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Conceptualization of the Hydrogeological System of Southern Caspian Coastal Aquifer of Amol – Ghaemshahr Plain, Mazandaran Province, Iran

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Abstract: Amol Ghaemshahr plain in Mazandaran province of Northern Iran hosts a two tier aquifer system. At places, groundwater has been induced to salinization by seawater intrusion, upconing of palaeoseawater and evapotranspiration processes thus rendering the water unusable. This paper attempts to develop a conceptual model of the hydrological system of the coastal aquifer of the Amol – Ghaemshahr plain. General Modelling System (GMS) was used to integrate log data and to construct a solid model inturn, to generate a 3D model of the hydrostratigraphy of the region. GMS borehole cross sections drawn depict three layer aquifer system- the upper unconfined, middle aquitard and the lower semiconfined aquifers. After calibration, the values of hydraulic conductivity of the upper and the middle impervious layers respectively are 1.9 – 10 m/day and 0.1 m/day, and for the bottom layer 1.9 – 10 m/day. Rivers, lateral inflow and agricultural return flow equally contribute for the recharge of the aquifer whereas the discharge from the wells is the main outflow component of the aquifer system. The construction of the conceptual hydrogeological model envisages the thickness and extent of the aquifer layers. The developed conceptual model serves as a prerequisite to develop a numerical model of the hydrologic system of the coastal aquifer of the Amol – Ghaemshahr plain.

Key words: *Mazandaran province, Iran, salinization, conceptual model, GMS, hydrostratigraphy.*

1. Introduction:

A conceptual model for a groundwater system is a working description or representation of the hydrogeological units and its flow system of groundwater. Development of the simulation model of seawater intrusion into the coastal aquifer demands careful conceptualization of the groundwater system, encompassing the hydrologic processes taking place in the targeted groundwater system. The purpose of building a conceptual model is to simplify the field problem and organize the associated data so that the aquifer system can be analyzed more readily (Anderson and Woessner, 1992). Thus, model conceptualization is, perhaps, the most critical step in developing a groundwater model (Kresic, 1997). Preparation of conceptual model involves identification of the study area, deciding appropriate boundary conditions, creation of usually three dimensional model of hydrogeological system and estimation of sources and sinks. In theory, the closer the conceptual view approximates the real-world conditions, the more accurate the groundwater modeling results (Maidment and Hooper, 2005). At the same time, the conceptual view should be as simple as possible, as long as it remains adequate to reproduce the system's behavior (Anderson and Woessner 1992; Hill, 1998; Hill, 2006).

In the Amol – Ghaemshahr plain of Mazandaran province, Iran groundwater occurs under semiconfined and unconfined conditions within the Quaternary alluvial soils in (Khairy et al., 2012a). Investigations carried out elsewhere in Iran on the chemical and physical properties of surface water indicates anthropogenic impacts on stream water quality (Marofi and Joneidi Jafari, 2003; Karami and Mahmoodi, 2008; Jamshidi et al., 2012) and also on groundwater quality (Taher-Shamsi and Moussavi 2003; Khorsandi and Alaei Yazdi 2004, Jalali 2007, 2010). Further, salinization problem is severe in Mazandaran province owing to steady increase in the population and also the demand from the agricultural sector. As the salinization problem is increasing and more and more wells are being abandoned, it is becoming a herculean task for the water authorities to augment the supply of the fresh water to its citizens. In the absence of detailed study, water management poses a threat to its civilians. Therefore the situation warrants in-depth study of the problem and demands a model to take up the remedial measures to minimise the salinization problem. The present paper aims at developing a conceptual model for visualization of the groundwater framework based on hydrological properties of the coastal aquifer of the study area. Development of conceptual groundwater flow model serves as a prerequisite to develop a numerical model and hence is a foundation to mathematically model the Amol Ghaemshahr aquifer system to seawater intrusion.

2. Study Area:

Mazandaran province, North Iran, is located in the South Caspian coastal region. The study area, Amol Ghaemshahr plain (Fig. 1) of Mazandaran province lies between latitudes 36° to 37° North and longitudes 52° to 53° East covering an area of 2300 sq.km. It is bound on the north by the Caspian Sea, south by the Alborz Mountain chain, east by the Siahroud river and on the west by the Alishroud river. The study area is composed of different physiographic units, which include alluvial fans, alluvial plains, marine deposits and flood plains. At the foot hills of the Alborz Mountains, the study area is at an elevation of ~ 200 m above msl, which gradually slopes down towards Caspian Sea. Near the coast, but away from it, several places are at a depth of ~ 20 m below msl. The Mazandaran plain is covered with alluvial sediments of Tertiary and Quaternary age and consists of rhythmically bedded fluvial – deltaic sediments of Aleshroud, Harz, Garmroud, Babolroud, Talar and Siahroud river systems. The Amol – Ghaemshahr plain consists of two freshwater aquifers: unconfined aquifer and underlying large semiconfined aquifer, the latter extending up to the shore line of the Caspian Sea. Groundwater table, near the foot hills of the Alborz Mountains, is at an elevation of ~ 106 m above msl, which gradually slopes down towards the Caspian Sea. Near the shore line the water table is at shallow levels, generally at a depth of ~ 25 m below msl. In the study area, groundwater flows from south to north and the hydraulic gradient of the water table decreases from west (0.17^0) to east (0.09^0).

The climate of the study area is sub-humid to humid with an average rainfall varying between 600 and 1000 mm. The rivers of the study area are perennial and their waters are used for irrigation of farmlands growing semi salt-sensitive variety of paddy, locally known as shaltoot rice. In the study area, bore wells are being drilled since 1961 and in greater number in 1981 and thereafter to meet the demand for freshwater for irrigation and urban utility purposes (Najihammodi and Khadir 2003).

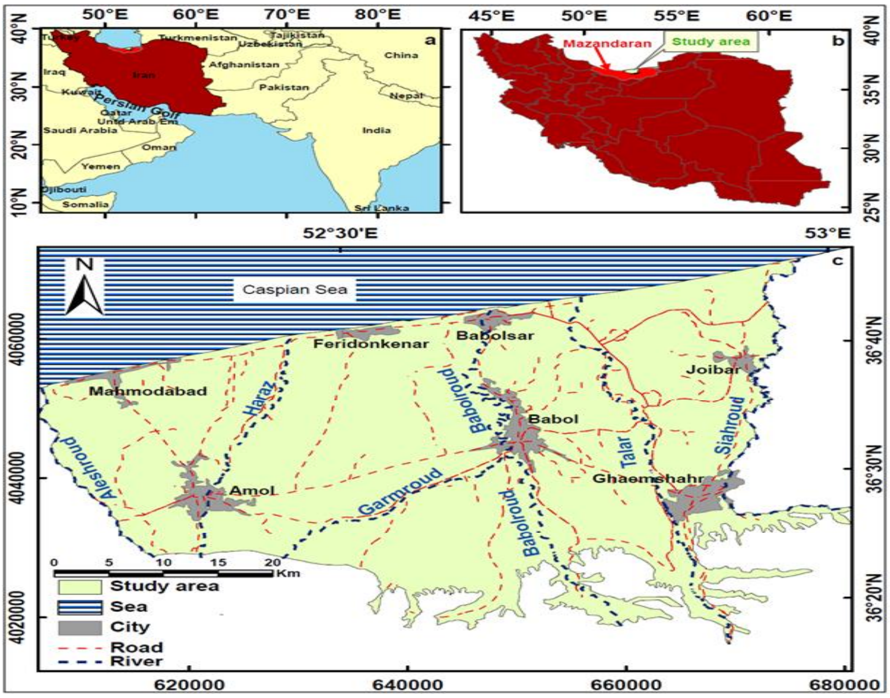


Fig1: *Location map of the study area (a and b) and plan view of two-tier aquifer system of the Amol – Ghaemshahr plain (c)*

2.1 Salinization Problem:

There are widespread fresh water resources (surface and groundwater) in Mazandaran province but at several places the fresh groundwater is subjected to salinization (Fig. 2) and contamination by traditional anthropogenic inputs (Gholami et al., 2010). In recent years, the growth of industry, technology, population, and water use has increased the stress upon water resources of Mazandaran province (Mehrdadi et al., 2007) and salinization problem has engulfed many of the wells thus rendering them useless. Proximity to the sea and over exploitation has accelerated the salinization problem affecting the cultivation. The preliminary damage estimation indicates that the main paddy crop is sensitive to the amount of salt present in the irrigation water and therefore the salty water cause about 20 percent damage to its production (Najihammodi and Khadir, 2003). The reasons attributed for salinization are (1) depth to water table is less than 5 m and sea level change (-25 to -28.5 msl) (2) evaporation on static shallow water resources (3) upconing of palaeo brine due to over exploitation (Khairy et al., 2012; Khairy and Janardhana, 2012).

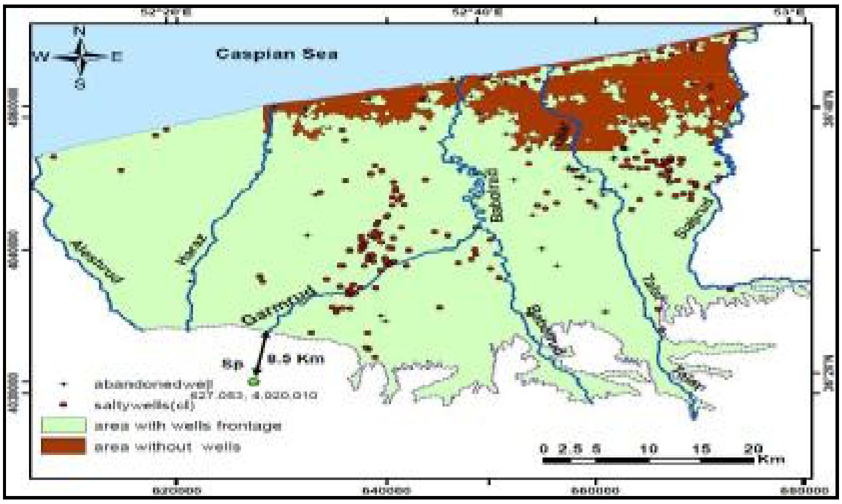


Fig2: *Map showing salty wells and salinized part in study area*

2.2 Groundwater Resource:

Groundwater is the main source of potable water in most areas of Mazandaran province for all needs and there are more than 80, 000 wells in an area of 2300 sq. km. In the Amol- Ghaemshahr plain, depth of the wells from ground level vary from less than 5 m to 245 m and the depth of water table are found to vary from less than 1 m to about 100 m. However, due to the demand by domestic and agricultural sectors, the fluctuation of water table is high between crop and noncrop seasons. Table 1 shows the number of wells in the Amol-Ghaemshahr plain and their abstraction for various needs. In the study area 78 have been abandoned owing to salinization problem. In addition, during the years 1951 to 1973, Russian Exploration Company had put 34 bore wells varying in depths from 120 m to 245 m with an average depth of 167 m. However, due to high salinity in the groundwater of these wells, in later years, Mazandaran Regional Water Company of Iran Government closed down all these wells by injecting cement slurry into the wells so as to avoid their uprising (Fig. 3).

Table1: *Number of wells in two-tier aquifer and utility of groundwater (2005)*

Layer No	**\ Consumption**	**Agricultural**	**Drinking**	**Industarial**	**Abandoned**	**Sum**
layer1	No. of wells	76273	362	222	22	76879
	Discharge(MCM)	207.94	6.50	1.80	-	216.24
layer3	No. of wells	2974	325	46	56	3401
	Discharge(MCM)	80.79	101.54	2.91	-	185.24
Total	No. of wells	79247	687	268	78	80280
	Discharge(MCM)	288.73	108.03	4.71	-	401.48

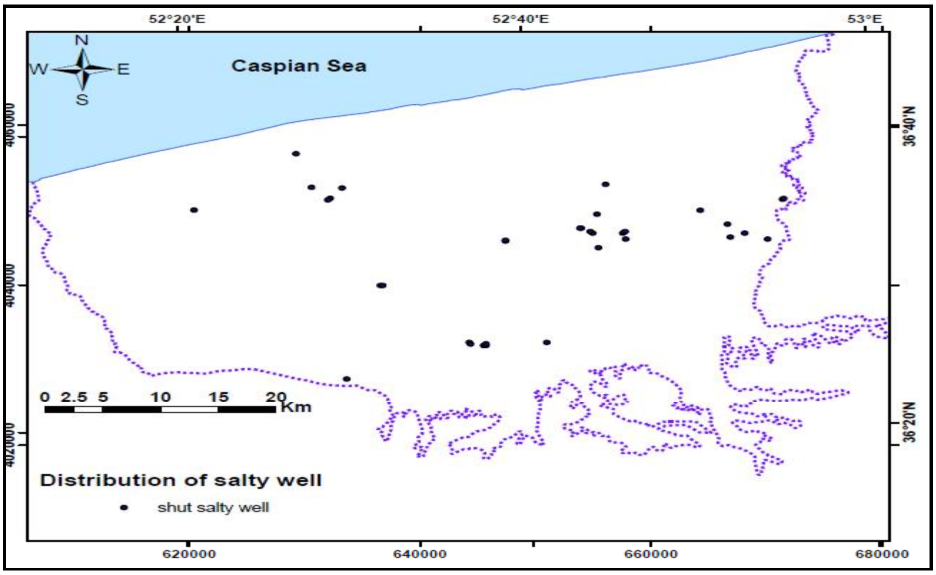


***Fig3:** Spatial distribution of wells in the study area plugged by grouting*

2.3 Aquifer System:

Conceptualization of a groundwater system usually starts with identifying the hydrostratigraphic units in the study area that contain similar hydrogeologic properties. The hydrostratigraphic units are then categorized as either aquifers or aquitards depending on their capabilities of conveying water. The resulting conceptual view conceives the groundwater system as a series of aquifer or aquitard layers, each with its own aquifer properties and water boundary conditions. Numerical modeling of groundwater flow systems requires correct prediction of the role of geological structures in controlling the groundwater flow (Spottke, Zechner et al. 2005). This requires sufficient information to develop an acceptable hydrogeological framework (Rudorfer 2009). The subsurface materials need to be defined in terms of distinct model layers which constitute hydrostratigraphic units with similar hydrogeologic properties (viz., porosity and permeability) (Sanchez, Coloma et al. 1999). This may require a combination of geological formations into one hydrostratigraphic layer, or conversely subdividing a single geological formation into aquifers and confining units (Anderson and Woessner 2001).

The study area is covered with a thick pile of quaternary unconsolidated to semiconsolidated detrital sediments, which, based on exploratory bore wells and geophysical data, are found to extend to a depth of more than 500 m. Log data of exploratory drill holes drilled to a maximum depth of ~350 m provide reliable details on the subsurface geological features of the study area. The study area, Amol – Ghaemshahr Aquifer (AGA) system is consists of three hydrogeological units: an unconfined aquifer, an aquitard and a semiconfined aquifer. In the vertical section, the unconfined aquifer consists of more or less horizontal horizon of alluvial deposits of Quaternary age. The unconfined aquifer covers the entire study area. It ranges in thickness from 10 to 60 m (av. = 25 m), is highly permeable and consists of sand, gravel and silt. The aquitard, located below the unconfined aquifer, is composed of clay, silty clay and sandy clay and constitutes the impervious layer separating the upper unconfined aquifer and the lower semi-confined aquifer. It varies in thickness from 6 to 62 m (av. = 19 m) and extends in the E-W direction for a distance of about 65 km. It varies in width along N – S direction from 14 to 24 km (av. = 20 km). The aquitard is limited in extent and is confined to the central part of the AGA. The semiconfined aquifer consists of silt, gravel and fine to medium sized sands and varies in thickness from 50 to 200 m (av. = 150 m). It is underlain by marine sand and silt with bivalves and contains brine/saline water.

3. Hydrostratigraphic Model Design and Description:

Figure 4 shows the distribution of bores that were considered in the stratigraphy analysis of the study area. In this study, for the preparation of hydrostratigraphic units, initially 99 well logs of the study area were assessed and finally 66 well logs were selected (Fig. 5). Hydrogeologic units (HGUs) were defined based on boreholes. HGUs typically constitute simplified representation of the soil layers (Table 2) from the borehole field data. The initial stratigraphic analysis considers a locally complex sedimentary geology that includes three major alluvial units together with several other layers that are not laterally extensive. The side elevation view of the bores has been used to interpolate the stratigraphy across this study area. GMS was used to integrate the borehole lithology picks for conceptual understanding of the hydrological framework of the study region.

After preparation of all well logs diagrams and defining relationship between them, cross-sections of study area were created. Borehole cross sections (an example is shown in Fig. 6) were created manually using the Boreholes menu command. This uses a triangulation process to determine the most likely connections between boreholes. For the interpretation of well logs data, GMS 8.0 software was used. When locations for currently existing bores were made available in a single coordinate system (WGS84), then the GMS software was used to create numerous cross-sections (Fig. 7) and solid model of the alluvial plain. Even though the GMS has an automatic function to create cross-sections, the present authors opted for manual tools to draw cross sections based on the prior knowledge of the depositional environment and interpolation between the bores to obtain more detailed and satisfactory output. The solid module of GMS was used to construct three-dimensional model of hydrostratigraphy of the study area.

Figure 8 shows a three dimensional (3-D) conceptual Model of the aquifer system with the third layer made up of silt, gravel and fine to medium sands, containing fresh water. The surfaces exhibit some broad patterns, such as the general northward dip of the top of the Amol Ghaemshahr coastal plain and alluvial plains all along the major river courses. From the solid model created, cross sections (Fig. 8a, b, c) were cut on the model to show the hydrostratigraphy of the study region in the desired directions. Solid and cross sections were used for the site characterization and visualization. Most importantly, the solid created in this study was used to define layer elevation data for MODFLOW models using the Solids → MODFLOW command or Solids to HUF and to define a layered 3D mesh using the Solids → Layered Mesh.

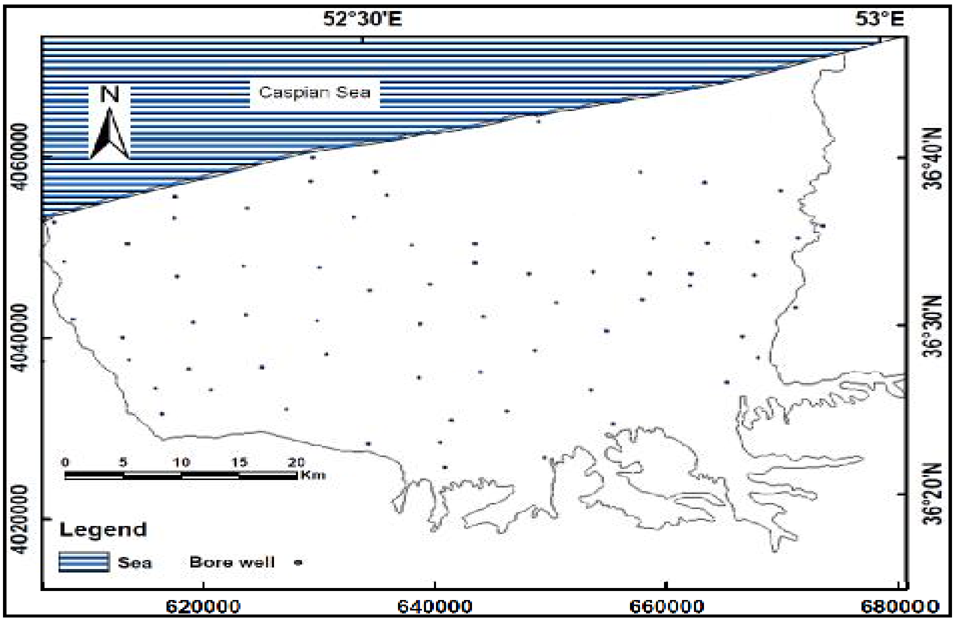


Fig4: *Spatial distribution of bores that were considered in the stratigraphy analysis of the study area.*

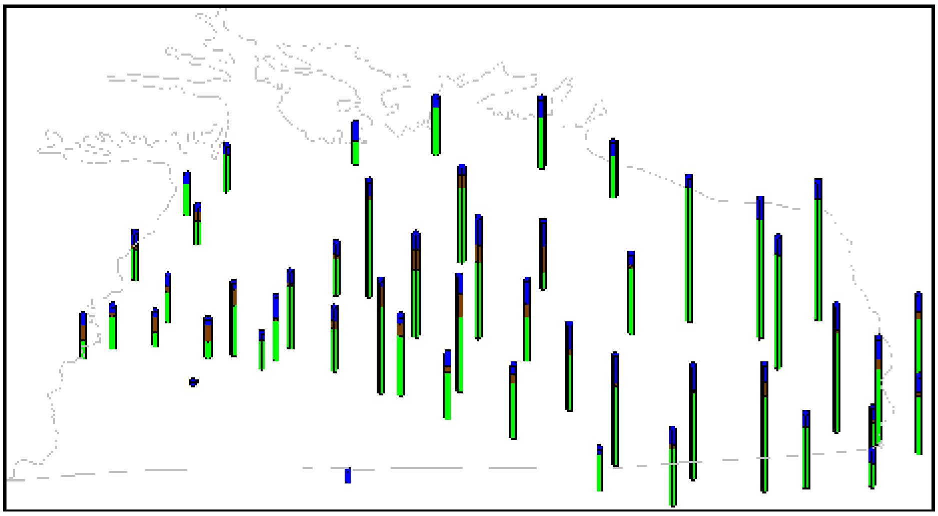


Fig5: *Display of well logs used to create cross sections and solid model of the alluvial plain*

Table2: *GMS: Borehole Hydrogeologic Units used in the creation of Conceptual model*

MATERIALS LEGEND			
H1	Sand, gravel and silt	Layer one with fresh water	
H2	Clay, silty clay and sandy clay	Impervious layer	
H3	Silt, gravel and fine to medium sands	Layer three with fresh water	
H4	Marine sand and silt with bivalves	Bedrock with brine water	

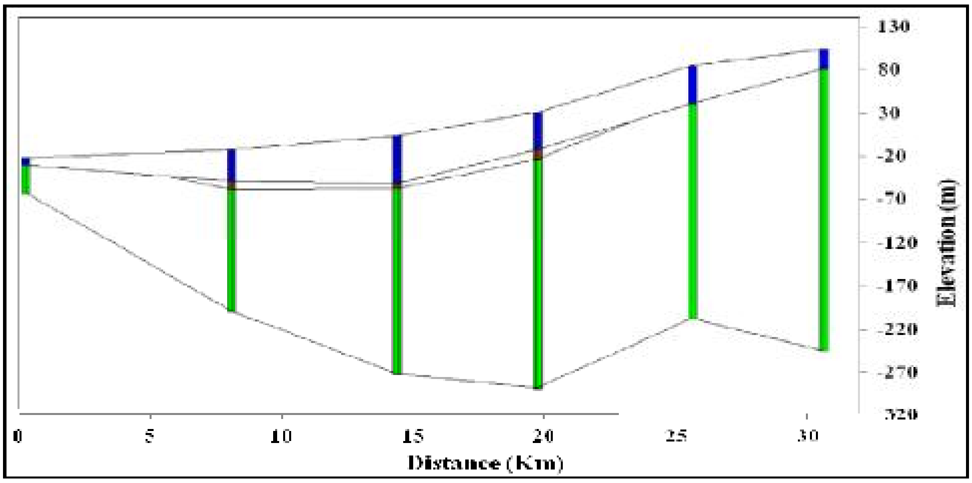


Fig6: *Cross section created by GMS software*

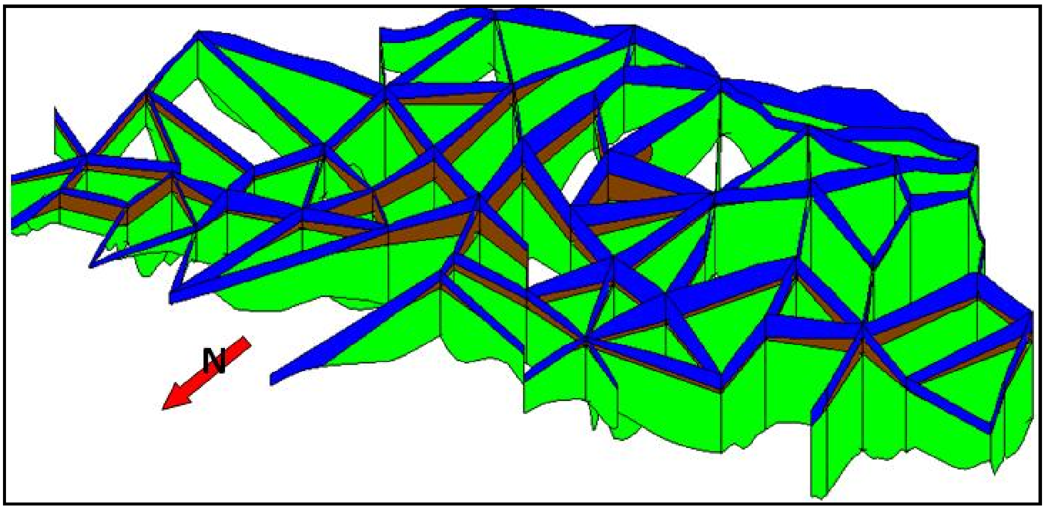


Fig7: *Fence diagram showing the vertical relations between the hydrogeological units of the study area.*

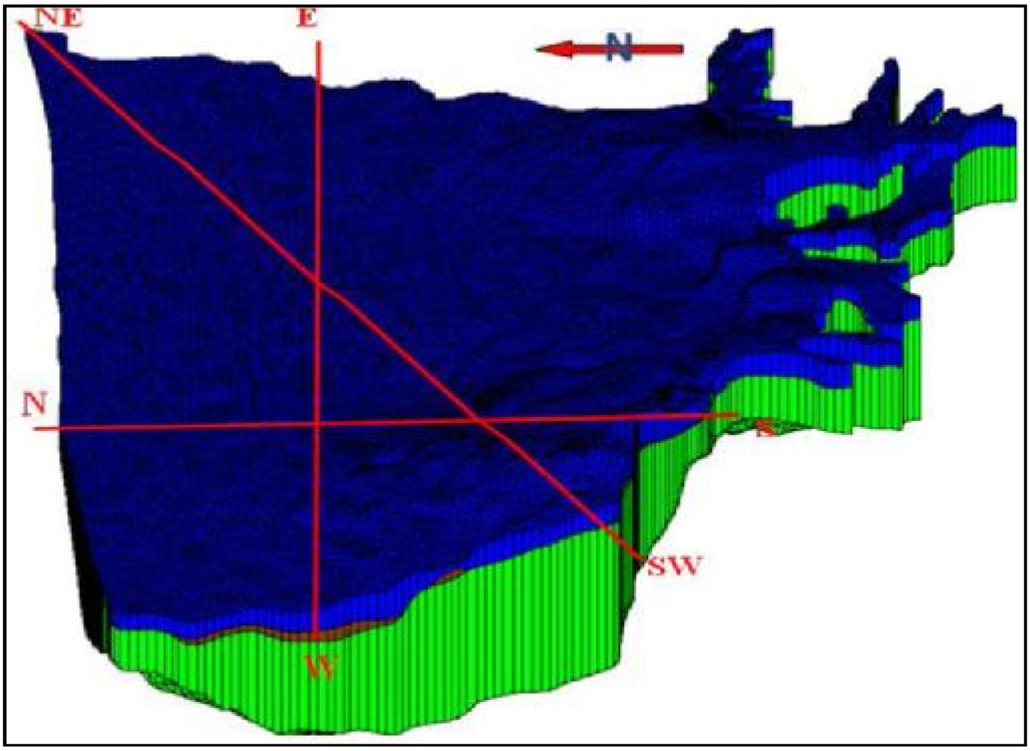


Fig8: *3D Hydrostratigraphic model of the study area*

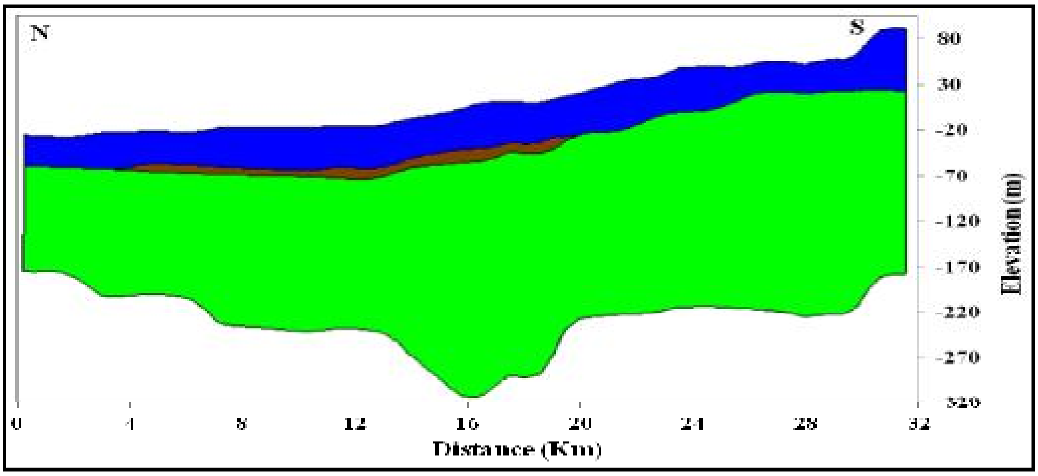


Fig8a: *GMS Borehole Cross section created from solid in N - S direction*

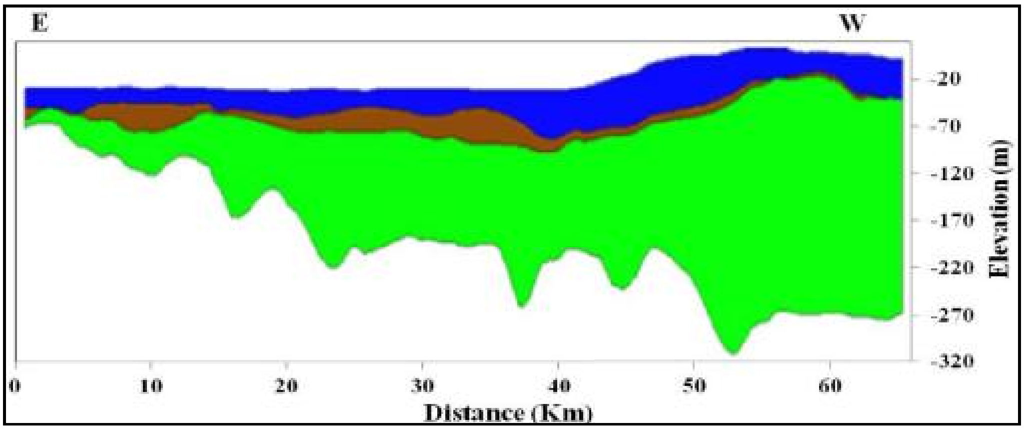


Fig8b: *GMS Borehole Cross section created from solid in E W direction*

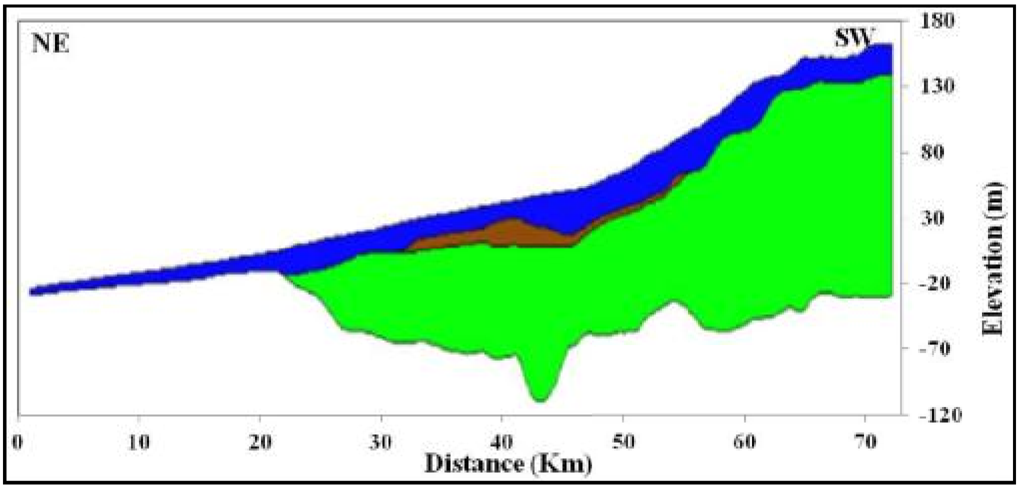


Fig8c: *GMS Borehole Cross section showing different aquifer layers with variable thickness created from solid in NE – SW direction*

4. Hydraulic Properties:

The Amol – Ghaemshahr aquifer system was constructed based on the log data of exploratory boreholes and is composed of three layers of hydrogeological units – an unconfined aquifer, an aquitard and a semiconfined aquifer. The semiconfined aquifer is underlain by a horizon with brine water. Two types of saline water occur within the aquifers of the Amol – Ghaemshahr plain; recent and palaeo seawater. Recent seawater is present in the fine grained sediments in the unconfined aquifer at its NE region. Old seawater in the form of brine is present in the bottom most layer.

The model development requires data on hydrologic properties. The aquifer hydrologic properties characterize the geological medium through which groundwater flows and include hydraulic conductivity, specific yield and storage coefficient. Initial estimates of the hydraulic properties of the Amol – Ghaemshahr aquifer made by the Mazandaran Regional Water Authority, created a data set by regularly carrying out the pumping test of the aquifer system. From the pumped aquifer transmissivity, hydraulic conductivity (horizontal and vertical) and storativity (storage coefficient) were determined. In layered systems, one also uses pumping tests to estimate the properties of aquitards (vertical hydraulic conductivity and specific storage). These estimates were used as input data in a digital groundwater flow model and calibration of the model led to refined estimates for some hydrogeologic units. The estimated values of the aquifer parameters were used to draw time draw down curve for individual test and compared with the observed time-drawdown/recovery data. The values of the aquifer parameters were calibrated till a best match is obtained

Horizontal hydraulic conductivity map generated from the aquifer thickness and aquifer transmissivity show that horizontal hydraulic conductivity ranges from 0.22 to 58.6 m/day with an average of 4.87 m/day (Fig. 9). Southern part of the study area shows maximum hydraulic conductivity values witnessed in the area and the value steadily decreases towards the northern part. High conductivity values correspond to the areas of intense recharge regions in the area. Vertical hydraulic conductivity was estimated for the hydrogeologic units of the study area on the basis of published and well log data. Vertical hydraulic conductivity was assumed 20% of horizontal hydraulic conductivity for upper layer and 6.6% of horizontal hydraulic conductivity for impervious layer and lower layer. In the field horizontal hydraulic conductivities are generally greater than vertical hydraulic conductivities, as a result of the depositional history of the sediments. During the calibration of the model, hydraulic conductivity of the upper layer and impervious layer was estimated respectively at 1.9 -10 m/day (av. = 6.22 m/day) and 0.1 m/day. For lower pervious layer it was assumed to be 1.9 - 10 m/day (av. = 6.22 m/day).

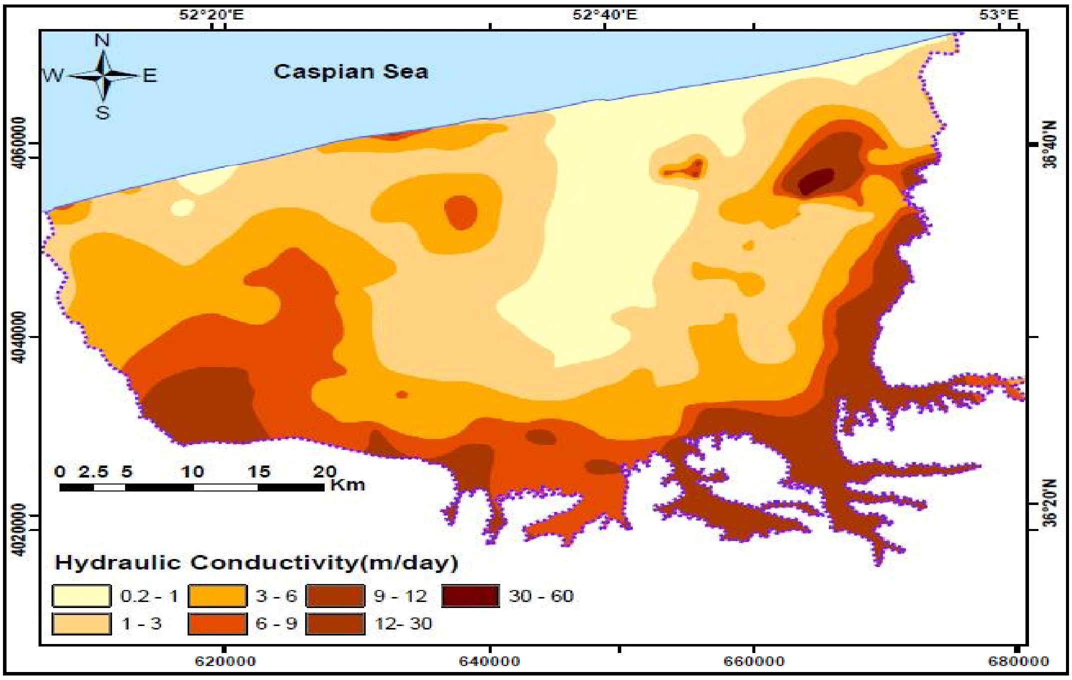


Fig9: *Map showing distribution of horizontal hydraulic conductivity of study area*

Specific yield (S_y) is an important factor in water availability. Specific yield of the aquifer materials were estimated from the data on sediments obtained from the exploratory borehole logs and average values of sediments given in the literature (Freeze and Cherry, 1979; Todd, 1980; Driscoll, 1986). The specific yield map (Fig. 10) generated for the AGM area indicates that the aquifer is highly productive excepting in a small zone in the northern part of the area wherein the estimated value is around 8.05 %. Highly saturated zones are located all along the coastal belt and the specific yield is relatively low in the zones of recharge.

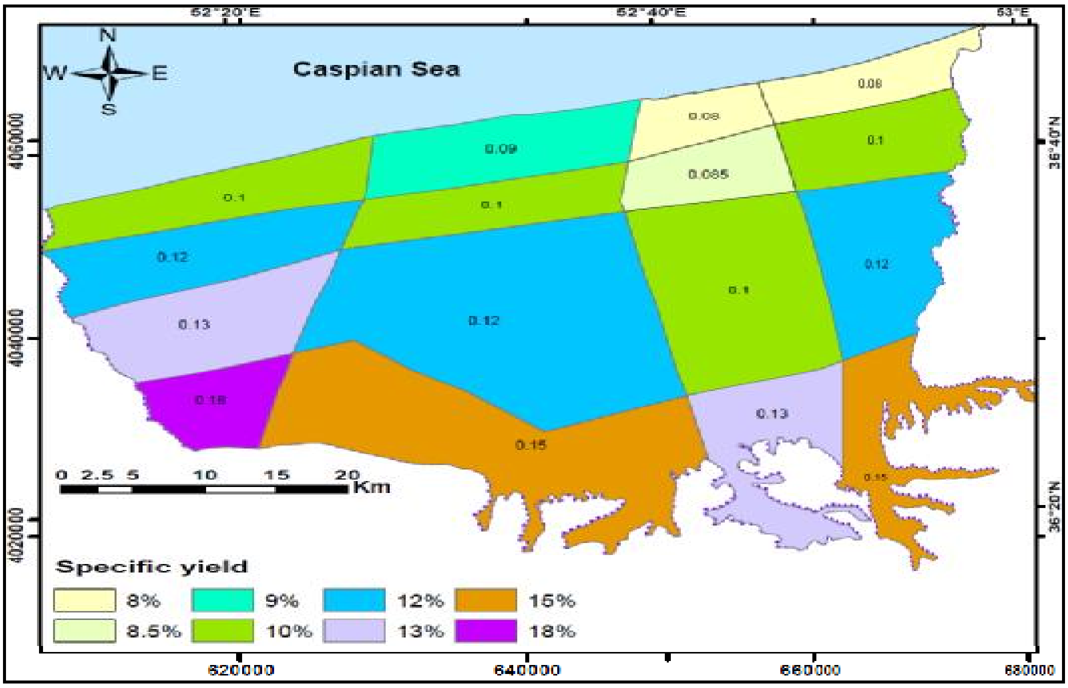


Fig10: *Map showing specific yield zones of study area*

The storage coefficient of unconfined aquifer is virtually equal to the specific yield, which means that nearly all the water is released from storage is by gravity drainage. Thus, the storage coefficient which is approximately equal to the value of specific yield and ranges from 0.1 to about 0.3. The storage coefficient for semiconfined aquifer was calculated by multiplying specific storage with their thicknesses. They are fractions between 0 and 1. From the published literature, it is known that the storage coefficient of most confined aquifers ranges from about 10^{-5} to 10^{-3} (0.00001 to 0 .001) (Heath, Ralph C., 1983). By considering the storage coefficient of geologic material of (Domenico and Mifflin 1965 as reported in Batu 1998), an initial value of 4.5×10^{-5} to 1×10^{-4} was assumed of the storage coefficient for the confined aquifer and permeable zones. The value was reduced during model calibration to a maximum of 0.15.

5. Water Balance:

According to Mazandaran Regional Water Authority there are about 80,200 wells of varying depths in Amol – Ghaemshahr area. Groundwater use of the study area is steadily increasing from time to time as the population is increased. The groundwater discharge from the two aquifer units of the area is mostly by withdrawals from wells. The estimated abstractions from wells viz., municipal, agricultural, settlement abstractions, etc., constitute nearly 84% of the total discharge of groundwater from the study area. Quantification of the rate of natural groundwater recharge is a basic prerequisite for efficient groundwater resource management (Lerner et al., 1990). A common indirect method for hydrologic system under equilibrium condition is to equate groundwater recharge to groundwater discharge (Belay, 2006). The Recharge Package of MODFLOW was used to simulate the spatial distribution of the recharge to the study area. For the study area, recharge from rivers and lateral inflow are the main sources of recharge. Return flows from irrigation and domestic use account for nearly 40 % of the recharge whereas the rain contributes only 5 % to the recharge of the aquifers. Based on the estimates of all water inputs and outputs to the AGA aquifer system, a water balance chart for the period of 3 years from 2008 to 2011 has been prepared and is shown in Table3.

Table3: *Water balance from 2008-9 to 2010-11 of the AGA aquifer*

Water Budget							
Inflow(m^3)				**Out flow(m^3)**			
Components	**Water year**			**Components**	**Water year**		
	2008-9	2009-10	2010-11		2008-9	2009-10	2010-11
Rivers	382244	353720	337855	Lateral outflow	49462	41366	39285
Lateral inflow	344936	355692	358168	Rivers	74059	57115	58064
Rain	74570	65846	41870	Drains	114563	70620	60846
Return water from irrigation	270366	289846	316298	Wells	1134870	1136984	1162307
Return water from domestic water	212216	216876	222410	Evapotranspiration	26354	26896	28210
Sum	1284332	1281979	1276601	Sum	1399307	1332980	1348712

6. Boundary Condition:

Water boundary conditions characterize water flux between the aquifer layers and surface features such as well pumping schedule and groundwater recharge rate (Yang a et al, 2010). For modeling the first step involves delineation of the groundwater system of the study area is to be delineated from the surrounding groundwater systems. Consequently, a model boundary needs to be defined before taking up any groundwater modeling exercise. Model boundary is the interface between the study area and the surrounding environment (Spitz and Moreno, 1996). Anderson and Woessner (1992) have defined boundary conditions as mathematical statements specifying the dependent variable (head) or the derivative of the dependent variable (flux) at the boundaries of the problem domain. They have also mentioned that regional groundwater divides are typically found near topographic high and may form beneath partially penetrating surface water bodies. It is common for large scale models to be bounded by well-defined physical features such as rivers, bedrock outcrops or groundwater divides (Gurwin and Lurbczynski, 2005; Idrysy and Smedt, 2006).

The Amol – Ghaemshahr plain is characterized by well defined physical boundary conditions. Fig. 11 shows the boundary conditions. In the south, specified flow pattern was taken as the boundary and the geographical boundaries were used to conceptualize the other sides of the model. The eastern and western boundaries coincide respectively with existing main river courses of Aleshroud and Siahroud. The northern boundary coincides with the south Caspian coastal line.

In the study area, the general direction of groundwater flow is from south to north i.e., from piedmonts of Alborz mountains to Caspian Sea. Groundwater as a base flow enters in the Active Model Area at its southern boundary and outflows at its northern boundary. For modelling purpose, Aleshroud and Siahroud rivers have been treated as line sources of recharge and/or sinks. The upgradient (south) boundaries are being simulated using specified flow package. The inflow in each layer has been distributed among the active cells along the southern boundary. The down gradient (north) Caspian sea constant head value was assigned as -26.62 m, which is equal to the sea level during the running time of the conceptual model.

The upper boundary of the model is the water table, which is a free surface boundary that receives spatially variable recharge from precipitation, river, agricultural and wastewater return flows. The lower boundary of the freshwater flow system is the transition between freshwater and palaeobrine/saline water. The arbitrary bottom altitude was specified as a no-flow boundary for this analysis.

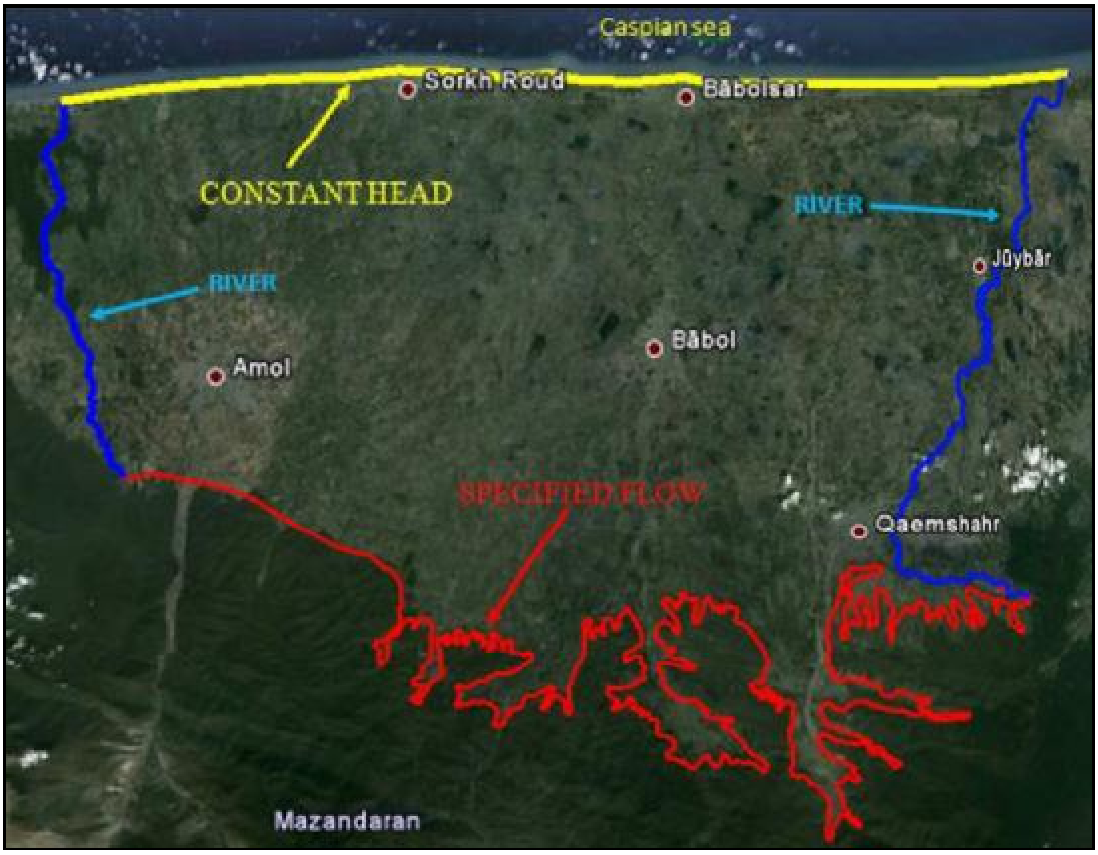


Fig11: *Satellite imagery of the study area showing the boundary conditions fixed in the model*

7. Spatial Discretization:

Finite-difference methods require the discretization of space into a grid consisting of rows, columns, and layers of model cells. Hence, the aquifer system of the study area was spatially discretized into square grid encompassing 112 rows and 150 columns. Vertically the aquifer is treated as a 3 layer system. Each model cell covers an area of 500 by 500 m. The 500 m X 500 m cell size was chosen based on the large size of the area. The discretized model area is shown in **Error! Reference source not found.**12.

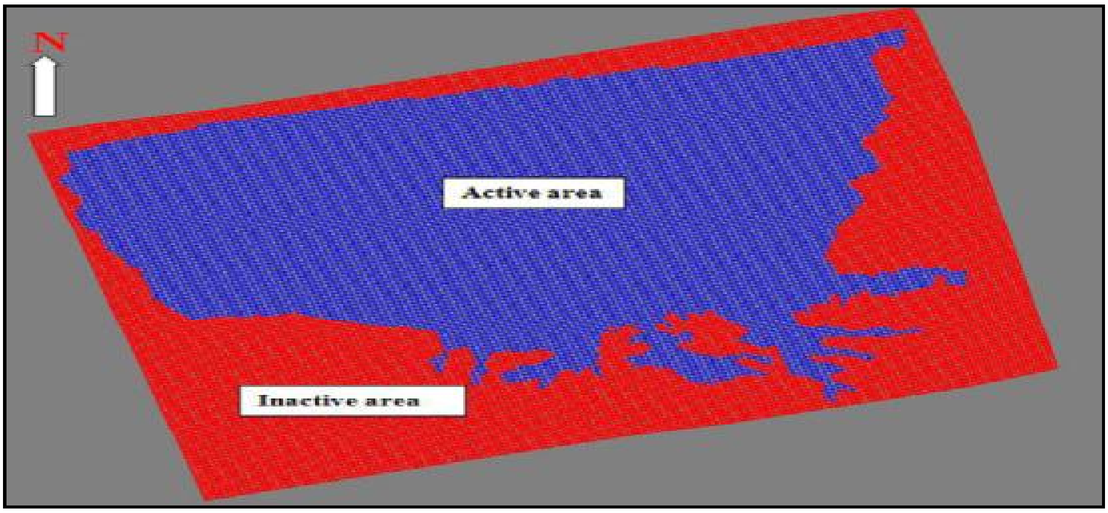
The model covers an area of 2434 km^2 (active area). The model area was discretized into 16805 cells (Table 4). The areas lying outside the boundary of the study area (about 1767 sq. Km) constitute inactive cells i.e., the cells existing outside the Aleshroud -Haraz and Talar-Siahroud basins. Left side of Aleshroud river and right side of Siahroud River have been treated as inactive cells. The remaining cells were treated as active cells. The model grid is aligned 15 degrees towards west so as to align the model grid with dominant direction of groundwater flow and also to the existing coastline.

Table4: *Spatial discretization of model domain*

DESCRIPTION	No of Cells	AREA(Km^2)
Inactive cells	7068	1767
Active cells	9737	2434
Sum	16805	4201

As mentioned above, in the vertical dimension, the model is a three-layered and the top most surface of the model represents the land surface of the study area. Second and third layers of the model were visualized from the field data obtained from the exploratory wells, from the vertical electrical sounding and also from 3D hydrostratigraphic model.

While developing a groundwater model, not only spatial domain is discretized into cells and temporal domain is discretized into time steps. Typically a year is digitized into 2 to 4 time periods based on seasons. During each time period, various stresses and parameters exhibit either unique relationship or remain constant. In the present study, one year time is discretized into two periods, that is, non-growing season and growing season. Non-growing season is considered from the end of September to the end of February. Most of the rainfall in the study area occurs during this period owing to which the requirement of fresh water for agriculture is low. The remaining period is considered as growing season where there is practically less recharge from rainfall and groundwater extraction is more in comparison to the non-growing period.



*Error! Reference source not found.**12:** Model configuration of Amol-Ghaemshahr aquifer*

8. Conclusions:

The development of a conceptual model is the fundamental approach used in all hydrogeological assessments ranging from simple desk studies to complex large-scale investigations and no widely accepted methodology that defines process exists, possibly because this is necessarily iterative and therefore complicated to describe (Brassington and Younger, 2010). In the Amol – Ghaemshahr plain of Mazandaran province, the groundwater is variously salinized and the coastal aquifer is vulnerable for seawater intrusion. The development of numerical model based on the constructed conceptual model is now under way and this is likely to provide further insight into the saltwater intrusion phenomenon taking place in the southern Caspian coastal plain. The construction of conceptual hydrogeological model presented in this paper provides an insight into the extent and thickness of the three hydrogeological units namely an unconfined alluvial aquifer, an aquitard and a semiconfined aquifer. During the calibration of the model, hydraulic conductivity of the upper layer and the underlying impervious layer was estimated respectively at 1.9 -10 m/day (av. = 6.22 m/day) and 0.1 m/day. For lower previous layer hydraulic conductivity was assumed to be 1.9 - 10 m/day (av. = 6.22 m/day). The specific yield map constructed for the study area indicated that the highly saturated zones are located all along the coastal belt and the yield is relatively high in the zones of recharge. The water balance studies identified various sources of recharge while the discharge is mainly from wells. The cross sections of the hydrostratigraphic model envisages the horizontal and vertical extent of the hydrogeologic units (aquifers – unconfined and semiconfined and aquitard) and the direction of inclination of the strata. Both unconfined and semiconfined aquifers are hydraulically connected with each other in the areas of recharge i.e., in the southern part of the study area. In the northern part they form a unified aquifer system. The thickness and extent of the impermeable layer between these two aquifers are variable and hydraulic connectivity may be there between the aquifers in certain parts of the study region.

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