The groundwater hydraulics of the Garmsar alluvial fan, Iran, assessed with the SahysMod model.

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Abstract
The Garmsar alluvial fan is located approximately 120 km southeast of Tehran, at the southern fringe of the Alburz mountain range, where the Hableh Rud River emerges and where the Dasht-e-Kavir desert begins. The elevation of the area ranges between 800 to 900 m above sea level. The radius of the fan from top to bottom is some 20 km.
The area is intensively irrigated. At the apex the water table is deep and the percolation losses of the irrigation water are carried downslope through a deep aquifer. At the bottom of the fan, the aquifer is less deep and its permeability for water is reduced, so that the water table becomes shallow and it gets at a depth from which capillary rise and evaporation of the groundwater occurs. As the salts remain behind, the soil salinizes here.
In this article, the groundwater hydraulics of the fan, that play an important role in the use of pumped wells for irrigation and the depth of the water table at the foot of the fan in relation to salinization of the soils, will be assessed using the spatial (polygonal) agro-hydro-soil-salinity model SahysMod.

Contents

1. Introduction

Figure 1 shows a picture of the Garmsar alluvial fan from space. The fan has been discussed before in general terms [Ref. 1].

A sketch of the irrigation infrastructure is shown in figure 2. The figure shows that the traditional systen of qanats (ghanats, karezes) by which water is abstracted from the aquifer, is still present. The qanats are dug underground channels, almost horizontal, stretching up against the slope of the terrain, so that they reach the water table. The abstracted water is used for household purposes and crop irrigation, especially in the lower lying fringe lands, where surface irrigation water gets scarce and saline soils occur. Salinity control is done here by "sacrificial drainage" whereby part of the land is left fallow, so that here the water table is deeper than in the neighboring irrigated land with the result that it attracts the groundwater from irrigated area, taking the salts away from the cultivated fields and collecting them in the abandoned land, which becomes very salty. This land is sacrificed. The method is also called: "dry land drainage".

2. Geo-morphology, depth of the water table

The Garmsar project area is situated on an alluvial fan, a body of cone-shaped sediments built up by the Hableh Rud at the mountain front (Figure 2).
The apex of the fan at BoneKuh is at an elevation of 990 m above seas level. The radius of the fan is some 20 km.

At the head of the fan, the slope of the land is about 1:70. This gradient decreases to 1:200 at the base of the fan

At the apex, the river diverges into numerous branches radiating out over the fan.

The upper part of the fan consists of course and stony colluvial deposits. In the middle and lower parts, the course deposits are overlain by fine clayey sediments.

The base of the fan is a seepage zone where groundwater approaches the soil surface. The evaporation from the shallow water table (figure 3) is the cause of the salts in the Kavir desert.

Figure 1 The Garmsar alluvial fan seen from from space.

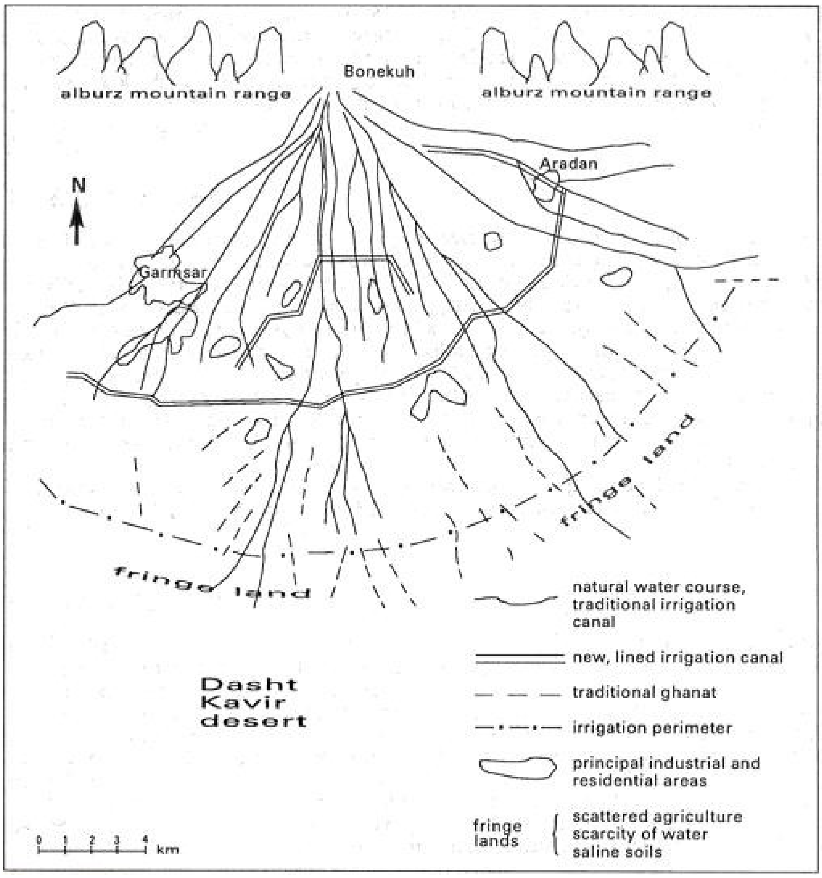


Figure 2. Sketch of the alluvial fan of Garmsar and its irrigation canal system.

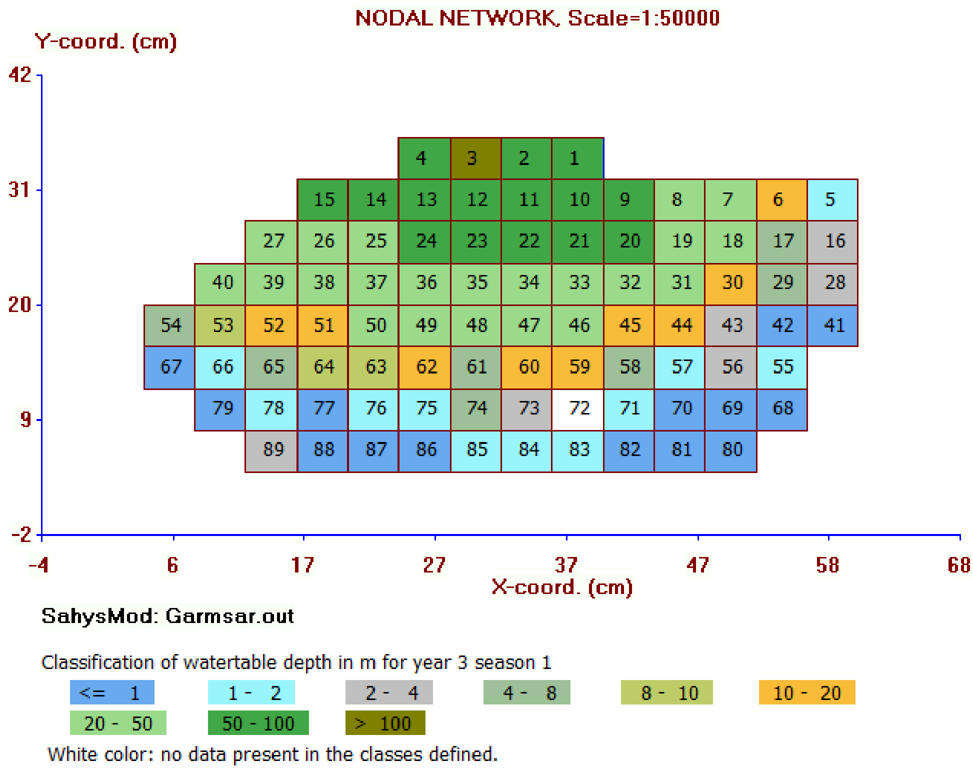


Figure 3. Map of the depth of the water table in year 3 season 1 calculated with SahysMod [Ref. 2]. The southern part of the region has the shallowest water tables.

3. Water resources

The Hableh Rud River is the main source of water. However, its supply is not dependable as the annual discharge varies fourfold (between 4 and 16 m^3/s on average). The annual mean discharge is 8.72 m^3/s or some 530 x 10^6 m^3/year. The highest monthly discharge occurs in March with on average 40 x 10^6 m^3, ranging widely from 10 x 10^6 to 100 x 10^6 m^3. The lowest discharge occurs in October with on average 14 x 10^6 m^3, ranging from 9 x 10^6 to 19 x 10^6 m^3.

The many river branches and the irrigated fields provide recharge to the aquifer. Since ancient times, groundwater in the Garmsar area has been exploited by ghanats (qanats, karezes) and shallow wells, mainly for irrigation of agricultural land, but also for household purposes. In the last decades, the number of deep-wells has increased sharply and the ghanats have fallen dry. The safe yield of the aquifer, whereby the water-table does not unduly drop, is unknown.

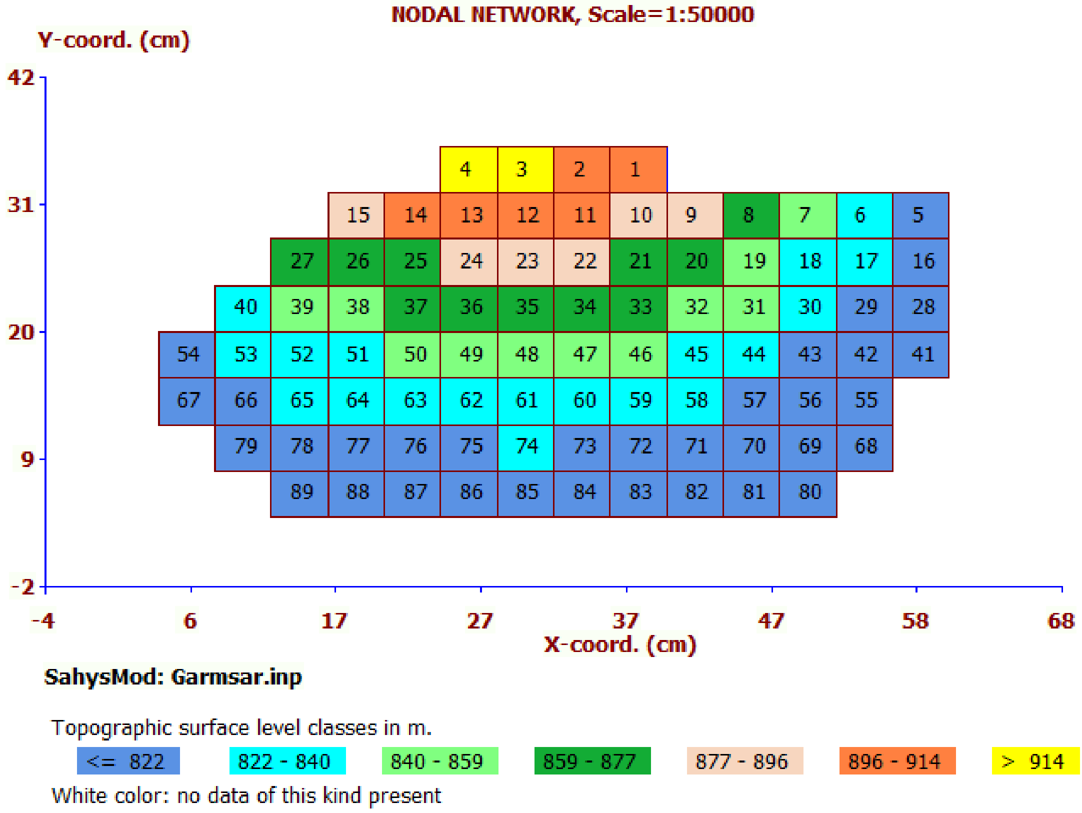


Figure 4. Topographic map of the Garmsar alluvial fan, prepared with the SahysMod model [Ref. 2], which is based on a polygonal network.

4. Geo-hydrology, hydraulic conductivity

The thickness of the aquifer, i.e. the depth of the impervious bedrock, varies from 250 m near the apex of the alluvial fan to 100 m in the lower parts (Figure 5).

The hydraulic transmissivity of the aquifer (i.e. the product of hydraulic conductivity in m/day and the thickness in m), found through pumping test from wells, is high. It varies from 4000 m^2/day in the upper part to 500 m^2/day in the lower part.

The aquifer is unconfined in the upper part. It is not known whether, at the lower part, semi-confined conditions (i.e. the permeable aquifer is overlain by a slowly permeable layer so that over-pressures in he aquifer develop) exist, but it is quite certain that purely confined, artesian, aquifers are absent.

The slope of the groundwater table in the upper part is quite flat and varies from 1:1400 in dry years (i.e. when the Hableh Rud brings relatively much water) to 1:700 in dry years (when the Hableh Rud brings relatively little water). Hence, the groundwater flow in dry years is half the flow in wet years. In wet years the water-table rises due to a high recharge, while in dry years it drops 20 m or more. In the lower part of the fan the slope is steeper and ranges from 1:100 to 1:400.

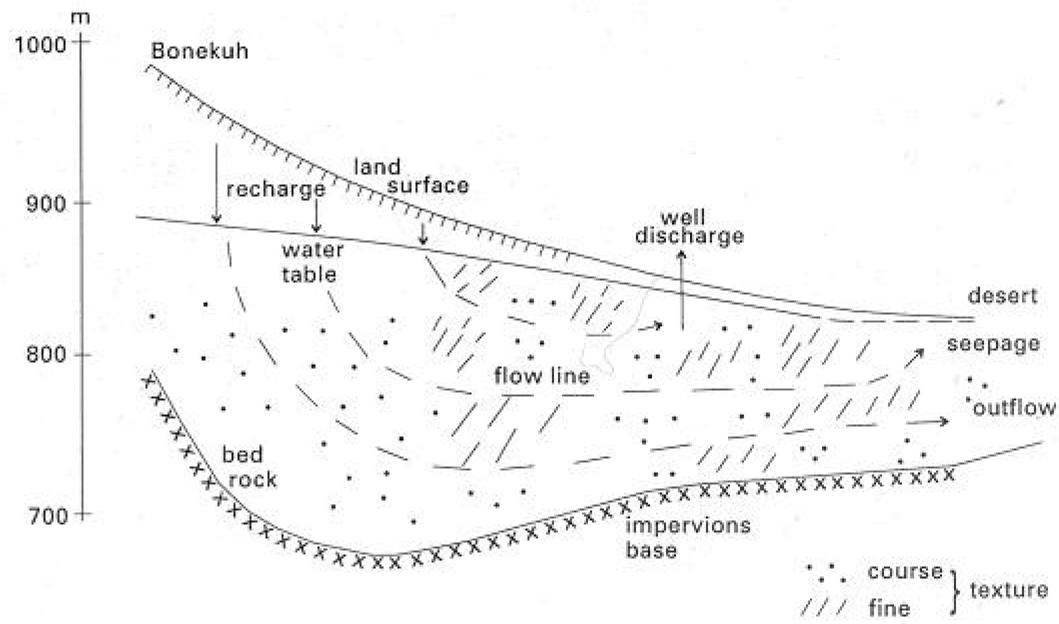


Figure 5. Cross-section schematically showing aquifer conditions of the Garmsar alluvial fan

The data on hydraulic conductivity used in the Sahysmod model [Ref. 2] are shown in figure 6 and 7 hereunder. The figures give the aquifer conductivity Kaq (m/day) at the boundaries of a polygon (node) in the first column to its neighbors (2nd column). The Ktop is not used as the aquifer is unconfned, it is only needed for semi-confined aquifers. It can be seen that the polygons in the upper part of the alluvial fan, having the lower node numbers, have higher hydraulic conductivities and those in the lower part with higher numbers.

from node number	to node number	Kaq m/day	Ktop m/day
1	90	71	-
	124	71	-
	10	62	-
	2	72	-
2	91	74	-
	1	72	-
	11	74	-
	3	74	-
3	92	74	-
	2	74	-
	12	74	-
	4	48	-
4	93	21	-
	3	48	-
	13	21	-

from node number	to node number	Kaq m/day	Ktop m/day
	85	3.75	-
	106	3.8	-
	87	3.4	-
87	76	7.4	-
	86	3.4	-
	105	2.9	-
	88	2.85	-
88	77	3.95	-
	87	2.85	-
	104	2.8	-
	89	2.4	-
89	78	3.3	-
	88	2.4	-
	103	2	-
	102	2	-

Figure 6. Parts of the input menu of SahysMod for hydraulic conductivity of the aquifer.

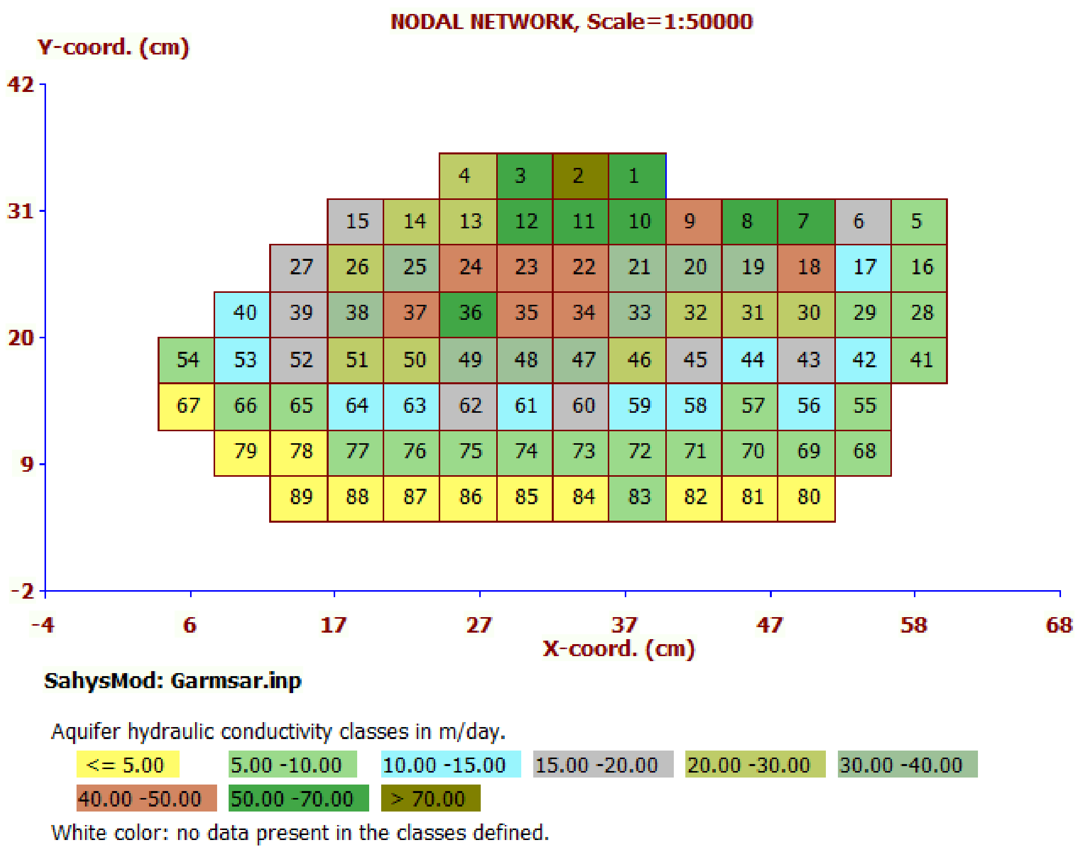


Figure 7. Map of the average hydraulic conductivity of the aquifer per polygon..

Some of the data on pumping from wells (Gw) used in the Shaysmod model are shown in figure 8. In several parts of the alluvial fans tube-wells are used to pump up irrigation water. The following figure shows the pumping rates per season. The polygons 58, 59 and 62 have tubewells operation, while 60 and 61 don't. The factor Frd, representing a reduction of the pumping rate to check effective drainage, is not applicable in this case.

Node nr	Season	Gw	Frd
-	number	m/season	fraction
58	1	0.151	-
	2	0.151	-
	3	0.302	-
59	1	0.029	-
	2	0.029	-
	3	0.059	-
60	1	0	-
	2	0	-
	3	0	-
61	1	0	-
	2	0	-
	3	0	-
62	1	0.052	-

Figure 8. Part of the input menu of SahysMod for pumping from tube-wells

The pumping from wells exerts a considerable influence on the groundwater hydraulics..

5. Groundwater flow

Figure 9 gives map of the net groundwater flow per polygon. When outflow is more than the inflow, the net flow is negative, otherwise it is positive.

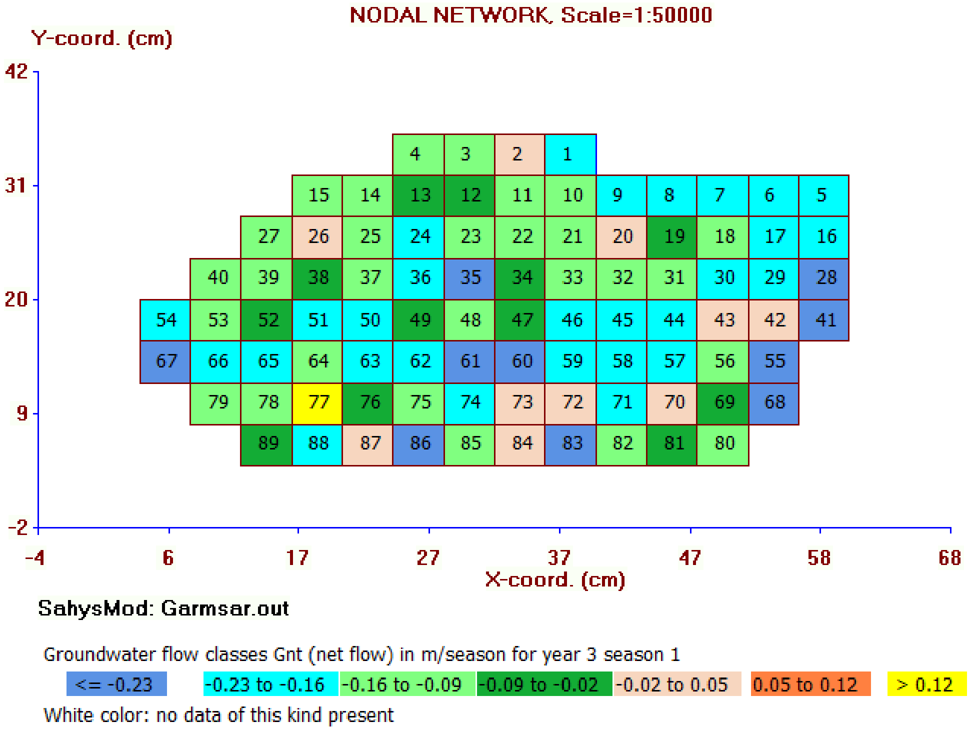


Figure 9. The net groundwater flow Gnt in m/season per polygon for year 3 season 1 as calculated by SahysMod for the Garmsar alluvial fan. Gnt is the difference between incoming and outgoing groundwater. When negative (blueish and greenish colors), the outgoing flow is more than the incoming flow and the aquifer is drained, else it is recharged.

A graph of all groundwater flow factors for all polygons is show in figure 10. The pattern is here difficult to see owing to the large number of polygons. Therefore, the SahysMod facility to select a smaller group of polygons has been used to present a similar graph for the polygons in a section over the area in an approximately North-South direction as an example (see figure 11). The G symbols used here stands for groundwater flow, the suffix t is used for the transition zone (the zone in which the direction of floe changes from horizontal to vertical and vice versa) whereas the subscript *q* is used for the mainly horizontal flow in the aquifer proper. The second subscript *i* stands for inflow, and *o* for outflow. The symbol Gtv stands for Gti – Gto, while the symbol Gaq stand for Gqi – Gqo.

The last symbols Gnt stands for Gtv + Gaq, which is the amount of flow used in figure 9. It can be seen in figure 9 that the Gnt (the black lines) in this selected section are negative, meaning that there is more outflow from the polygons than inflow.

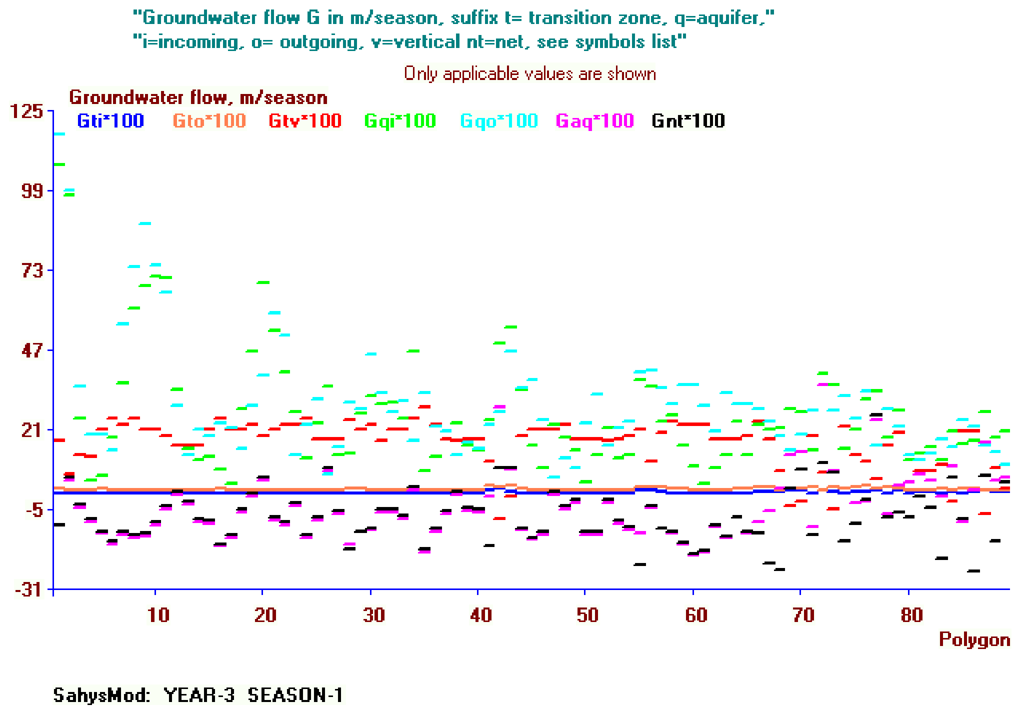


Figure 10. Graph giving an overview of all the subsoil groundwater flows. Owing to the large number of polygons, the picture is not very clear. Therefore, in figure 9, a selection of polygons is used to get a better picture.

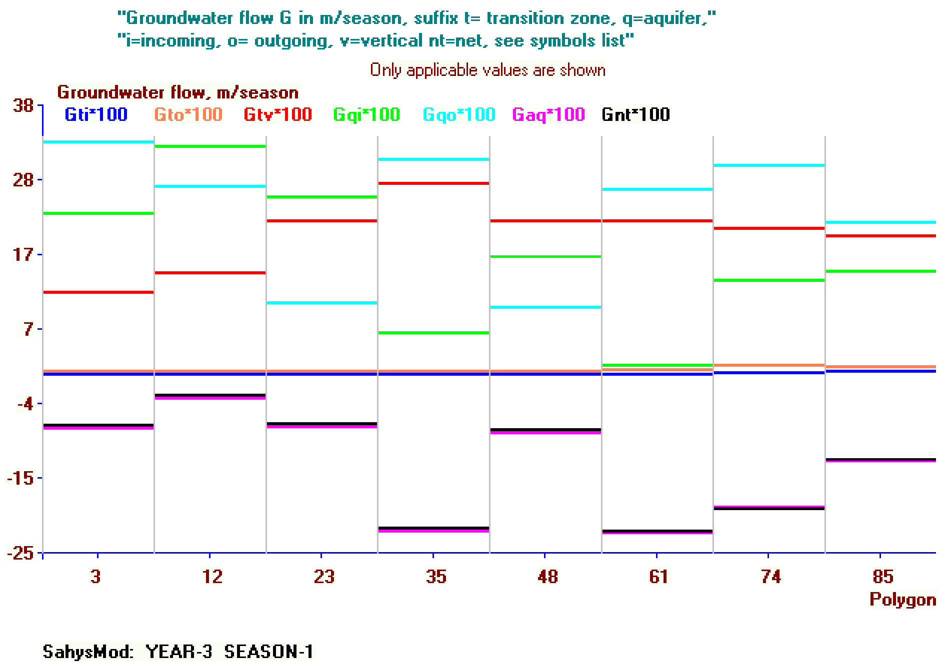


Figure 11. A selection of polygons in North-South direction gives a clearer picture of all the groundwater flows than in figure 8. In this cross-section over the area there is nopronounced trend.

6. Salinity of the groundwater

The salinity of the groundwater is influenced by the amount and salinity of the incoming and outgoing groundwater flows. SahysMod calculates these salinities and reports them in the output. See for example figure 12.

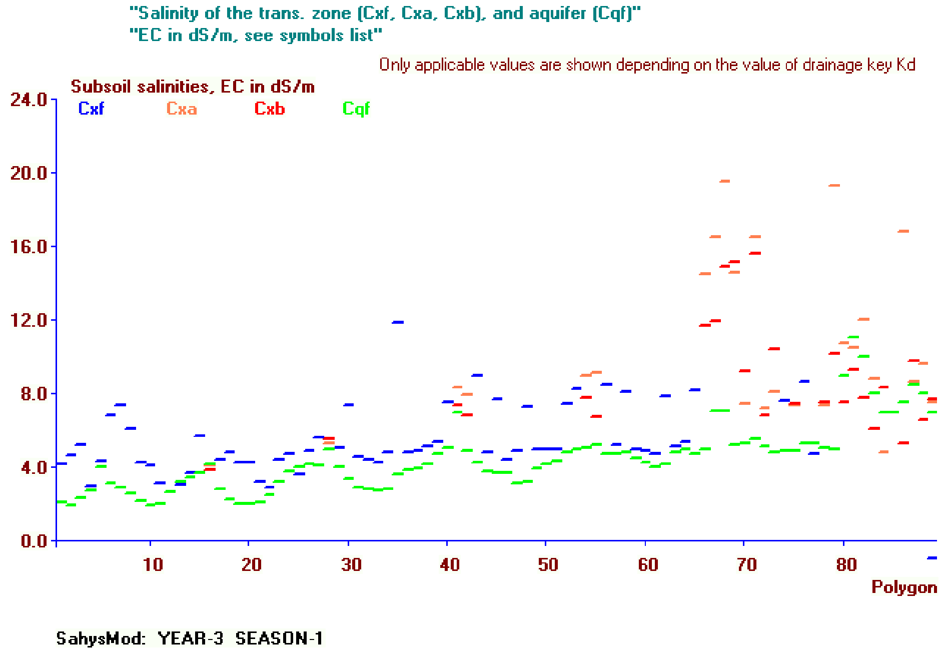


Figure 12. Salinity C *of the groundwater in dS/m. The suffix* x *stands for the transition zone and* qf *for aquifer (the green line segments). When a subsurface drainage system by ditches is present, the* Cx *values are given as* Cxa *(above drain level) and* Cxb *(below drain level) otherwise the symbol* Cxf *is used. Hence, the polygons with orange and red line segments have a subsurface drainage system, and they occur understandably mainly in the lower lying polygons with the higher node numbers, which also have a higher salinity.*

In Figure 12 it is seen that the salinity of the aquifer does not vary a lot over all the polygons, though there is a slight trend of increase towards the polygons with the higher node numbers. As was done in figure 6, a selection of polygons in a certain cross-section over the area, would give a clearer picture.

7. Subsurface drainage

When subsurface drainage systems are present, SahysMod calculates the drain discharge, the salinity of the drainage water, the effect on the depth of the water table and on the soil salinity in the course of the time. Examples are given in figure 13 and 14 for two neighboring polygons 77 (no drainage system) and 78 (drainage by ditches). It can be seen that in Polygon 10 the soil salinity tends to increase with time, while in polygon 78 there is a decreasing trend until it will remain constant at around 8 dS/m.

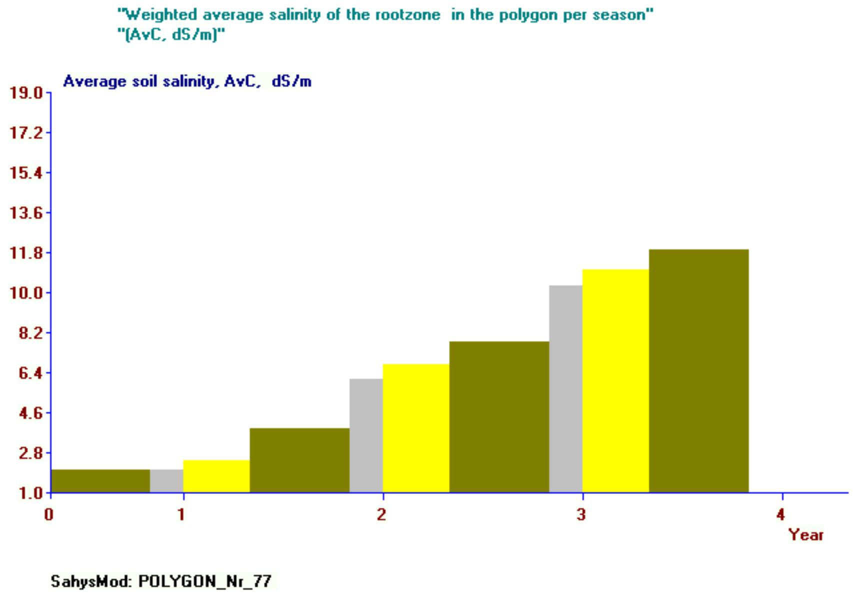


Figure 13. Development of the average soil salinity in the undrained polygon 77 in the course of the years. There are 3 seasons per year.

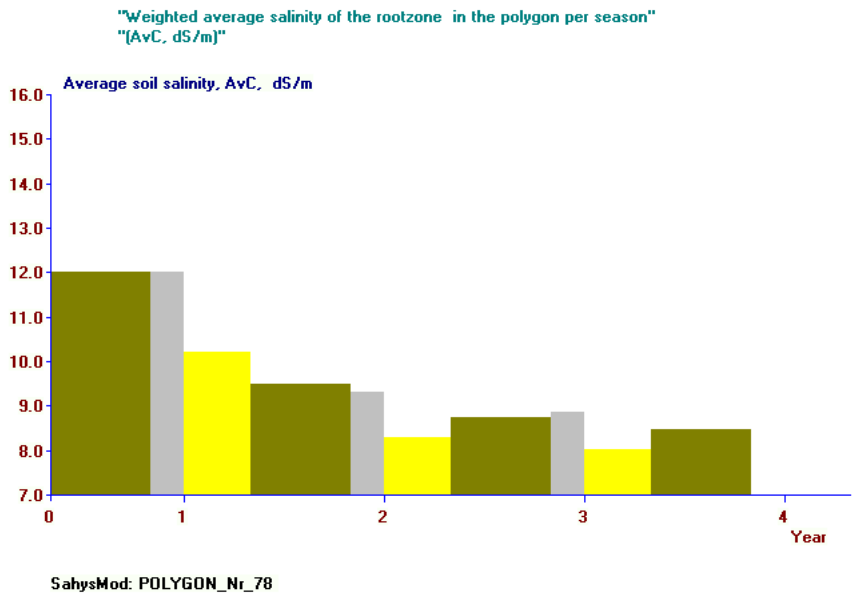


Figure 14. Development of the average soil salinity in the drained polygon 78 in the course of the years. There are 3 seasons per year.

8. Conclusion

The use of SahysMod promotes the understanding of all the relations between surface and subsurface hydrological factors, the soil and aquifer properties, the cropping patterns and the soil and water salinities. Further, it can be helpful to predict the effects of changes in the cropping patterns and the hydrological management of the area.

9. References

[Ref. 1] Agro-hydro-soil-salinity characteristics of the irrigated Garmsar alluvial fan, Iran, described with the SahysMod model. On line:
https://www.researchgate.net/publication/336680433_Agro-hydro-soil-salinity_characteristics_of_the_irrigated_Garmsar_alluvial_fan_Iran_described_with_the_SahysMod_model
or:
https://www.waterlog.info/pdf/Garmsar.pdf

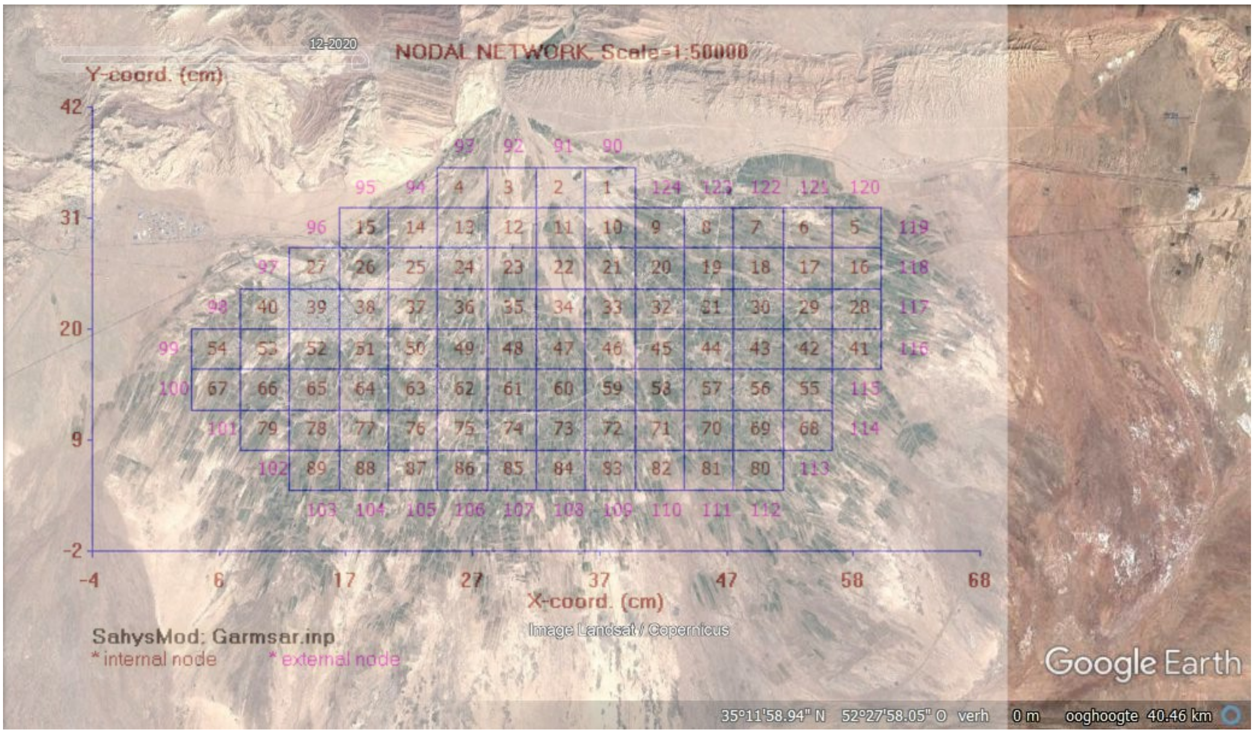
[Ref. 2] Sahysmod, free software for the agro-hydro-soil-salinity model. Download from:
https://www.waterlog.info/sahysmod.htm

See also:

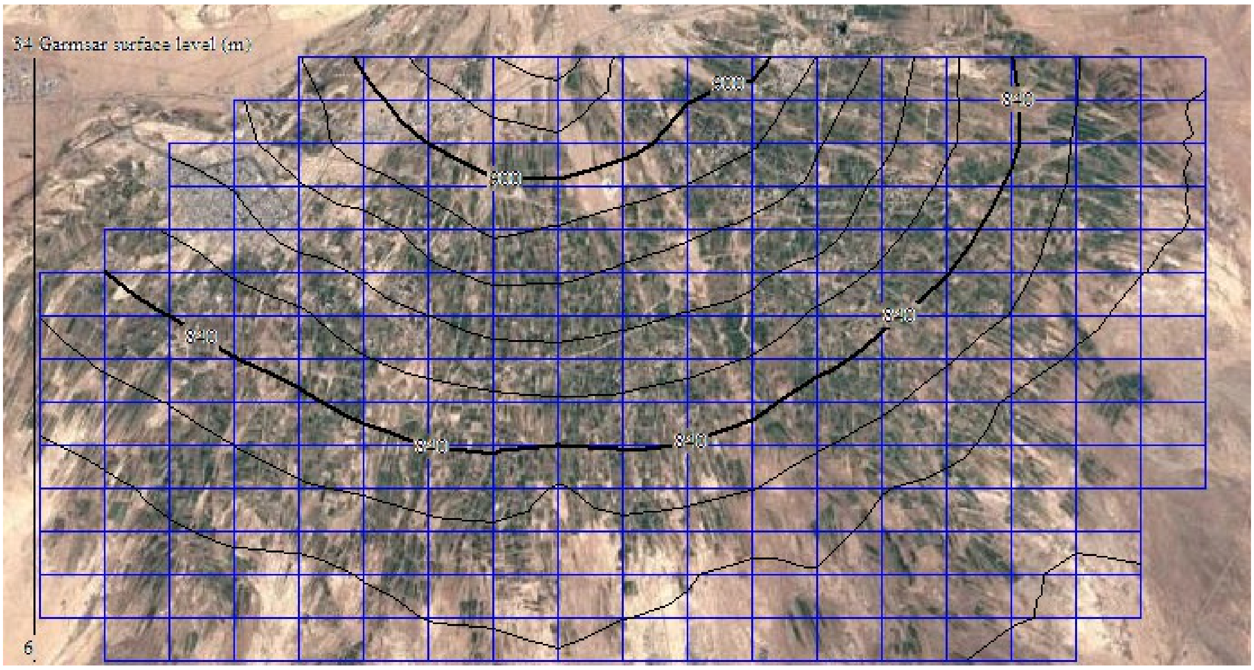
Irrigation, groundwater, wells, drainage and soil salinity control in the alluvial fan of Garmsar, Iran – assessments with the Sahysmod model. On line:
https://www.researchgate.net/publication/341607069_Irrigation_groundwater_wells_drainage_and_soil_salinity_control_in_the_alluvial_fan_of_Garmsar_Iran_-assessments_with_the_Sahysmod_model
or:
https://www.waterlog.info/pdf/Garmsar irrigation.pdf

List of publications in which SahysMod is used:
https://www.waterlog.info/pdf/sahyslist.pdf

10. *Appendix. SahysMod nodal networks overlaid on Google Earth*



The Garmsar alluvial fan (Google Earth) overlain by the SahysMod nodal network (blue lines) with internal/external polygon numbers using https://overlay.imageonline.co/



The Garmsar alluvial fan (Google Earth) overlain by the SahysMod nodal network (blue lines) and the surface level contour lines (black) made with the QuikGrid program, see https://www.waterlog.info/pdf/QuikgridHelp.pdf .