Zone selection for floodwater spreading using DDS, RS and GIS techniques

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ABSTRACT
Most aquifers of semi-arid Iran suffer from over-exploitation of groundwater for irrigation purposes. It is therefore important to augment the groundwater resource by artificial recharge, using floodwaters. This paper deals with developing a DSS to assist decisions as to where suitable catchments and associated infiltration areas are located. The DSS developed relies on the combined use of RS information and GIS techniques. A region (Fasa) was selected as the case study for suitable zone(s) selection.

Keywords: DSS, Fasa, flood Mitigation, GIS, Floodwater Spreading, Remote Sensing

RÉSUMÉ
La plupart des aquifères semi-arides de l'Iran souffre de la surexploitation des eaux souterraines pour l'irrigation. Il est donc important d'augmenter les ressources en eaux souterraines par la recharge artificielle, en utilisant les eaux de crue. Ce document traite de l'élaboration d'un DSS à aider les décisions appropriées quant à l'endroit où les bassins versants et des zones d'infiltration sont situés. Le DSS développée repose sur l'utilisation combinée de la RS d'information et de techniques GIS. Pour la mise en oeuvre de la relation avec la phase de la DSS, Une région (Fasa) a été choisi comme étude de cas, pour de diffusion de crue.

1 INTRODUCTION

The DSS for floodwater spreading site selection developed in this research has a scale hierarchy consisting of three levels (phases) of scale and data contents:
Phase 1: small scale (cartographic) for the identification and selection of potential zones (based on qualitative estimations)
Phase 2: medium scale for area(s) suitability evaluation
Phase 3: large scale for evaluating the suitability of site and type of design.

The main objective of this paper which emphasis on the first phase (small scale) is to develop a method for screening zones containing feasible areas, as a component of the DSS. By using the remote sensing data and expert knowledge, screening is done qualitatively for potentially suitable zones at the small scale. A potential zone is a more or less contiguous tract of land where alluvial aquifers are found which the land not fully occupied by irrigated lands. Zone selection is a screening process and the first step in a hierarchical procedure that should lead to the identification of the most promising areas. A prior selection has to be made in qualitative terms in order to find the most promising areas in a zone. Areas that are not feasible within potential zones will be excluded from further consideration. The result of this screening phase will be a few potential areas within a zone for floodwater spreading. The application of the exclusionary and suitability criteria by interpretation of satellite images, supplemented by other data, will be illustrated by a number of cases. Most potential areas for floodwater spreading schemes in Iran are the alluvial fans usually located in the intra-montane depressions or as foot-slopes on the hills and mountains bordering plain along the coast or large tectonic depressions, often with playas. Other fluvial plains, not in the form of alluvial fans, could also be suitable for schemes if the deposits are coarse-grained and of sufficient thickness. Therefore, attention in this study is focused on the alluvial fans.

2 STUDY ZONE (FASA ZONE)

The Fasa zone is located in the Iranian Zagros chain, where folded structures form the hills and mountains and where the synclines and other tectonic depressions contain the alluvial deposits that are of direct interest for floodwater spreading schemes. In most of the Khor zone, neotectonics have influenced erosion and deposition. The location and an overview of the zone is shown on a false-colour image (TM, 742) in Figure 1, with the locations of sub-zones I to III, which will be discussed below.

3 METHODS AND MATERIALS

Obviously, the problem is to gather the information on the many aspects that consider info in a spatial context and on their mutual relations. It is a time consuming process and many areas discarded after the screening because only a few suitable areas inside a zone will remain. The approach is similar for soil survey and land evaluation. This scale (small scale) explores to what extent interpretation of remotely sensed images supported by local field knowledge and supplemented by information from topographical maps and geological maps and by other data leads to the identification of potential areas in the zones. The image interpretation requires knowledge of (photo) geology, geomorphology and the relationships between physiographic and soils, supported by knowledge of local conditions or those having similarity.

The interpretation makes use of interrelationships between such factors as catchment geology and relief, the nature of alluvial deposits, tectonic and geomorphologic history, and the nature of the rivers and land cover. The aquifer presence and properties (depth, transmissivity and permeability) are mainly based on interpretation of the tectonic setting and geomorphologic history by applying principles of photo-geology [Drury, 1987] and [Miller,1961] and information from geological and topographical maps. Geophysical and drilling data for some aquifers are used, also for extrapolation to unknown areas on the basis of similarity. Geomorphologic interpretation [Verstappen, 1977] and [Way, 1978] is used to assess the nature of alluvial deposits in relation to the tectonic setting and to estimate relative sediment yields (qualitative). Image interpretation for groundwater is reviewed and discussed by Meijerink [Meijerink, 1996] and [Meijerink, 1988]. Transmission loss is judged (qualitatively) by variation in channel dimensions.

The land use patterns yielded information on the presence of aquifers, salinity problems and the availability of rangelands in the infiltration areas. The phreatophyte vegetation and water emergence in channels when coupled to soil salinity patterns are taken as an indication of groundwater outflow, hence shallow groundwater conditions.

The advantage of satellite images is that both catchment areas, infiltration and application areas can be viewed in a single image and that some aspects can be highlighted by using common image processing techniques and proper software[Budde at al. 2001]. Aerial photography has the advantage of high spatial resolution and good stereo display of the terrain. Various combinations of false-colour for TM are possible, e.g. the notation TM 742 stands for a combination whereby band 7 is coded in red, band 4 in green and band 2 in blue, etc. Since irrigated crops have a high reflectance in the near infrared band,and low reflectance in the other bands, the fields with green crops show up in green tones. TM band 4 coded in red (e.g. TM 432), so the fields would show up in red tones. Contrasts can be enhanced so as to 'sharpen' features on an image, by using appropriate histogram operations and by using Laplace type of filters. Certain features of interest, such as areas with loose sediments with high infiltration and deposited recently by active floods, can be highlighted by images resulting from orthogonal decomposition of the spectral data, such as the Principal Component method which was used in this research as will be shown in the further sections.

4 DECISION CRITERIA (QUALITATIVELY ESTIMATION)

The main criteria (exclusionary) for the qualitative evaluation are given below;

Runoff or floodwater availability

For most of the small and medium-sized catchments in Iran, there is no gauged data and therefore the initial selection procedure, or screening, has to rely on estimation methods. Rainfall data are not considered in the screening per se because it is assumed that in all arid and semi-arid regions there is a need for augmenting the groundwater resource. Moreover, in Iran provincial and local authorities decide on the location. However, in the arid tracts of Iran with less than 150 mm annual rainfall, settlements and irrigated agricultural lands are so sparse that recharge schemes are only relevant if some increase in Qanat discharge is desired.

Because of the absence of runoff regionalization studies in Iran, the relative magnitude of the ephemeral runoff in the screening is judged qualitatively on the basis of catchment size and overall catchment permeability based on the proportion of permeable rocks.

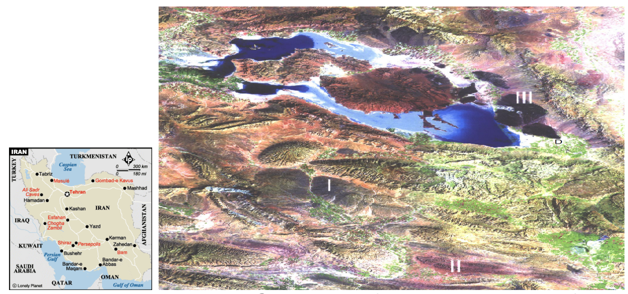

Figure 1 Location and Overview of the Fasa region (false-colour image, TM (ETM) 742)

Sediment, amount and type

The relative volumes of sediments judged from the catchment geology, relief and dissection, bankful width of the channel and strong signs of aggradations or sedimentation. It is of interest to detect excessive sediment yields, which affect the lifetime of a scheme to such a degree that it may not be feasible.

Excessive width of the river-bed for the size of the catchment and the gradient is usually associated with such fast geological erosion, but it should be remembered that aggradations could have been caused by episodic events when tremors occurred during a period with much rainfall. Such catchments have been excluded from further consideration.

Because of the large temporal and spatial variation and the difficulty of estimation, best use of local data on sedimentation should be made. In some cases, the relative sediment yield can be judged by the maintenance required in existing schemes. That information related to catchment geology and relief is of much help in making estimations in adjoining catchments. The relative magnitude of the coarse bed-load (sands and coarser) and that of the suspended/saltation load (sands and finer) can be judged from catchment geology and relief, as well as gradient of the fan, nature of the riverbeds and types of depositional patterns of low sediment yield. The alluvial deposition resulting from a suspended load type of river results in different patterns from those of bed-load deposition.

Surface area features (land use)

A trivial, but important criterion is that the potential infiltration area should be sufficiently large and the land cover should preferably consist of rangelands or bare areas, which generally belong to the government. Areas suitable for infiltration from a hydraulic point of view excluded if occupied by irrigated fields and industrial lands.

Presence of aquifer and its properties (transmissivity and permeability)

The presence of reflectance due to dense green crops and the absence of surface water irrigation indicates the presence of groundwater and hence an aquifer, because in hot regions with less than 350 mm annual rainfall no rain-fed agriculture is possible. The irrigation water comes from Qanats, topographical maps, and from wells, usually tube-wells fitted with diesel-fuelled pumps. It is a safe assumption to relate the extent of irrigated fields with good crops, as observed on RS images, to aquifer properties, except perhaps in some remote areas, where lack of capital and poor marketing conditions could have led to under-utilization of the groundwater, or in areas where water quality is poor.

In the screening process, attention should be paid to the transmissivity [Todd, 1980] of the aquifer. Most recharge by floodwater spreading takes place in mountain-front alluvial fans, where transmissivities vary much in the downstream direction. The general permeability can be interpreted by considering the catchment lithology and relief and the steepness of the alluvial fan, because of the relationship between gradient and average grain size of deposits [Pettijohn, 1957].

Transmission loss

The importance of transmission loss, can be so high that little floodwater of the smaller systems leaves the area, and that can be interpreted on images. When natural recharge is important, the urgency for artificial recharge may be questioned. Such high loss witnessed by a sharp reduction in the bankful width of ephemeral rivers on alluvial fans. The width to depth ratio or shape of the bankful channel does not change much in the unconsolidated coarse bed and bank materials in the downstream direction. Hence, if the width is reduced, the depth is reduced and thus the cross-sectional area, which indicates loss of discharge (transmission loss) because the gradient becomes less in the downstream direction.

Strong sedimentation or aggradations can cause water to spread out over a wide surface on the alluvial fan, increasing both infiltration area and time for infiltration. In the interpretation for the screening, attention should be paid to the mountain front because most irregularities can be expected here, such as outcrops at shallow depth and the presence of impervious lime crusts. If the tectonic setting indicates rapid fill of a subsidence area along an active fault, the deposits are likely to be thick, fairly homogeneous and permeable.

Saturated zone

Below the infiltration area, the groundwater table should be at sufficient depth to enable an increase in head by recharge without reaching the upper zone. If so, evaporation losses will occur owing to capillary rises. However, there will be considerable time delays of recharge fluxes if the groundwater table is deep, and the probability of perched water tables and semi-confined groundwater water is higher in deep aquifers than in relatively shallow phreatic aquifers, and this complicates the evaluation of the effectiveness of the recharge scheme. For unsaturated zone thickness, some thickness classes were introduced by [Kheirkhah Zarkesh, 2005] on the strength that shallow thickness (<20 m) could cause salinization and evaporation losses, and that great thickness (>150 m) would cause substantial delay in the effect of artificial recharge, raising (political) questions as to the short-term effectiveness of the investment in a scheme.

In the lower alluvial fan, outflow of groundwater can occur in riverbeds, signifying the intersection of the piesometric surface and the topographical surface. Assuming a semi-logarithmic shape of the groundwater surface and by having information of a few depths to groundwater in the middle or upper fan, a fair idea of the groundwater surface can be obtained and, in combination with estimated depth and hydro-geological parameters typical of alluvial fans, the aquifer properties can be estimated at a level that is sufficient for the screening. In some areas, the lower part of the fan has an incised river. If groundwater from the fan flows into the river, increase in the head by artificial recharge increases the outflow, and hence loss of water. In such cases, a proper pumping scheme has to be adhered to. A groundwater or piesometric surface well below the capillary zone in the lower alluvial fan is favourable in terms of absence of salinity hazard [Warrence et al. , 2002].

Water demand

In this phase, the water demand estimated (qualitatively) based on the presence of areas suitable for irrigation, agricultural lands, villages, cities and industrial areas as indicators. The presence of irrigated lands on the lower to middle part of the fan indicates that soils are suitable for irrigation because textures become gradually finer in the downstream direction. The increase of clay contents accounts for increase in water holding capacity and soil fertility. It judged on images at the screening stage by how much the irrigation expanded. In addition, the presence of agricultural lands, villages, cities and industrial areas in the lower parts of the fan (water application part) will be a good indicator for water demand.

Fasa Region

The combination of exclusionary criteria – (1) sufficient size of catchment for runoff generation, and (2) presence of alluvial fans in connection with an aquifer with rangelands – yields only three zones of limited extension in this zone, denoted I to III on the image (Figure 2).

Sub-zone I: Variation of runoff and sediment yield within catchment and transmission loss (exclusionary criteria) in infiltration area

Most of the upper catchments (A) (see Figure 2) are underlain by hard marl and limestone. South of the upper catchments is a zone (B) with coalescing alluvial fans (bahada), where transmission losses occur. South of the bahada, hills are found that consist of continental

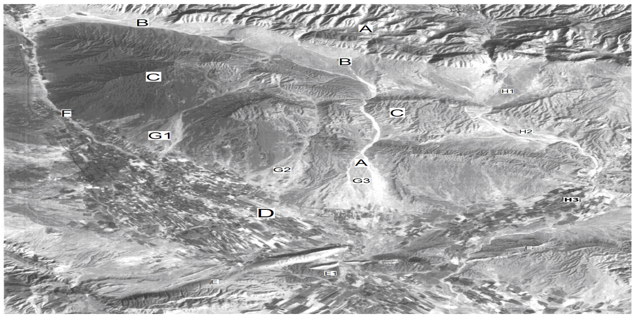

Figure 2 Fasa region, sub-zone I

Sub-zone I: Variation of runoff and sediment yield within catchment and transmission loss (exclusionary criteria) in infiltration area

Most of the upper catchments (A) (see Figure 2) are underlain by hard marl and limestone. South of the upper catchments is a zone (B) with coalescing alluvial fans (bahada), where transmission losses occur. South of the bahada, hills are found that consist of continental deposits of Tertiary age (C), composed of semi-consolidated shale, marl, sandy clay, sandstone and pebble beds, overlain partly by a cap of Quaternary pebble beds cemented locally by lime. The intramontane depression (D) is closed off by folded rocks (E), which contain impermeable units (E1). The northern flank of the depression is affected by uplift, which is witnessed by the raised and dissected older alluvial fan deposits that dip below the young floodplain deposits of the depression, indicating subsidence within the depression and thus sufficient thickness of the aquifer. As can be seen on the image, irrigated fields (by groundwater) occupy most of the depression.

Some of the valleys in the upper part (A) of the catchment of fan G3 consist of glacis, whose deposits have good infiltration. The runoff coefficient in the upper catchments is relatively low because of the presence of limestone and glacis deposits, and so is the sediment yield. The runoff and sediment load increase in the hill area (C) and flood flows reach alluvial fan G3. As can be seen, floodwater spreads out on the active fan and the question is how much of the flows infiltrate on the coarse-grained channel/fan deposits, or in other words what is the transmission loss. The importance of transmission losses recharging the groundwater can be judged by the near-disappearance of the river (F) in the downstream direction and the disappearance of the active channels of fan G1.

In this context, it should be noted that only a small channel exists in the gap just north of E1, indicating that there are also important transmission losses of the runoff on the alluvial fans G2 and G3. Only rarely does some floodwater flow through the gap, and then not sufficient to maintain the channel in the downstream direction. This evidence suggests that the large width of the riverbed of the river (G3) is caused by deposition of the bedload rather than by strong flash flows, and that most of the floodwaters infiltrate, so little water leaves the fan. A matter of concern is therefore that investments in a floodwater spreading scheme will not induce much additional recharge in the fans G1, G2 and G3. Furthermore, the wide depositional pattern on the fan suggests that the long dike type of scheme could be appropriate. The larger catchment upstream of H1 could be considered because of the runoff potential. However, a suitable area near H1 has the problem that not much space is available for a scheme or for the development of irrigated areas (exclusionary criteria). In addition, because of catchment geology and geomorphology, much of the sediment is fine- grained. The area around H2 also suffers from lack of space and so does the area around H3 , because most of the lands there are under irrigated agriculture.

In conclusion, although potentially promising areas seemed to be available, a closer view reveals that there are arguments against their adoption for more detailed field investigations.

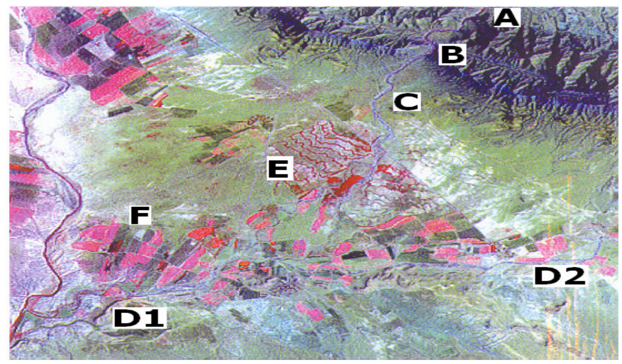

Figure 3 Fasa region, sub-zone II, Gareh Baygan area (false-colour composite, TM 742)

Sub-zone II: Large alluvial fan, groundwater loss by incised river and existing scheme

This sub-zone (Figure 3) consists of a wide alluvial fan of a sizeable catchment (193 km2) of the Bisheh Zard river. The catchment is underlain predominantly by folded rocks of low permeability (shales and marls). However, sandstones, conglomerates and limestone beds occur in the catchment and they give expression to the fold structures (e.g. a synclinal axis runs through A). Figure 4 shows the alluvial fan and its surroundings. The river breaks through the sandstone escarpment near B and has formed an alluvial fan with a relatively gentle slope. Only in the northern fringe of the alluvial fan are some outcrops found just south of the scarp slope. The southern part of the fan is bordered by a fault approximately along the east-west flowing river (D1-D2).

Just south of the fault, low outcrops of soft (impermeable) rocks are found, forming a barrier for the groundwater. It could be reasoned that the fan was formed in a subsidence depression and the fanglomerates have sufficient thickness to form an aquifer. The presence of large fields irrigated by groundwater demonstrates the aquifer transmissivity and the suitability of the soils for irrigated agriculture. The good water holding properties of the soils on the lower fan are not surprising because much of the catchment lithology consists of fine-grained rocks (shales, marls).

The resistant rocks of the catchment account for the wide nature of the riverbed in the middle part of the fan, which consists of coarse-grained materials (sands and pebbles), as well as for the good permeability of the aquifer in the upper and middle parts of the fan. All observations taken together suggest that the zone consists of a tectonic depression with permeable fanglomerates in the upper and central parts (phreatic conditions) and more fine-grained deposits in the downstream part (semi-confined or confined conditions), as was confirmed by the hydrogeological study of [Fatehi-Marj 1994]. The fan surface is not dissected and the upper to middle part consists of light textured soils, overlaying very coarse-grained alluvial fan deposits. The river is incised in the northernmost part of the alluvial fan; thus the river course is stable in that part. The river channel extends to beyond the fan; hence floodwater is 'lost' (low transmission loss). So far, the aspects that favour selecting this area for a floodwater spreading scheme are in the upper-middle part of the fan.However, there are aspects of concern. Comparison of old (1950s) aerial photos and the

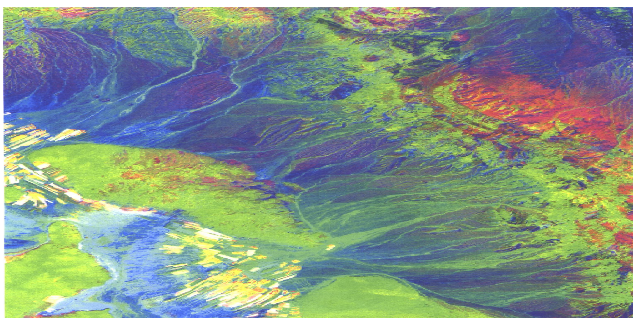

Figure 4 Fasa region, sub-zone III (PC 421)

1988 TM image shows shifts in the river in the central part of the fan, downstream of the incised course in the upper part of the fan. Such shifts are likely to continue because the river deposits bedload in that part of the fan. Therefore, either river training is included or repair activities are anticipated in any possible scheme, raising the costs.

The east-west flowing river is incised near the confluence with the large north-south flowing river, and a phreatophyte vegetation can be observed in the channel. This indicates outflow of groundwater. The stereo aerial photos show that the incision is deep and the walls are steep, indicating materials of high cohesion and hence the presence of clay and silt. Therefore, the amount of artificial recharge should match the amount withdrawn for irrigation, otherwise recharged groundwater is lost. Towards the east, the thickness of the alluvial deposits is probably not great, because the depression is pinching out and low outcrops of impermeable rocks appear. Hence it is wise to ascertain the aquifer thickness in the eastern part and the permeability in the southern zone. The above leads to the conclusion that the area has many factors in favour of a scheme and no exclusionary criteria have been met by the area. In fact, a floodwater spreading scheme of the channel and shallow basin type was started in 1984 [Kowsar 2005]. The planted trees along the channels make the conveyance channels visible (near E) on the 1988 Landsat TM image. Since then, the scheme has been expanded and is considered a success in terms of recharge and ecology, although quantitative figures are not available.

Sub-zone III: Constraint of catchment size in relation to transmission loss bahada zone

The image in Figure 5 shows a playa with a bahada, with a fringe of cultivated fields in the lowermost part and low hills with shales, which have low reflectance in the TM bands. The irrigation water for cultivation is derived mainly from qanats tapping the water in the bahada. The adjacency of the irrigated fields to the salt lake excludes the use of tubewells in the irrigated area because lowering the pressure by pumping causes upwelling of the brackish water interface. Figure 5 shows the moisture and salinity variations within the playa, caused by episodic inflow of flash floods and followed by drying up due to evaporation.

The question in sub-zone III is whether transmission loss (exclusionary criterion) in the bahada is so high in view of the small catchments feeding the bahada, where nearly all water infiltrates, that a scheme is superfluous. To obtain a better view of the active riverbeds, Principle Component (PCA) Analysis was conducted and yielded the desired results, as shown in Figure 5, which is a false-colour image of PC's 4, 2 and 1, coded in red, green and blue respectively. The runoff on the bahada is partly concentrated in ephemeral rivers and partly in the form of sheetwash. The PC IV image was included, although it contains about 1% of the spectral information, because it discriminated the parts with active channels or flow paths and parts not affected. The latter parts have soil formation and a (sparse) rangeland vegetation adjusted to the soil conditions. The spreading out of the sheetwash in the lower part is associated with deposition of finer-grained materials (silty clays to sandy clays).

As the image in Figure 5 shows, there are no channels reaching the lake. Most of the remaining sheetwash is captured in the fields to augment soil moisture. Obviously more field information on this aspect is needed because, if most of the water infiltrates in the bahada, there is little point in artificial recharge.

Sub-zone III-D: Low sediment yield, constraint of size of infiltration area, alternative for flood control

A township (1; see Figure 6) is located on the apex of a gentle sloping alluvial fan cum inland delta of a river with a substantial catchment east of the town and with bahadas in the north and south. West of the town outcrops (2) occur, indicating that the alluvial deposits have probably no great thickness. Water from qanats and shallow wells in the upper part of the delta fan and the bahadas is used for irrigation. East of the city, orchards are watered by wells, and west of the city irrigated agriculture is possible up to the areas where soils are saline.

Flash flows spread out just upstream of the town, causing a flood hazard, and are therefore an additional reason for considering a floodwater spreading scheme that captures at least part of the floodwaters. A man-made diversion channel exists (3) that leads most of the water via location 4 into the lake (5). Such a scheme can mitigate the flood hazard that would otherwise be an argument for a floodwater spreading scheme.

Relatively little sediment is deposited in the alluvial area because of the presence of resistant rocks (limestone) in the catchment and of alluvial fans and colluvial valleys that capture sediment within the catchment. The overall permeability of the catchment is high, as is also evidenced by the small dimensions of the river channel and those of the diversion channel. The limited sediment splay along the playa shores also indicates relatively low sediment yield. The space for a possible floodwater spreading scheme to induce recharge in the upper part of the aquifer is limited to the small triangular area east of the city, thus limiting choice of scheme type.

Evaluation

Of the areas reviewed in this zone, there is only one that has predominantly favourable conditions, namely the Gareh Baygan area, zone II. Area IG3, area III bahadas, and area III-D have limited possibilities, and data collection for further evaluation will depend much on the depletion of the aquifer and the amount of water that leaves the area. The general results of the evaluation for all the areas discussed in case I and the exclusionary criterion/criteria for each excluded area are shown in Table 1.

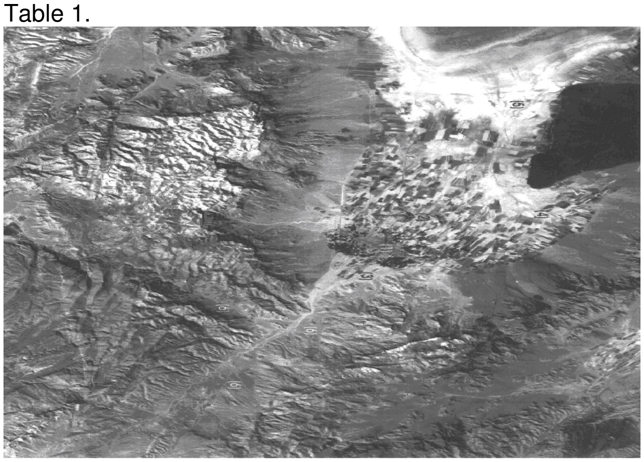

Figure 5: Fasa region, sub-zone III, area D (printed in black-and-white FC 453)

Discussion and Conclusions

The objective of this paper was to develop a method for screening zones containing feasible or potentially suitable areas, as a component of the DSS. The screening was done at a small scale. It was based on the interpretation of remotely sensed images supplemented by generally available additional sources of information, such as geological and topographical maps.

It was concluded that the interpretation results could be regarded as being more than the sum of separate interpretation layers, i.e. geology, geomorphology and land use. The study has shown that image interpretation facilitated by field visits and by the presence of hydro-geological data allows empirical knowledge to be accumulated for understanding interrelationships of features on the images and for extrapolation purposes. This enables potentially suitable areas to be identified and areas with little or no promise to be excluded by using criteria such as catchment size, presence of aquifer, water quality, excessive sediment yield, high transmission losses and lack of space for schemes in suitable infiltration areas, and so on. The end product of the screening was the identification of possible suitable areas within a zone, grouped according to a relative qualification.

The screening for zones with potential was based on qualitative results achieved using the interpretation of remotely sensed images, supplemented by generally available additional sources of information, such as geological and topographical maps. By interpreting these data and using criteria such as catchment size, presence of aquifer, water quality, excessive sediment yield, high transmission losses, lack of space for schemes in suitable infiltration areas, and so on, it was possible to obtain sufficient evidence to exclude areas that seemed potentially suitable at first glance. It was found that zones with potentially suitable areas to be retained for further scrutiny consisted of catchments of medium size (a few tens to hundreds of square kilometres in size) with rivers that formed alluvial fans. The interpretation of the collected data also resulted, before ending the screening, in specifying the nature of the field data required and in giving specific points of attention for the next stage of evaluation, such as the presence of a salinity hazard. By coupling groundwater-level fluctuations in wells close to active rivers or active sedimentation on alluvial fans, the importance of river recharge or transmission loss could be demonstrated. The type of image processing technique to highlight such areas was mentioned. To arrive at results, the interpretation required a holistic approach, supported by field knowledge of various regions of Iran. The geological setting and dynamic geomorphology had to be assessed first to estimate relative runoff and sediment yield, as well as probable gross nature and depth of aquifers. In many parts of Iran, it was found that neotectonics played a role in the erosion and deposition. Using images to study details of the fluvial geomorphology gave information on the general feasibility of a scheme, considering transmission losses and the main type of scheme possible in view of suitable sites for intakes for a diversion scheme. Because of the age-old use of groundwater in Iran, interpreted land cover information allowed conclusions to be drawn on the presence of aquifers, the suitability of soils for irrigation and possible increase in acreage using artificially recharged water, saline water, and space for floodwater spreading schemes (also in relation to land acquisition). Because of the interrelationships that, owing to cause-and-effect relationships, often exist between the terrain features of relevance for the selection of areas for floodwater spreading schemes, it can be concluded that the interpretation results could be regarded as being more than the sum of separate ‘interpretation’ layers: i.e. geology, geomorphology, land use. The interpreter has to have a firm footing in earth science. The end product of the screening was the identification of potentially suitable areas within a zone, grouped according to a relative qualification, leaving options open for the selection of the most suitable areas when considering the size of possible scheme.

References

Budde, P.E., Nijmeijer, R.G., Dost, R.J.J., Haas, A.de., ILWIS 3.0 Academic: User's Guide, The Integrated Land and Water Information System, 2001.

Drury, S.A., Image interpretation in geology. Chapman and Hall, London,1987.

Fatehi-Marj, A., Evaluation of artificial recharge using numerical models: a case study in Gareh Baygan plain, Fasa, Fars Province, Iran. MSc thesis, ITC, Enschede, The Netherlands, 1994, pp.111.

Kheirkhah Zarkesh, M., Decision Support System for Floodwater Spreading Site Selection in Iran, Ph.D thesis, Wageningen university, the Netherlands, 90-8504-256-9, (2005).

Kowsar, A., Desertification control floodwater spreading in Iran. In: Unasylva 168, Arid Zone Forestry, 2002

Meijerink, A.M.J., Remote sensing applications to hydrology: groundwater. Hydrological Sciences Journal,Vol. 41 (4), 1996,pp. 549-561.

Meijerink, A.M.J., Valenzuela, C.R. and Stewart, A. (eds)., ILWIS: the integrated land and watershed management information system: scientific status report on the project geo-information system for land use zoning and watershed management. ITC Publication 7, Enschede, The Netherlands, 1988.

Miller, V.C. and Miller, C.F., Photogeology. MacGraw Hill, New York, 1961.

Pettijohn, F.J., Sedimentary rocks. Harper and Row, New York, 1957.

Todd, D.K., Groundwater hydrology. John Wiley and Sons, New York, 1980.

Verstappen, H.Th., Remote sensing in geomorphology. Elsevier, Amsterdam, 1977, pp. 214.

Warrence, N.J., Bauder, J.W. and Pearson, K.E., Basics of salinity and sodicity effects on soil physical properties. Land Resources and Environmental Sciences Department, Montana State University, 2002, pp. 29.

Way, D.S.,Terrain analysis (2nd ed.). Dowden Hutchinson and Ross, Stroudburg, USA, 1978.