 to 24 meters, and changes in hydraulic gradient of groundwater are between 1.13 to 0.23 percent. Maximum seawater intrusion into coastal aquifers (x_{max}) is variable 254 meters at the section I to 15.8 meters at the section J. Latitudinal permeability of freshwater (x_0) from coastline to the sea is variable between 12.16 m at section L and 2.9 m at section C. Groundwater discharge per unit length of coastline is variable between 2.5 to 0.5 (m^3/day) from Ramsar area (section A) to Galandroud (section L). Maximum discharge is

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at east of Kojoor and Kelarabad and minimum discharge is at section I that is located in east of Noshahr. Variation of transmissivity coefficients is 180 to 150 (m^2/day) from Rostamroud (section M) to west of Babolsar (section Q). Changes in aquifer thickness are from 50 to 20 meters, and changes in hydraulic gradient of groundwater are 0.25 to 0.08 percent. Maximum seawater intrusion into coastal aquifers (x_{max}) is variable 426.8 meters at the section O to 15.8 meters at the section Q. Latitudinal permeability of freshwater (x_0) from coastline to the sea is variable between 2.02 m at section Q and 0.56 m at section P. Groundwater discharge per unit length of coastline is variable between 0.4 to 0.2 (m^3/day) from Rostamroud area (section M) to west of Babolsar (section Q). Maximum discharge is at west of Babolsar (section Q) and minimum discharge is at section M, O and P. The average discharge rate calculated 0.26 (m^3/day) per unit length of coastline which is about 6 times smaller than the average discharge rate at the Ramsar – Galandroud zone (1.575 m^3/day per unit length of coastline), see Table 2 and fig 6.a, 6.b and 6.c.

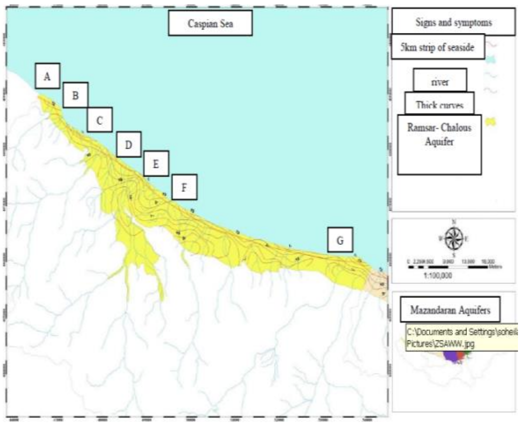

Fig (6). a. sections (A- G) in Ramsar- Chalous Aquifer [12].

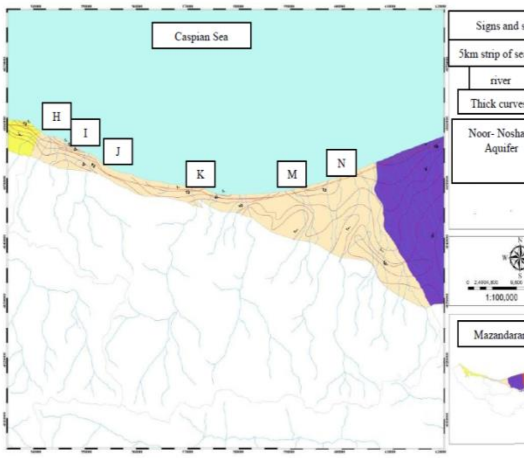

Fig (6). b. sections (H- N) in Noor- Noshahr Aquifer [12].

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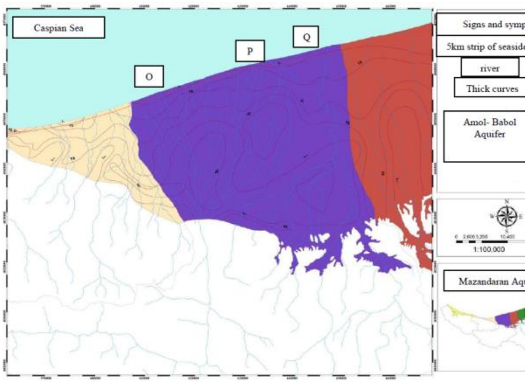

Fig (6). c. sections (O- Q) in Amol- Babol Aquifer[12].

4. Determination Limitation for seawater intrusion to the Amol- Babol coastal aquifer

Based on Fatemi & Atayani's Information (2008), in this paper saltwater and freshwater interface distance to sea level in Amol-Babol Coastal Aquifer is calculated. The amount of transmission coefficient for the boundary between Babolroud and Haraz rivers is 5 m^2/day and the average thickness of the aquifer is 25 meters and the hydraulic conductivity of 0.2 m/day and the hydraulic gradient 3.18e-3 and the transmission coefficient of transmission for the boundary between the Heraz and Alashroud rivers 23.1 m^2/day and the average thickness of the aquifer is 50 meters and the hydraulic conductivity coefficient is 0.462 meters per day, and the hydraulic gradient is 5.45e-3 and the transmittance coefficient for the boundary between the Talar and Babolroud rivers is 3.75 m^2/day and the average thickness The aquifer is 25 meters and the hydraulic conductivity is 0.15 m/day and the hydraulic gradient is 4.82e-4.

Fig (7). Amol- Babol Aquifer[12].

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Fig (8). Alashroud, Haraz, Babolroud and Talar are available rivers in Amol- Babol Aquifer in south of Caspian sea [12].

The amount of fresh water flow in unit length along the distance between Babolroud and Heraz:

$$q = T.I = \left[\frac{5\left(\frac{m^2}{m.day}\right)}{86400\left(\frac{day}{s}\right)}\right] \times 3.18 \times 10^{-3} = 1.84 \times 10^{-7} \left(\frac{m^3}{s.m}\right)$$

The amount of fresh water flow in unit length along the distance between Heraz and Alashroud:

$$q = T.I = \left[\frac{23.1\left(\frac{m^2}{m.day}\right)}{86400\left(\frac{day}{s}\right)}\right] \times 5.45 \times 10^{-3} = 1.456 \times 10^{-6} \left(\frac{m^3}{s}\right)/m$$

The amount of fresh water flow in unit length along the distance between Talar and Babolroud:

$$q = T.I = \left[\frac{3.75\left(\frac{m^2}{m.day}\right)}{86400\left(\frac{day}{s}\right)}\right] \times 4.82 \times 10^{-4} = 2.1 \times 10^{-9} \left(\frac{m^3}{s}\right)/m$$

To ensure that saline water does not advance more than 2,000 meters to the coast, the total pumping of all existing wells will be obtained according to the Verruijt formula, so that $h_s = 25m$:

$$q^2\left(\frac{1-\beta}{\beta K}\right) + 2xq - h_s^2 \beta k\,(1 + Bk) = 0$$

For Babolroud and Talar river: $6 \times 10^{-10}\,\frac{m^2}{m.s}$

For Babolroud and Haraz river: $9 \times 10^{-10}\,\frac{m^2}{m.s}$

For Alashroud and Haraz river: $2.1 \times 10^{-8}\,\frac{m^2}{m.s}$

The amount of discharge can be removed from the aquifer between Babolroud and Talar river is equal to $h_s = 25m$:

$$q = 2.16 \times 10^{-9}\,\frac{m^2}{m.s} - 6 \times 10^{-10}\,\frac{m^2}{m.s} = 1.416 \times 10^{-9}\,\frac{m^2}{m.s}$$

The amount of discharge can be removed from the aquifer between Babolroud and Haraz river is equal to $h_s = 25m$:

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$$q = 1.84 \times 10^{-7} \frac{m^2}{m.s} - 9 \times 10^{-10} \frac{m^2}{m.s} = 1.831 \times 10^{-7} \frac{m^2}{m.s}$$

The amount of discharge can be removed from the aquifer between Alashroud and Haraz river is equal to $h_s = 25m$:

$$q = 1.456 \times 10^{-6} \frac{m^2}{m.s} - 2.1 \times 10^{-8} \frac{m^2}{m.s} = 1.435 \times 10^{-6} \frac{m^2}{m.s}$$

In total, the discharge can be measured to the extent $1.619 \times 10^{-6} \frac{m^2}{m.s}$ that, given x = 2000m, the number of wells in the region is 23443, the annual harvesting of the area provided that the depth of the salt water $h_s = 25m$ is equal to:

For discharge of 4000 wells in Alashroud-Haraz region:

$$1.619 \times 10^{-6} \frac{m^2}{m.s} \times 86400(s) \times 365(day) \times 2000(m) \times (4000) \times 10^{-6} = 362 \text{ Million cubic meters}$$

For discharge of 12434 wells in Babolroud-Haraz region:

$$1.831 \times 10^{-7} \frac{m^2}{m.s} \times 86400(s) \times 365(day) \times 2000(m) \times (12843) \times 10^{-6} = 137 \text{ Million cubic meters}$$

For discharge of 7000 wells in Babolroud-Talar region:

$$1.416 \times 10^{-9} \frac{m^2}{m.s} \times 86400(s) \times 365(day) \times 2000(m) \times (7000) \times 10^{-6} = 6.118 \text{ Million cubic meter}$$

5- Discussion and conclusion

Changes of hydraulic gradient in groundwater aquifer are caused advance of saltwater far away the sea at the coast. This phenomenon is called seawater intrusion. x_{max} (Maximum seawater intrusion) in sections of Mazandaran coastal aquifers and allowable development of exploitation of this area have been calculated. These data show that the maximum advancing seawater in coastal aquifers in existing condition is 426.8 meters at O section that appears in hypothetical condition (contaminated 10% of below the aquifer thickness) to 470 meters. Analysis of the data related to interface in Table 4 show that maximum advancing saltwater in aquifer from M to Q section is more than the other sections**.** Results show that development of exploitation is not possible for section A, B and O among total sections of Mazandaran coastal aquifers. Therefore, according to the available information, the development of exploitation of this region (Alashroud to Talar river in Amol-Babol aquifer in south of Caspian sea) for distances less than 2000 m to sea is greater in the Haraz to Alash river. The total amount of water that can be harvested in the three regions is 505 million cubic meters, based on available data. According to statistics, 458 million cubic meters of these three areas are allowed to be harvested therefore, taking into account the withdrawal of unallowable wells, it can be assumed that the saltwater intrusion has more than 2000 meters to the coast.

The results of this study are based on the hydrodynamic parameters of the aquifer for the past 9 years and seawater intrusion may be aggravated by climate change and hydrodynamic parameters changes this aquifer. Therefore, it is necessary to carefully study hydrodynamic parameters of this aquifer. Seawater intrusion would be investigated in aquifers by studying of aquifer characteristics, hydrologic conditions of upstream, discharging from the aquifer, tidal and seasonal fluctuations of sea water in future.

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