Agro-hydro-soil-salinity characteristics of the irrigated Garmsar alluvial fan, Iran, described with the SahysMod model.

R.J. Oosterbaan, 20-10-2019

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 agro-hydro-soil-salinity characteristics of the area are described in detail using the SahysMod model.

Contents

1. Introduction

Figure 1 shows a picture of the Garmsar alluvial fan from space.

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.

Figure 1 The Garmsar alluvial fan seen from from space.

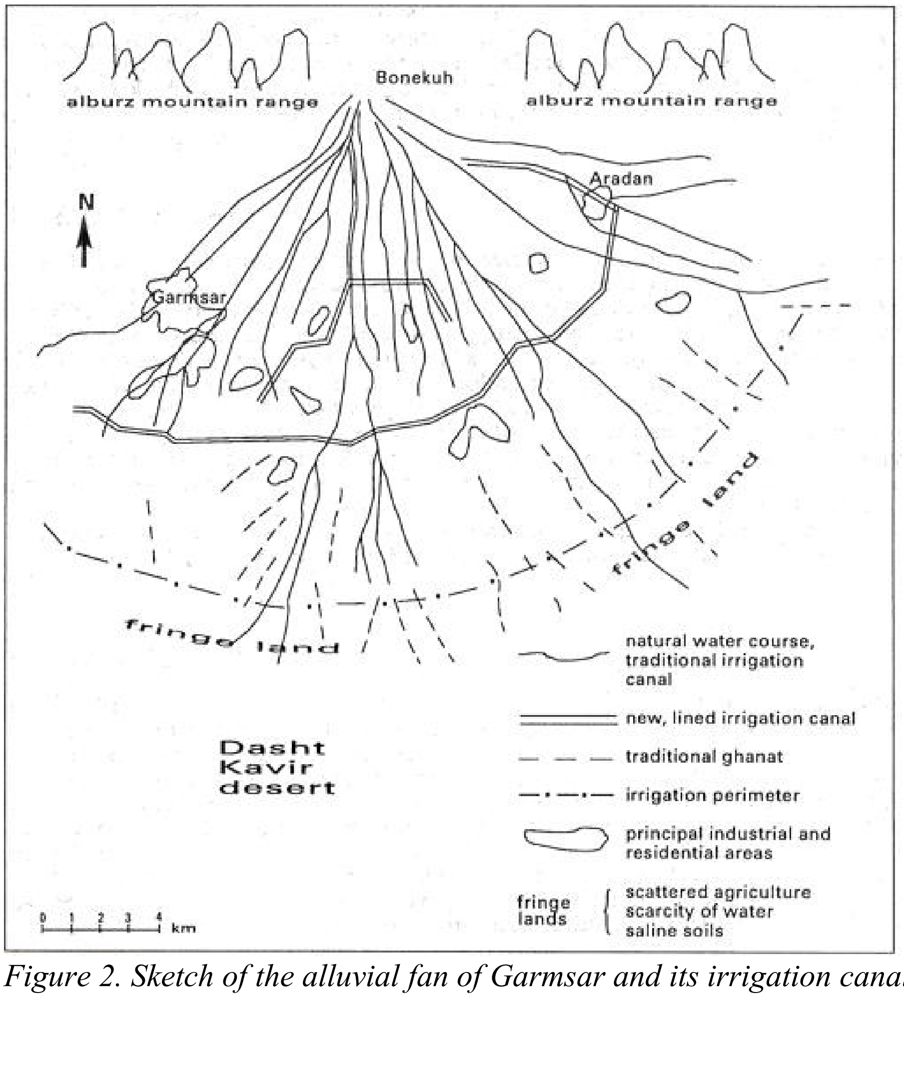


Figure 2. Sketch of the alluvial fan of Garmsar and its irrigation canal system.

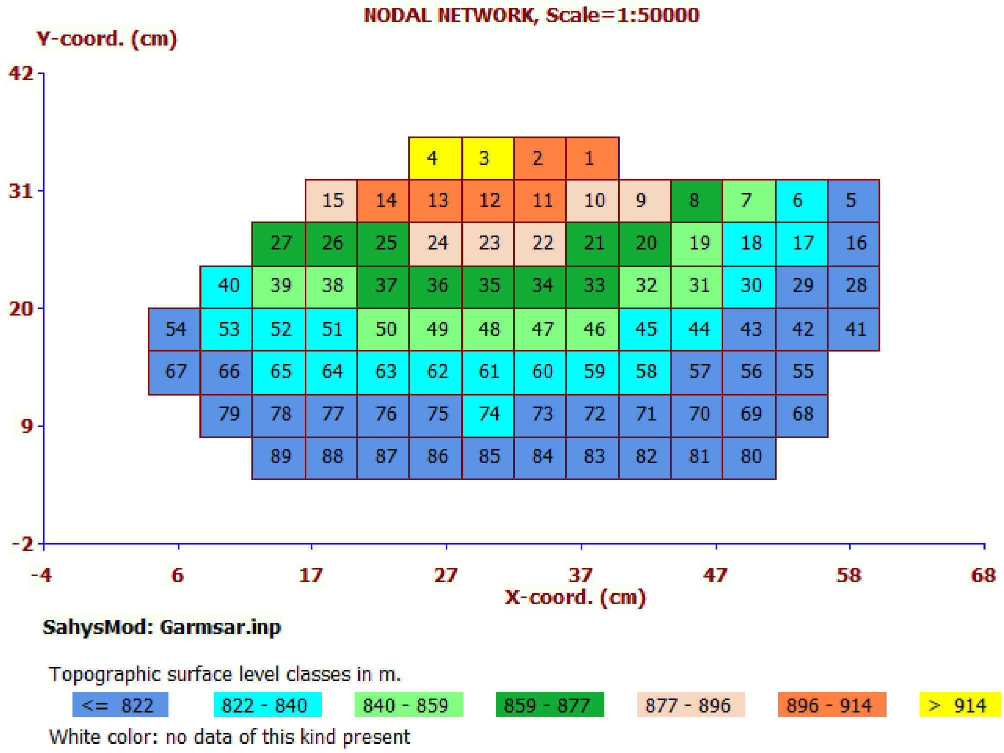
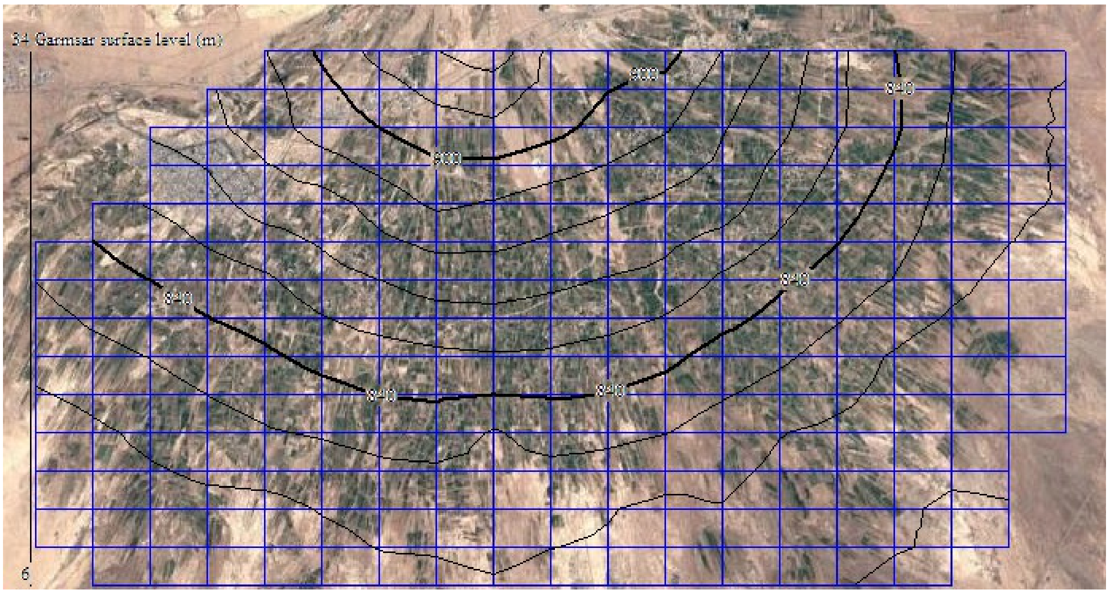


Figure 3. Topographic map of the Garmsar alluvial fan, prepared with the SahysMod model [Ref. 1], which is based on a polygonal network.



Garmsar alluvial fan (Google Earth) with overlay of the Sahysmod polygonal network (blue lines) and the surface level contour lines (black) made with the Quikgrid model

2. Climate

The climate of the Garmsar area is continental arid. The rainfall and humidity are low. The average annual rainfall is 120 mm and occurs mainly from January to March.

The summers are hot, the winters cold. The monthly average temperature ranges from 4^0C in January with a minimum of -10^0C, to 32^0C in July with a maximum of 42^0C.

The potential evaporation is high. The class-A pan evaporation has an annual value of 3200 mm. The monthly values range from 50 mm in January to 500 mm in July.

Wind speeds are modest. The average annual wind velocity is 11 km/hr. The maximum velocity is 40 km/hr. The windiest month is April, with an average velocity of 15 km/hr.

3. Geo-mophology, 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 is the cause of the salts in the Kavir desert.

SahysMod [Ref.1] calculates the depth of the water table from the hydrological factors, the aquifer characteristics, and groundwater flow equations. Figure 4 gives a graph of the depth of the water table per polygon, from which it is seen that the depth is vary variable ranging from very deep to shallow.

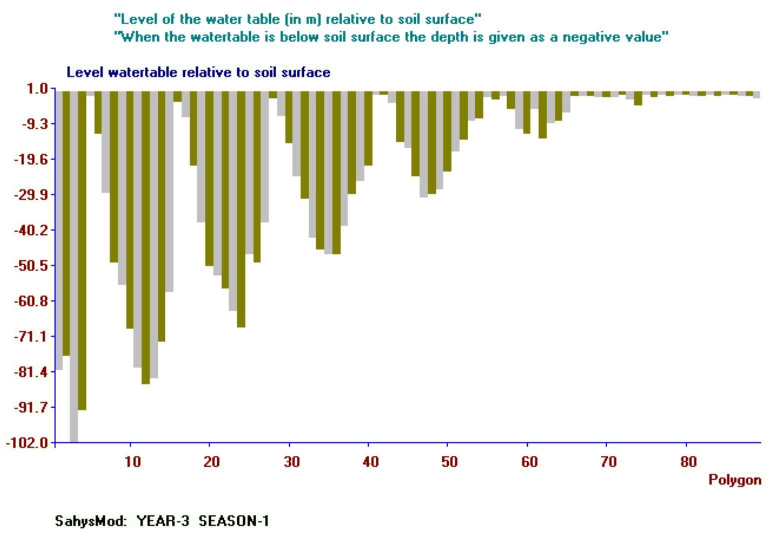


Figure 4. Result of SahysMod calculations of the depth of the water table per polygon in year 3 season 1.

Figure 5 shows a map with standard (automatic) classification of the depth of the water table. As the shallow water tables are more critical with respect to soil salinization, SahysMod provides the opportunity to manually change the class limits and map colors as demonstrated in figure 6

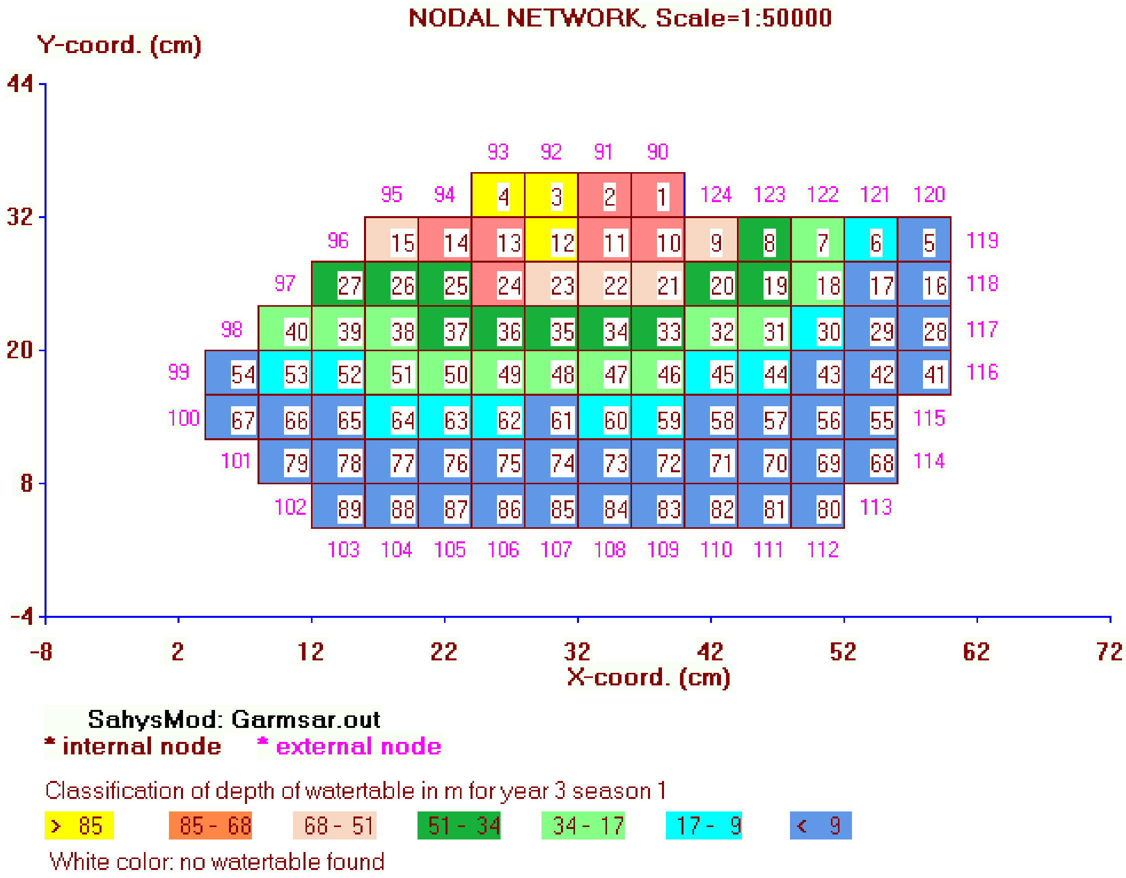


Figure 5. Map of the depth of the water table in year 3 season 1 calculated with SahysMod. The southern part of the region has the shallowest water tables.

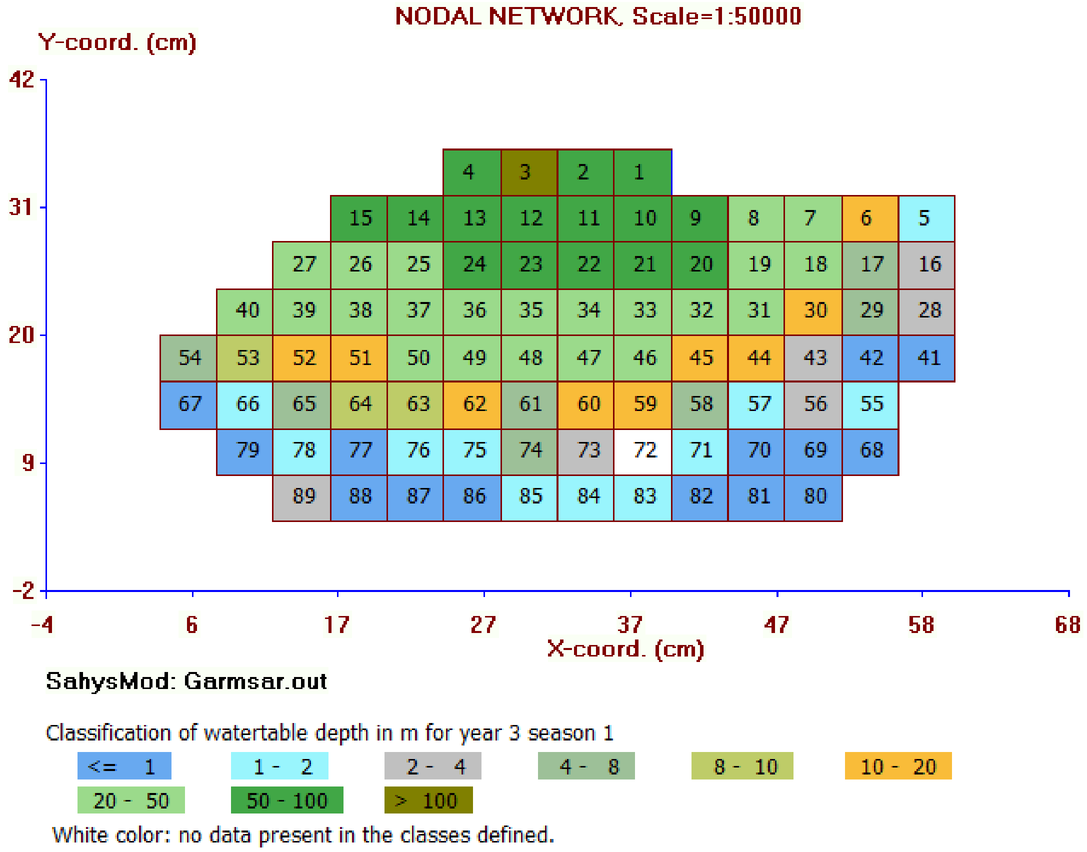


Figure 6. Manually adjusted classes of the water table depth with emphasis on narrow class limits for the shallow water tables. Compare with figure 4.

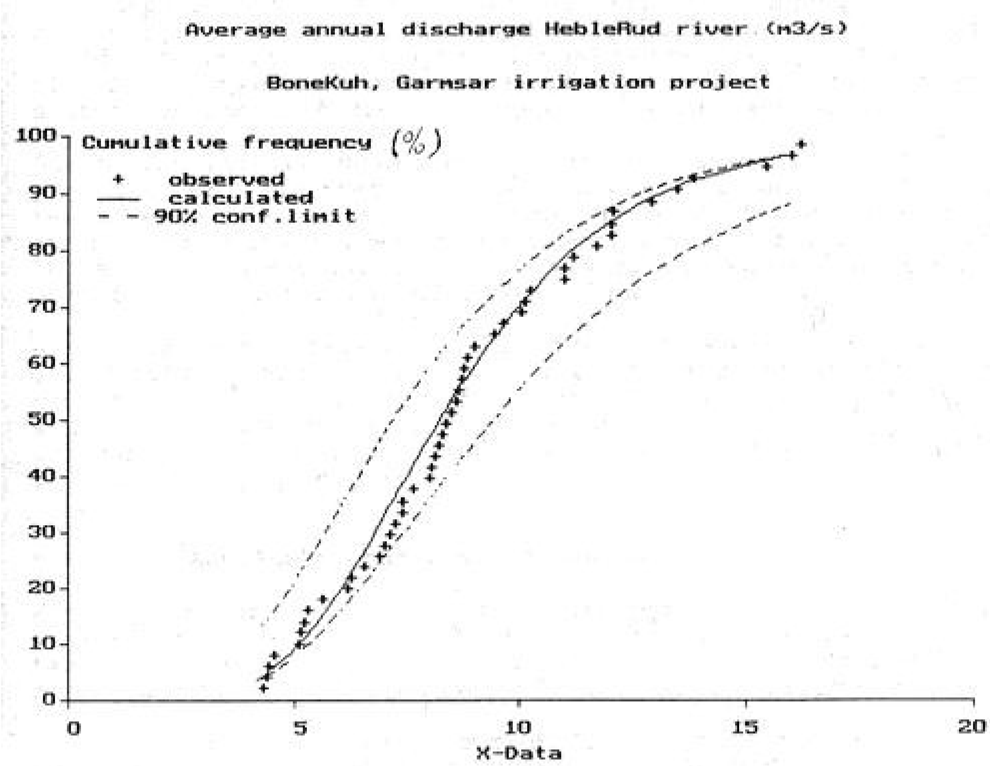
4. Water resources

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.

5. Discharge statistics of the Hableh Rud river

A cumulative frequency distribution of the average annual discharge of the Hableh Rud at BoneKuh in terms of m^3/s has been prepared with the CumFreq program [Ref. 2]. The results are shown in Figure 7.
It is recommended that the frequency distributions are also made in terms of MCM per month.



Results of the CumFreq program, Cumulative frequency analysis

---

Average annual discharge (X) of the Heblerud river (m3/s)

The cumulative frequency function (F, %) is double exponential:
F = exp[-exp{-(0.38X-2.78)}]

Mode: 7.28 Median: 8.26 Average: 8.72 St.Dev: 3.05

Figure 7. Probability distribution of the average annual discarge of the Hableh Rud river at BoneKuh, where the river enters the alluvial fan.

The above figure tells us that the annual discharge of the Hableh Rud river is very variable and ranges from 5 to 15 m3/sec on average.

6. Water quality

The water of the Hableh Rud at BoneKuh has a salinity of about 1 g/l or an electric conductivity (EC) of 1.7 dS/m. This signifies a medium quality for irrigation. In the major part of the alluvial fan, the natural drainage to the underground is high. Hence, enough leaching can take place to avoid soil salinity problems.

Occasionally the river produces “red floods”, when the water is sediment laden and highly saline (EC > 10 dS/m). The floods are the result of rain-showers in the lower parts of the Alburz mountains, where saline marls dominate.

The major part (90%) of the salts consists of chlorides and sulfates. Sodium salts (60%) are slightly in excess of calcium and magnesium (40%). The residual sodium carbonate content is low, hence the water is not giving serious alkalinity problems.

The salinity of the groundwater is very similar to that of the surface water, except that the total salt concentration is about double that of the river water. With sufficient leaching, the groundwater can be confidently used for irrigation. The aquifer itself is also continuously subject to flushing, as a part of the groundwater proceeds permanently to the Dasht-e-Kavir desert. Therefore, deterioration of the groundwater quality does not occur.

7. 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 8).

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.

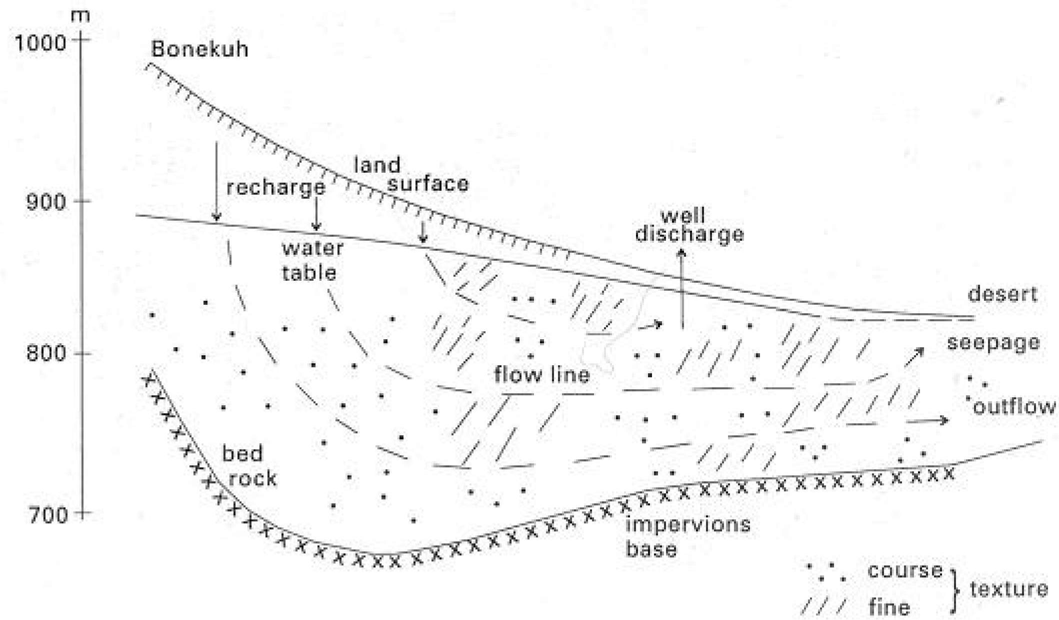
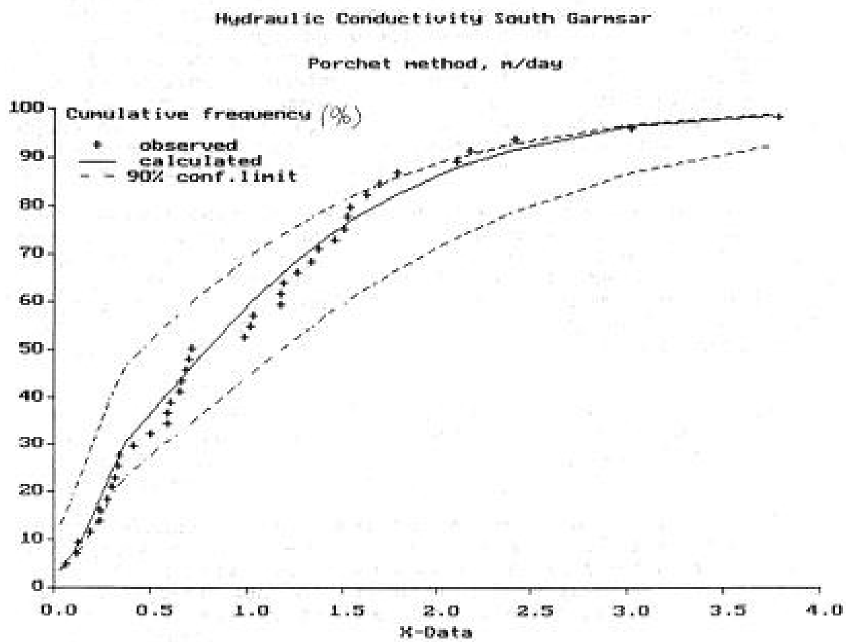


Figure 8. Cross-section schematically showing aquifer conditions of the Garmsar alluvial fan

Abvarzan Co. has been hundreds of measurements of the soil's hydraulic conductivity in the fringe lands of the Garmsar irrigation scheme. The majority of the measurements were made at about 2 m depth. As the water table was mostly deeper than 2 m, the Porchet infiltration method (also called inversed auger-hole method) was used for measurements above the water table [Ref. 3].

Given the geo-hydrological buildup of the area, it is unlikely that flow-impeding soil layers are found within 10 m depth.

Figure 9 shows the cumulative frequency distribution of the first 50 measurements (up to hole H58) according to the Porchet method excluding 5 measurements with hydraulic conductivity values greater than 5 m/day. The figure was made with the CumFreq computer program made available to Abvarzan Co. The figure shows that the soil's hydraulic conductivity, with and average of 1 m/day, is fairly high. This confirms that soil alkalinity problems, and the associated soil structure decline, are not present and that the soils are well drainable. Nevertheless, there is a large variation in results.



Results of the CumFreq program, Cumulative frequency analysis

Hydraulic conductivity South Garmsar, Porchet method (X, m/day)

The cumulative frequency function (F, %) is twice double exponential:

Breakpoint: P = 0.32
X < P : F = exp[-exp{-(3.13X-1.28)}]
X > P : F = exp[-exp{-(1.28X-0.65)}]

Average X: 0.99 Median X: 0.67 St.Dev. X: 0.83

Figure 9. Cumulative frequency distribution of hydraulic conductivity which varies from 0.1 to 4 m/day [Ref.2]

It is recommended to repeat the analysis with CumFreq for the remaining observations on hydraulic conductivity. It can also be seen whether there is a systematic difference between hydraulic conductivities of the southwestern, the southern, and the southeastern fringe lands. Further it can be analyzed whether the Porchet method and the Hooghoudt auger-hole method, for measurements below the water table, give significant differences.

8. Irrigation and drainage

Of old, irrigation was performed by tapping water from the numerous branches of the Hableh Rud River fanning out over the area. The water was led from here into earthen irrigation canals. Shallow pumped wells were used to supplement the surface water, especially in summer and in periods of drought. Towards the fringes of the alluvial fan at least 30 ghanats (artificial underground galleries) were dug to abstract water from the aquifer by gravity.

In the mid-eighties, a new irrigation system was constructed and in 1990 it was put into operation. The main purpose of the system was to reduce the deep percolation losses from the many natural watercourses (Figure 2).

The new system consists of lined canals and is characterized by a ring or belt canal, running through the middle of the fan along a circular layout perpendicular to the down-sloping original watercourses. This has drastically changed the distribution system of irrigation water.

In addition, more than 400 deep tube-wells have replaced the shallow wells and ghanats.

In the fringe-lands below the area brought under the new irrigation system, irrigation is occasionally practiced by farmers-groups who avail of the excess waters from the new irrigation system, if any, and the flood waters in he natural watercourses next to pumped tube-well water.

In the area brought under the new irrigation system, drainage systems are not required. There are no problems of water-logging. Occasional river-floods area easily routed through the natural watercourses. Additional subsurface drainage is not needed, as the natural underground drainage capacity of the aquifer is ample. The recently established tube-wells have further increased the discharge of groundwater.

Drainage system can be found occasionally in the lower parts of the fan to combat problems of shallow water-tables and water-logging in the wet periods when the Hableh Rud brings relatively large quantities of water consecutively during a number of years. Then, the recharge of the aquifer in the irrigated area increases and the groundwater abstraction decreases so that the water-tables may rise. Such periods do not occur regularly.

The drainage systems in the lower parts consist of open ditch-drains and have been installed through contractors and with Agricultural Bank loans.

9. Distribution of irrigation water

At present, the distribution of surface irrigation water to the villages is determined by the Garmsar water Authority on the basis of water-rights and verbal agreements and communications with the water users in the absence of a written manual. The authority also maintains the irrigation canals and structures. The structures are sometimes re-designed to adjust to verbally communicated needs.

The water-rights are expressed in *sang*, a measure of continuous flow of about 10 l/s, but in practice it varies from 10 to more than 15 l/s. The water is delivered to about 100 tertiary units (often a village), within which the water is distributed by 12-day rotations amongst the farmers who each are entitled to receive the authorized *sangs* for a fixed number of hours during each rotation period. The village communities are, at the same, time water-user associations who take care of the water-distribution within the tertiary unit and they maintain the tertiary canals.

The deep tube-wells are privately owned. The drilling of wells is subject to license. Recently, the licensing has stopped for fear of over-exploitation of the aquifer. It appears that no operational rules are applied to the wells.

The drainage canals at the fringes of the irrigation perimeter are supposed to be maintained by the respective farmers groups.

10. Cropping patterns

In Table 1 and 2 an attempt is made to summarize the cropping sequences and maximum crop evaporation during the agricultural year 1998/1999.

Roughly the cropped area occupies 30% of the land each season, while 70% is left fallow. The winter crops are mainly wheat and barley, while the summer crops are cotton and melons.

In June the winter crops are harvested and in May the summer crops are planted. These two months constitute a period of overlap and consequently the fallow land is about 40%.

Over the years, the fallow land is fully rotated with the cropped land.

YEARLY CROPPED AREA AND CONSUMPTIVE USE IN GARMSAR

crop	ha.	season evap m3/ha	total evap MCM	length season days	mean daily evap mm	from month	to month
melon	5262	6630	34.89	180	3.68	May	Oct
cotton	5173	9240	47.80	180	5.13	May	Oct
wheat	8440	5015	42.33	240	2.09	Nov	Jun
barley	5612	4513	25.33	240	1.88	Nov	Jun
trees	1168	7250	8.47	360	2.01	Jan	Dec
alfalfa	191	15086	2.88	360	4.19	Jan	Dec
TOTAL	25846		161.69				

Table 1

Table 2

MONTHLY CROPPED AREA AND CONSUMPTIVE USE IN GARMSAR
(1 : cropped, 0 : no crop)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
melon	0	0	0	0	1	1	1	1	1	1	0	0
cotton	0	0	0	0	1	1	1	1	1	1	0	0
wheat	1	1	1	1	1	1	0	0	0	0	1	1
barley	1	1	1	1	1	1	0	0	0	0	1	1
trees	1	1	1	1	1	1	1	1	1	1	1	1
alfalfa	1	1	1	1	1	1	1	1	1	1	1	1
evap MCM	9.40	9.40	9.40	9.40	23.18	23.18	14.73	14.73	14.73	14.73	9.40	9.40
crop area	15411	15411	15411	15411	25846	25846	11794	11794	11794	11794	15411	15411
evap mm/d	1.83	1.83	1.83	1.83	2.69	2.69	3.75	3.75	3.75	3.75	1.83	1.83
monthly/yearly cropped area (%) :	59.6	59.6	59.6	59.6	100.0	100.0	45.6	45.6	45.6	45.6	59.6	59.6
monthly cropped/irrigable area (%) :	38.5	38.5	38.5	38.5	64.6	64.6	29.5	29.5	29.5	29.5	38.5	38.5

Note: The monthly evaporation is calculated from the mean daily crop evaporations per season weighted for crop area. Hence, for each crop, correction is required to account for monthly variations

Table 2

11. Soil water balances

As the annual rainfall is very small (on average only some 120 mm), the Hableh Rud is the main source of water in the Garmsar area. It brings on average some 275 MCM per year. The river water is mainly used for irrigation (on average possible some 210 MCM per year). The irrigation water is partly consumed by the crops or evaporated and partly it recharges the aquifer. Another portion of water given to the aquifer is by means of infiltration basins (on average some 15 MCM per year). The remainder (about 50 MCM per year) leaves the Garmsar area through the flood-ways to the lower lying desert region.

The yearly average recharge to the aquifer by deep percolation losses from the surface irrigation, at an overall irrigation efficiency of 40%, will be roughly 120 MCM. It is estimated that the average annual pumping rate from wells is about 175 MCM. A small fraction of the pumped water (say 15 MCM) is used for domestic and industrial purposes. The remainder (160 MCM) serves the irrigation of agricultural lands. But again, due to the low irrigation efficiency, about 90 MCM returns to the aquifer to be either lost as groundwater outflow to the desert or pumped up again.

Irrigations from surface and groundwater together satisfy the consumptive use of the agricultural crops (plus the direct evaporation from the land) to the tune of 160 MCM/year, (90 from surface water and 70 from groundwater).

The annual net recharge to the aquifer (60 MCM, consisting of 120 MCM deep percolation losses from surface irrigation, 90 MCM deep percolation losses of pumped well water, 15 MCM from infiltration basins, minus 175 MCM pumping from wells) will be either stored to raise the groundwater level or discharged as underground flow into the desert.

Figure 10a and 4b show a general picture of the annual water balance of the Garmsar plain. The figure is crude and it is recommended that it is verified and updated each year so that proper water-balance records will be obtained.

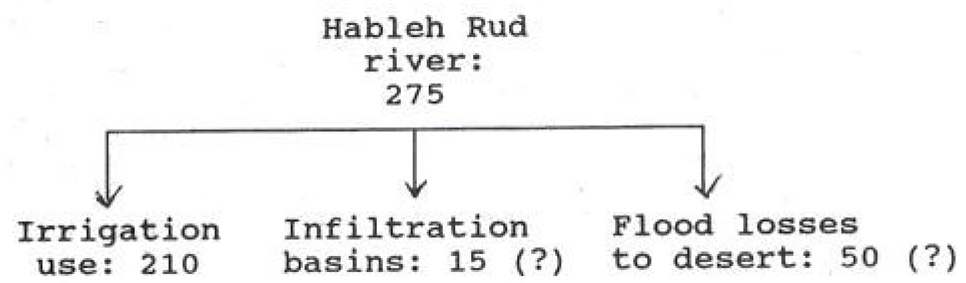


Figure 10a. Surface water balances, estimated annual average in MCM

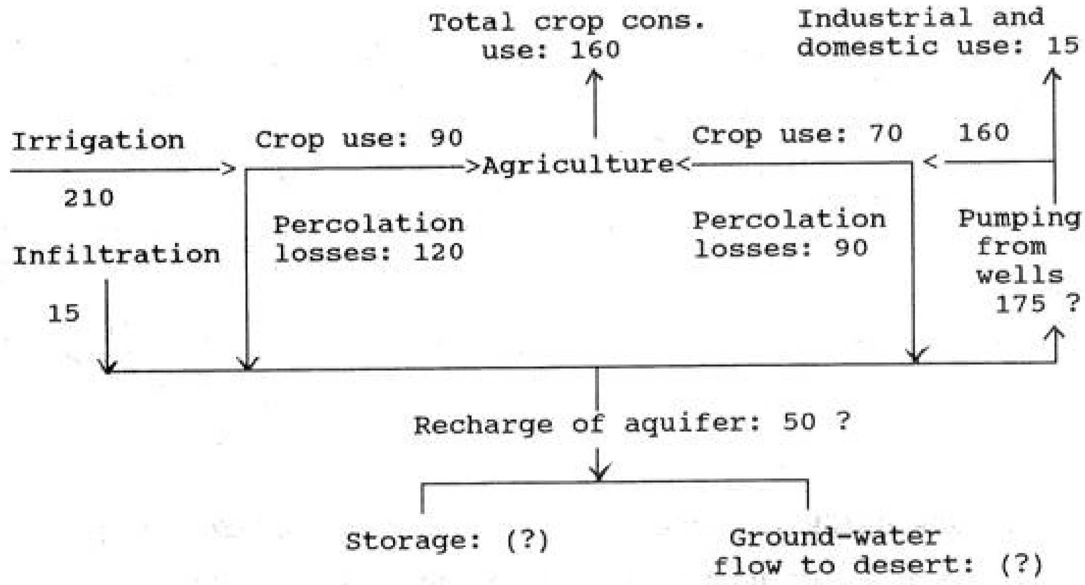


Figure 10b. Irrigation and groundwater balances, estimated annual average in MCM

12. Soils and salinity

12a. General

Soil salinity and alkalinity problems are reported to occur in the lower lying fringe-lands of the irrigation scheme (figure 11). These fringes are used for agriculture, mainly by *moshaa* groups, to whom the land were given free of charge. In the fringes one encounters an irregular mixture of cultivated lands, temporary fallow lands and unused lands. There is a scarcity of water, as the lands are outside the irrigation scheme proper. The *moshaa* groups use excess water from the irrigation scheme supplemented by groundwater.

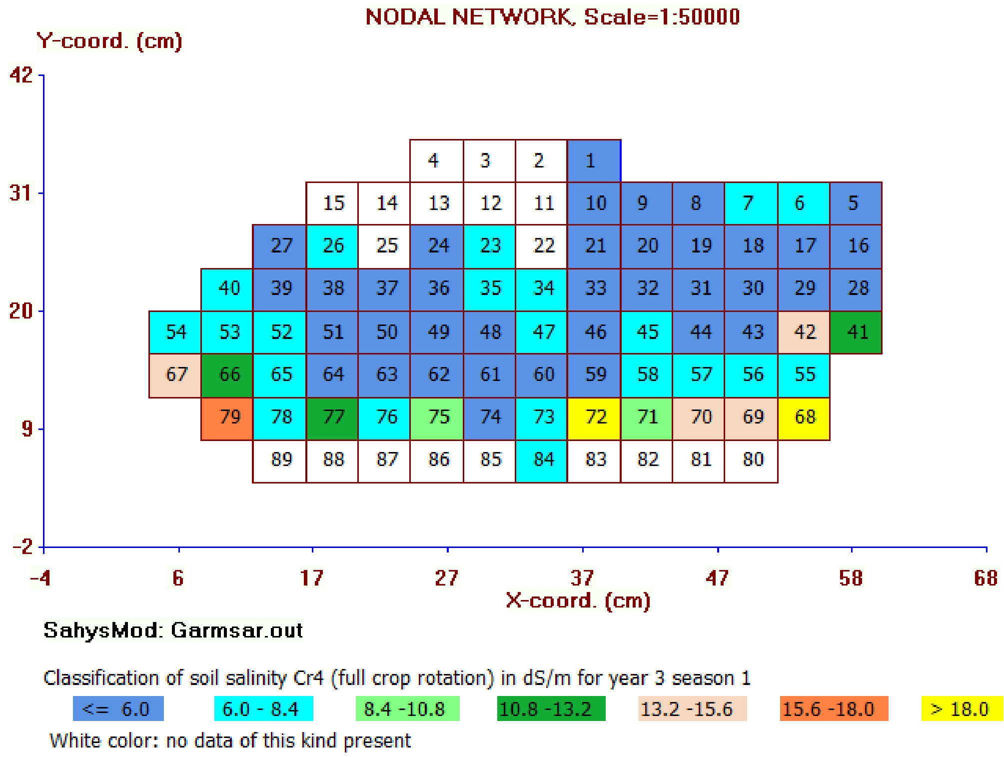
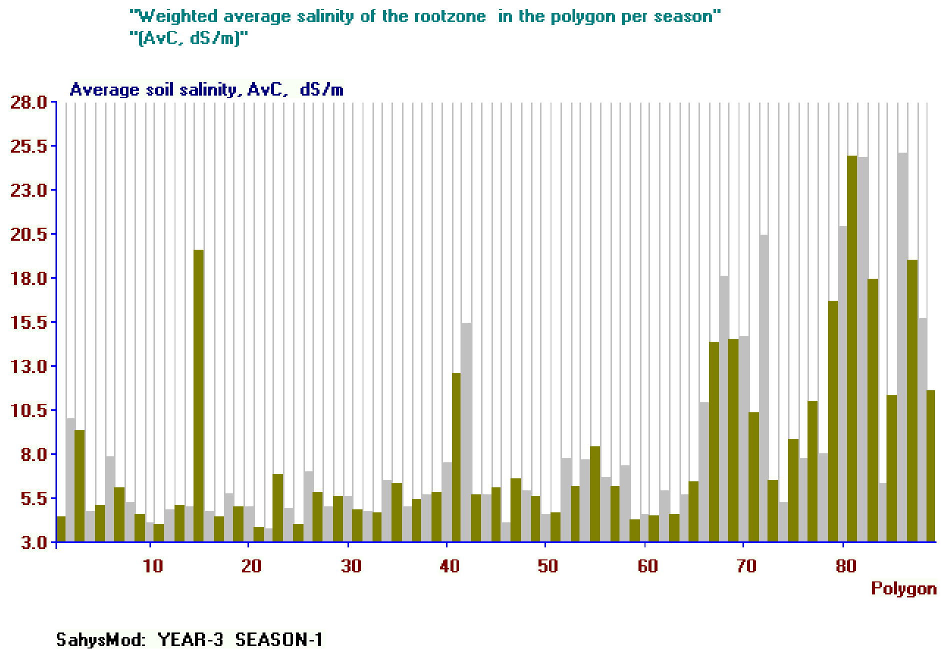


Figure 11. Map of soil salinity classes for Cr4, being the salinity of the land that is in full cropping rotation over the seasons. White color indicates that the area is not under full rotation and that permanent fallow land occurs. Map prepared with SahysMod [Ref. 1] which model calculates the soil salinity on the basis of water balances.

The following graph shows the average salinity per polygon in year 3 season 1, irrespective of the crop rotation type used in figure 11. It can be seen that, in general, the higher polygon numbers, which are closer to the foot of the alluvial fan, have the highest average salinity.

Polygon 15, that has not been classified in figure 11 because there is no full cropping rotation, shows a relatively high salinity due to the presence of permanently fallow land.



The water scarcity at the foot of the alluvial fan is the main cause of the inability to reclaim the major part of the saline soils. However, within the cultivated lands, the *moshaa* groups appear to provide sufficient water, over an above the amount of water required for crop consumptive use, so that they are regularly leached and have acceptable soil salinities.

To cope with the leaching water, some form of land drainage must be present. This can be natural and/or artificial subsurface drainage. This will be discussed further below.

12b. Soil salinity, sodicity, and alkalinity classification

The classification of soil salinity, sodicity, and alkalinity is based on the criteria published in the Handbook 60 of the USA Salinity Laboratory, 1960. Since then the insight into sodicity and alkalinity have undergone a change, as reported in the FAO Soils Bulletin authored by Yadav and Abrol.

When the sodicity/alkalinity is caused by sodium salts, and mainly sodium chloride, as is the case in Garmsar, a separate alkalinity classification is not required and it suffices to classify the soils according to the salinity status only. The reason is that saline soils are also sodic, but upon reclamation by leaching, they are usually converted into normal non-saline soils, without sodicity and alkalinity problems. Hence the dispersion problems of the soil's clay particles due to alkalinity will probably not occur and dangerous loss of soil structure need not be feared. The latter problems usually arise exclusively when the soils are sodic and non-saline while the sodicity is owing to the presence of sodium carbonates, which leads to immobilization of calcium, that precipitates as lime, as well as to the formation of sodium-hydroxide giving high pH values (pH > 9). Fortunately, the pH values of the soils in Garmsar are less than 8.5

The fact that many soils in Garmsar are rich in calcium (the soils contain up to 30% of lime) and that the surface and ground waters contain appreciable amounts of calcium sulfate (gypsum) also help to control the sodicity/alkalinity problems, if any. The results of the hydraulic conductivity measurements, done in these soils by Abvarzan Co. , support this conclusion as will be explained later.

It is concluded that the sodicity problems of the soils in the lower parts of the Garmsar area should rather be considered as salinity than alkalinity problems. The reclamation of these soils can be done using simple leaching techniques without applying chemical amendments and /or special reclamation crops. As the soils undoubtedly also contain gypsum (the quantity is to be verified), the leaching process will be further enhanced.

13. Use of saline soils

During the field visits it became apparent that the farmers are able to bring about a good crop production in the saline fringes of the Garmsar area. It can be concluded that the soils have a good production capacity and that the farmers are able to control the salinity problems to some extent. The main problem appears to be scarcity of irrigation water, which prevents all of the land to be taken into cultivation.

It is advisable to carry out regular soil surveys twice a year (e.g. in March and October) if farmers' fields to judge the severity and extent of the salt problems. It will not be required to carry out such a survey in the unused lands as these are not subject to leaching so that they will be quite saline anyway, and this salinity is irrelevant because the unused lands cannot be taken into cultivation due to the water scarcity. Many of the existing data on soil salinity were obtained through standard soil surveys including the un-farmed wastelands. Therefore, the data are representative for the farm-land problems and the probably give an un-representative picture of the situation.

If, owing to an increase of water resources, more land can be brought under irrigated agriculture, the presently uncultivated saline lands can probably be reclaimed fairly easily. The can be appreciated from the fact that the lands that are actually cultivated have minor or no salinity problems.

It is recommended to acquire EM38 electro-magnetic apparatus for the rapid survey of soil salinity over the entire depth of the root zone.

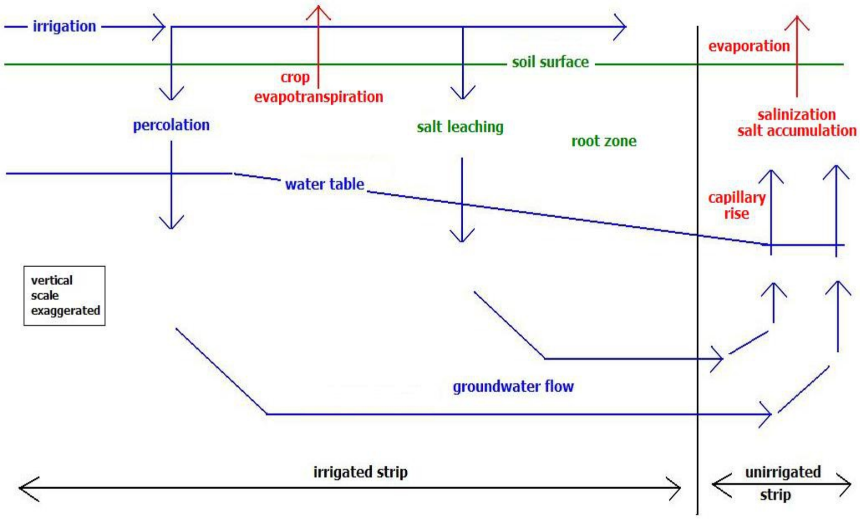
It is also advisable to apply a combined groundwater and agro-hydro-salinity model like SahysMod to predict the salinity development under irrigated conditions and to assess the amount of groundwater available for additional irrigation in the fringe lands by intercepting it through deep wells. It can then be verified how much groundwater reaches the low lying desert areas where it will eventually evaporate and it will be lost for agricultural production.

The possible application of SahysMod is further discussed later.

14. Soil salinity control

In irrigated arid zones with insufficient natural or artificial underground drainage, it is the experience worldwide that no more than 20 to 30% of the irrigated land eventually becomes salty. The salty land is abandoned. As the abandoned parts of the area no longer receive irrigation water, the water tables in these parts will drop and attract groundwater from the neighboring irrigated fields. Thus, the un-irrigated parts function as drainage sinks, permitting leaching of the cultivated parts and collecting the excess salts. If sufficient irrigation water is available, 70 to 80% can be preserved in good condition. When the land is undulating, especially the lower lying stretches and/or the depressions are subject to salinization. In Australia, the designation of certain parts of the area as sinks is called “sacrificial drainage”.

In the fringe lands of the Garmsar irrigation project water is scarce. Therefore, it would seem a good practice to reserve a part of the area for salt accumulation. This can be achieved by the method of “strip cropping”. In soils with good hydraulic permeability underlain by aquifers with good transmisivity, the cropping can be done in strips of land say 100 m wide separated by permanently uncultivated strips of say 30m wide. When the transimisivity is lower, the cropped strips may be taken narrower e.g. 50 m, with uncultivated strip.



Principle of strip cropping with a sacrificial strip for salinity control in the cultivated strip

The uncultivated strips can be put to good use by planting them to salt resistant trees or shrubs (e.g. casuarina, eucalyptus, artiplex) that can tap the groundwater. Additionally, the uncultivated strips can be provided with an open drain to control the water table in periods of water-logging with high water-tables.

The proposed system can also be practiced in the pilot areas that are planned to be installed by the government in farmers’ fields with farmer participation. The pilot areas need an intensive monitoring system and the use of an agro-hydro-salinity model like SaltMod can be instrumental in this. This model has been made available to Abvarzan Co.

A more precise determination of the width of the cultivated and uncultivated strips can be done using the computer model EnDrain, which permits the calculation of the shape of the water table in cultivated land in the presence of wide open drains of varying width, depth and spacing. In the case of strip cropping, the width of the open drains should correspond to the width of the uncultivated strips and the spacing should correspond to the width of the cultivated strips.

Alternatively, a combined groundwater and agro-hydro-salinity model such as SahysMod can also be used for the purpose. The model takes into account the capillary rise from the uncultivated strips.

16. Conclusions

The SahysMod model helps in explaining the hydro-soil-salinity features of an irrigation project. In the case of the Garmsar project, it still needs to be verified using measurements of certain properties of the region, especially depth of the water table and soil salinity.

15. References.

[Ref. 1] SahysMod, free software for spatial (polygonal) agro-hydro-soil-salinity modelling. Download from https://www.waterlog.info/sahysmod.htm

[Ref. 2] CumFreq, free software for probability distribution fitting. Download from https://www.waterlog.info/cumfreq.htm

[Ref. 3] Determining the saturated hydraulic conductivity https://www.researchgate.net/publication/265217207_Determining_the_saturated_hydraulic_conductivity

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.pdf

The groundwater hydraulics of the Garmsar alluvial fan, Iran, assessed with the SahysMod model. On line:
https://www.researchgate.net/publication/336232156_The_groundwater_hydraulics_of_the_Garmsar_alluvial_fan_Iran_assessed_with_the_SahysMod_model
or:
https://www.waterlog.info/pdf/Garmsar groundwater.pdf

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