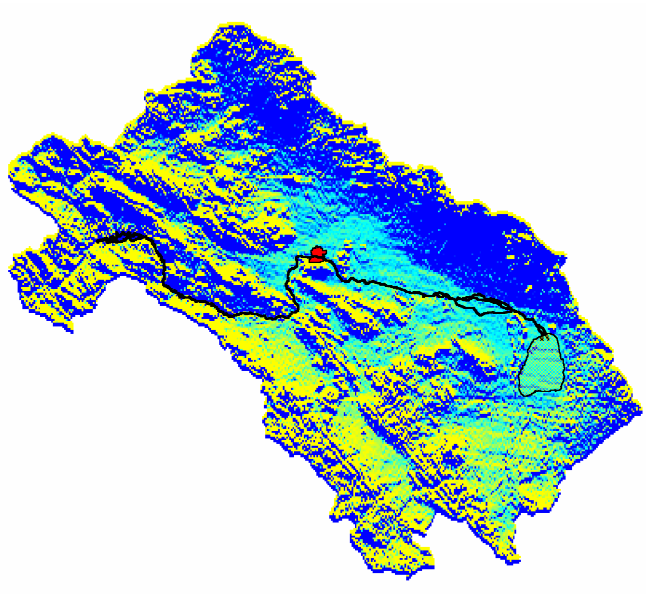
Sustainable Irrigation and Water Management in the Zayandeh Rud Basin, Iran

Irrigated area by NOAA-Landsat upscaling techniques

A. Gieske, N. Toomanian, M. Torabi



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The IAERI-EARC-IWMI collaborative project is a multi-year program of research, training and information dissemination fully funded by the Government of the Islamic Republic of Iran that commenced in 1998. The main purpose of the project is to foster integrated approaches to managing water resources at basin, irrigation system and farm levels, and thereby contribute to promoting and sustaining agriculture in the country. The project is currently using the Zayendeh Rud basin in Esfahan province as a pilot study site. This research report series is intended as a means of sharing the results and findings of the project with a view to obtaining critical feedback and suggestions that will lead to strengthening the project outputs. Comments should be addressed to:

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Irrigated Area by NOAA-Landsat Upscaling Techniques - Zayandeh Rud Basin, Iran

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Abstract

The processing and analysis is discussed of a set of NOAA-14/AVHRR images, obtained from the Satellite Active Archive (SAA) for the years 1995 and 1999. The NDVI values were calculated using the channel 1 and 2 reflection values after standard radiometric and geometric corrections. The average NDVI of the main irrigation systems in the Zayandeh Rud Basin was then determined for each image. This made it possible to analyze the temporal evolution of these NDVI values for the individual irrigated areas during 1999.

The NOAA NDVI values can in principle also be used in the determination of the size of the actual irrigated areas of the principal systems. However, calibration of the method proved necessary, because in most NOAA pixels the vegetation is only a fraction of the pixel area. Through the use of GIS operations on a Landsat 7 image (August 1, 1999), the actual irrigated areas in the Borkhar, Abshar Left and Right, Nekouabad Left and Right, were determined for that particular date. Five NOAA images were then selected for the period July-August, 1999. This made it possible to establish regression relations linking NOAA NDVI values to the size of the net irrigated systems, which were then applied to the 1995 data set.

Introduction

Access to NOAA satellite imagery has become much easier in recent years through the global data base systems and Internet. The Satellite Active Archive (www.saa.noaa.gov) allows downloading images free of charge, while data are being kept in the archive as far back as 1978. It has become possible therefore to build long time series of images for the areas of interest. This paper describes some application and development aspects of the methodology required to use these NOAA images in the framework of the IWMI-IAERI co-operative study of the Zayandeh Rud Basin (Salemi et al., 2000).

Fig. 1 shows 9 main irrigated areas along the Zayandeh Rud. Irrigation takes place mainly by surface water from an extensive irrigation canal system which is fed by water from the Zayandeh Rud. Water releases from Chadegan Dam regulate the flow of water to these irrigation systems. Further away from the river and irrigation system, fields are also irrigated by groundwater if available in suitable quantity. The hydrology of the Zayandeh Rud Basin was described by Murray-Rust et al. (2000). It is important to note that the rainfall in the basin is less than 150 mm on average, with precipitation occurring mostly between November and March. Because of the aridity of the climate there is no significant vegetation outside the irrigated areas. Therefore a significant link between vegetation and irrigated area can be expected.

Using satellite images a vegetation index NDVI (Normalized Difference Vegetation Index) is defined, which for NOAA images is determined from reflection coefficients in two channels (channels 1 and 2 visible and near infrared) as

$$NDVI = \frac{r_2 - r_1}{r_2 + r_1} \qquad (1)$$

Fig. 2 shows the NDVI values for typical NOAA image (25/7/99), where the red values in this case represent higher NDVI values and therefore a higher amount of green vegetation. The blue areas represent bare soil or outcrop areas.

For Landsat 7 images the NDVI is usually calculated from the reflection coefficients of channels 3 and 4:

$$NDVI = \frac{r_4 - r_3}{r_4 + r_3} \qquad (2)$$

An introduction into the use of NDVI in Remote Sensing techniques may be found in Lillesand and Kiefer (1987). NDVI values are also dependent on crop type and patterns. More information about the crop patterns in the Zayandeh Rud irrigation districts can be found in Salemi et al. (2000) and Sally et al. (2001).

In the following sections first the methods are described to download and process NOAA images in order to produce NDVI maps such as Fig. 2. Secondly, the problem of calibration of net irrigated areas as a function of NDVI is discussed. Because this problem involves two different satellites, Landsat-7 and NOAA-14, with pixel sizes of respectively 30 m and 1 km and with different sensors, the calibration is not straightforward.

The analysis of the set of NOAA-14 images from 1995 makes it possible to show the evolution of the NDVI values – and associated areas - for each of the nine irrigation areas during 1995. Because NOAA-14 images from 1999 were used in the calibration process, a comparison could be made between 1995 and 1999 for the months July and August.

Image Pre-Processing

As mentioned above, the NOAA-14 images were downloaded from the Satellite Active Archive's website (www.saa.noaa.gov). These Local Area Coverage (LAC) images have a spatial resolution of 1 km at nadir, with Level 1B File Format. Many Remote Sensing Packages (Erdas, PCI) have standard import options for this type of files. For ILWIS a special NOAA-14 import module (NPR1B) was developed by Gieske and Dost (2000). In this program, adapted from the method by Liping and Rundquist (1994), information from the data's scanline header is used to calibrate the thermal channels 3, 4 and 5, while the Rao and Chen (1998) method was used to compensate for sensor degradation in the visible channels.

The scanline header also contains information on the latitudes and longitudes of each pixels and a first step georeference is made automatically. To compensate for small deviations (a few pixels) a second step final georeference has to be made manually. The NOAA-14 images of the Esfahan area are generally of high quality, because the area's position is close to nadir at satellite overpass. A one km resolution is obtained as a matter of routine.

It should be noted that apart from radiometric corrections, no atmospheric corrections are made by NPR1B. It is also necessary to check all images for cloud cover, and discard them if none of the irrigation systems is visible. From the original set of 40 images only 25 were useful. Because cloudy days tend to be more frequent in winter than in summer, the frequency of useful images in summer is higher than in winter.

Upscaling from Landsat to NOAA pixel size

The pixel size of the Landsat 7 channels 3 and 4 is about 30x30 m=900 m^2, whereas the pixel area of the NOAA images in the present case is about 1 km^2. Consequently, the size of the actual irrigated (green) areas, can be much more accurately determined using the Landsat images. The NOAA pixels will in nearly all cases cover a range of fields with ploughed or harvested land in between. Thus the NOAA NDVI pixel values will be the result of averaging the response of the different land types in the pixel area. In this section a discussion is given of this effect - resulting from the mixture of green and non-green areas within one pixel -, on the resulting NDVI value.

For the NOAA images the NDVI is calculated as

$$NDVI = \frac{r_2 - r_1}{r_2 + r_1} \qquad (3)$$

where r_1 and r_2 are respectively the reflection coefficients of the light in channels 1 (0.58-0.68 μm) and 2 (0.725-1.10 μm) of the AVHRR instrument. Most of the variation in NDVI arises

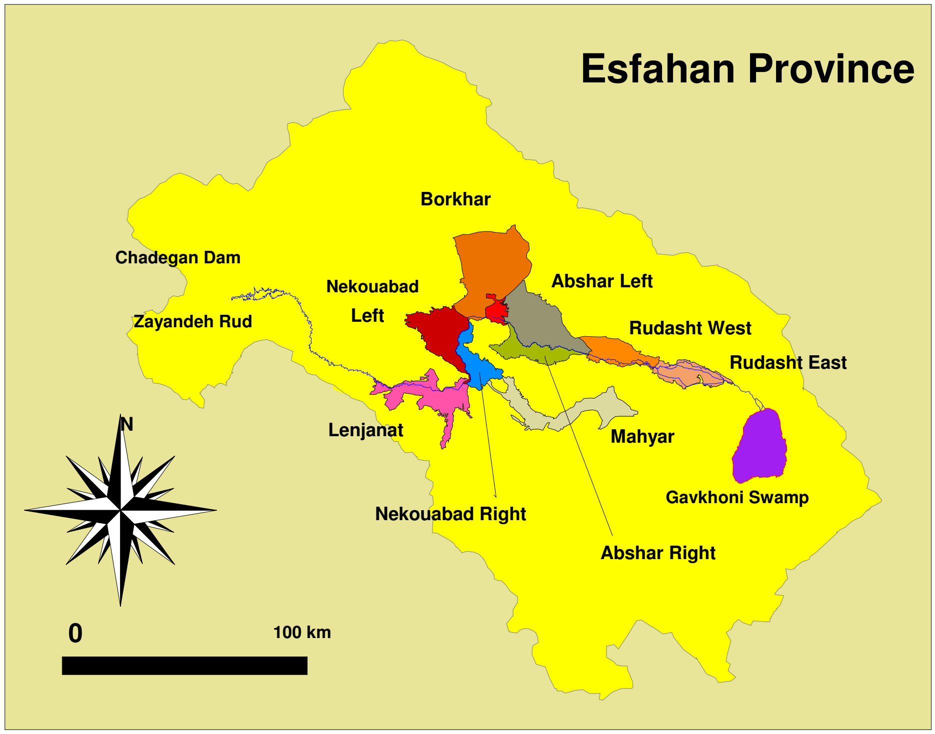

Figure. 1 Layout of main irrigation systems along the Zayandeh Rud.

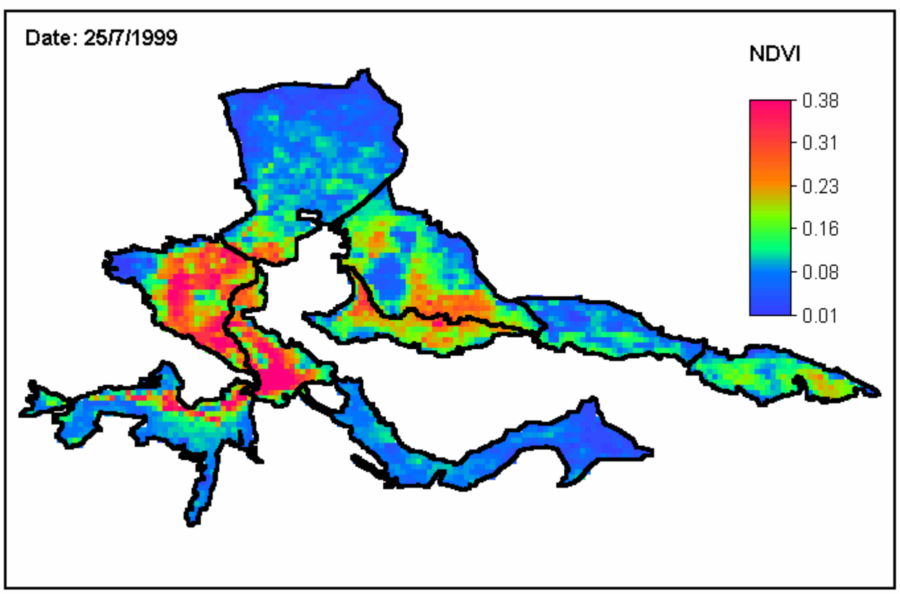

Figure 2. NOAA NDVI values in the main irrigation districts on 25-7-1999.

from variations in r_1. For example, typical values for r_1 and r_2 in the present case are 0.25 for dry non-green areas (NDVI=0), whereas r_2=0.25 and r_1'=0.10 for green areas (NDVI=0.43). Note that r_1 indicates the reflection coefficient of the non-green part of the pixel, whereas r_1' indicates the reflection of the green part.

Suppose that the area of a NOAA pixel is 1 km^2, that f_g and f_n' represent respectively the green and non-green fractions of the pixel. The non-green fraction f_n' is then equal to

$$f_{ng} = 1 - f_g \tag{4}$$

The average reflection coefficient r_{1avg}, can be expressed as

$$r_{1avg} = r_1(1 - f_g) + r_1^{'} f_g \tag{5}$$

or

$$r_{1avg} = r_1 - f_g(r_1 - r_1^{'}) \tag{6}$$

Relations (5) and (6) express the fact that when f_g=0, r_{1avg} becomes equal to r_1, in which case the pixel is completely non-green, and when f_g=1 r_{1avg} becomes equal to r_1' (the pixel is completely green).

The NDVI is calculated as

$$NDVI = \frac{r_2 - r_{1avg}}{r_2 + r_{1avg}} \tag{7}$$

Inserting (6) into (7) yields after taking r_2 equal to r_1

$$NDVI \cong \frac{f_g(r_1 - r_1')}{2r_1 - f_g(r_1 - r_1')} \tag{8}$$

Solving (8) for the fractional pixel vegetation cover f_g results in

$$f_g = \frac{2r_1}{(r_1 - r_1')(1 + NDVI)} NDVI \tag{9}$$

Equation (9) shows that the fractional vegetation cover is not a linear function of the NDVI pixel function. However, the term (1+NDVI) in the denominator does not vary much for low NDVI values. Fig. 3 shows f_g as a function of the NDVI for the r_1 and r_1' values given above.

The value of the constant $2r_1/(r_1-r_1')$ is for the number example given above, equal to 3.33. Its value depends on the vegetation characteristics of the irrigated areas. However, its average value is not expected to vary much from about 3. It should be noted that for high values of the NDVI, the fractional vegetation cover cannot rise above 1. The factor (1+NDVI) in the denominator becomes important in that case. However, as will be shown later, the relation f_g=c*NDVI gives good practical results.

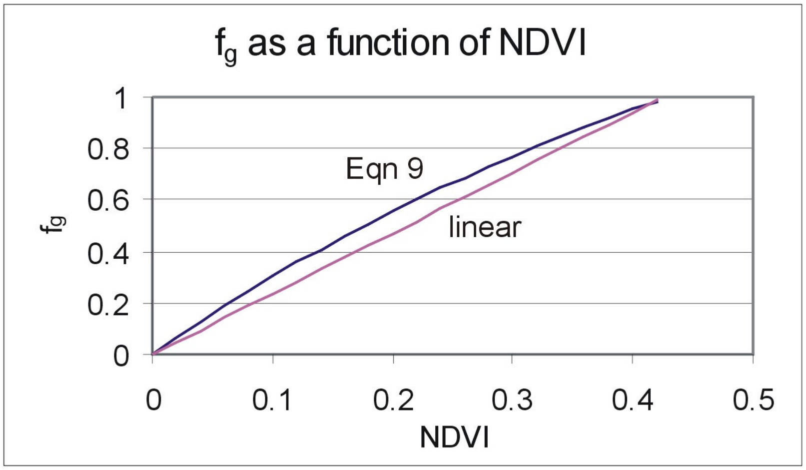

Figure 3. Fractional vegetation cover f_g as a function of NDVI for r_1=0.25 and r_1'=0.10 according to Eqn (9).

The total irrigated area can be evaluated as

$$I = A\sum_i f_{gi} n_i \tag{10}$$

where n_i is the number of pixels with one particular value of f_g and where A is the area of one NOAA pixel, which is in the present case equal to 0.996 km^2.

$$N = \sum_i n_i \tag{11}$$

where N is the total number of pixels in the image.

A further complication is that the NOAA NDVI values (derived from channels 1 and 2) are not entirely comparable to those of the Landsat 7 instruments (using channels 3 and 4). Suppose that there is a homogeneous area of 30x30 Landsat 7 pixels all with very low NDVI. Then the average Landsat NDVI value should be the same as the NOAA pixel value for that area. Unfortunately this is not the case. Fig. 4 illustrates the situation following from comparison of the images of 25/7/99 (NOAA) and 1/8/99 (Landsat).

In this case NOAA NDVI values have a minimum of about 0.02, while the corresponding Landsat average over an area of 1 km^2 is –0.12. Similarly for high NDVI values of respectively 0.47 (NOAA) and 0.57 (average Landsat NDVI) are found. From the analysis of the Landsat image it follows that a zero NDVI threshold distinguishes quite well between irrigated and non-irrigated areas. Figure 4 shows that the corresponding threshold for a uniform NOAA pixel would then be 0.1. However, because normally the NOAA pixels

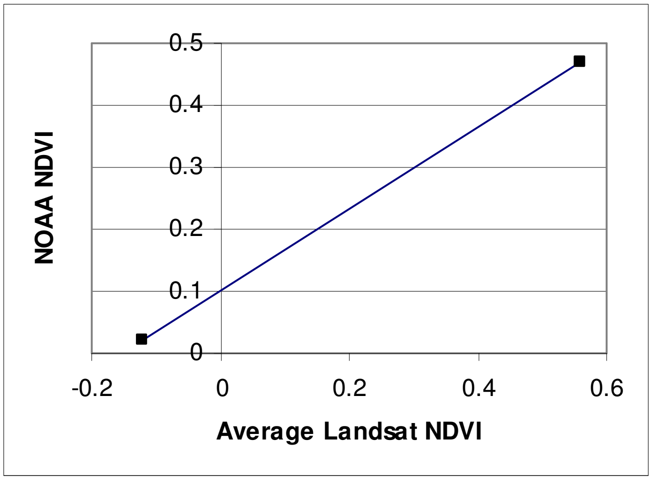

Figure 4. Relation between Landsat and NOAA NDVI for homogeneous areas of 1 km^2.

represent mixtures of irrigated and non-irrigated land, the threshold value is lower. In the present case 0.06 was found to be a reasonable threshold. This aspect is further discussed in the next section. For high NDVI values the difference between NOAA and Landsat appears to be less critical.

The method used here to calibrate NOAA NDVI against irrigated area can be summarized as follows:

- All values of NOAA NDVI pixels less than or equal to 0.06 are considered to represent non-irrigated areas.
- For the NOAA NDVI values greater than 0.06 the irrigated area is calculated as in Eqn 10, while f_g is taken as c*NDVI (see Eqn 9).
- Proportionality constant c is then determined by regression against the areas as determined by a Landsat image. As shown above this constant should have a value of about 3.

Calibration results

A Landsat 7 image of August 1, 1999 was used to calculate the irrigated and non-irrigated areas through standard GIS/RS techniques. Five areas were selected : Borkhar, Nekouabad Left and Right Bank, Abshar Left and Right Bank. A set of 5 NOAA images was used (July 7, 8, 25 and August 21 and 29) in the calibration procedure as outlined above. The results of the calculations are summarized in Table 1.

The table shows that there is a clear increase in area from July 7 to August 29. Comparison with the Landsat values can be made through the averages of the 5 images or through the use of the July 25 NOAA image. Figs 5 and 6 show the result of the regression analysis.

Table 1 Review of the area calculations (all areas in ha). For NOAA uncalibrated areas are given according to Eqn 10.

	07-Jul	08-Jul	25-Jul	21-Aug	29-Aug	average	stdev	Landsat 7
	7	8	25	52	60			
Borkhar	3813	7225	5462	7790	8681	6594	1949	15915
Nekou-L	6693	9590	8609	11644	11094	9526	1988	27912
Nekou-R	3415	4469	5174	5985	5912	4991	1075	12922
Abshar-R	3312	4053	4142	5833	5684	4605	1103	12382
Abshar-L	6187	7836	7235	10134	10689	8416	1925	22874
totals	23420	33173	30622	41386	42060	34132		92005

The value of the proportionality constant varies from 2.73 (Fig. 5) to 3.05 (Fig. 6). Inspection of the results shows that the error in the determination of the areas ranges from 10 to 15%. Some of the larger errors may be due to (a) the presence of small clouds in parts of the images (b) differences in atmospheric conditions from day to day (especially between July 7 and 8). The method using the average of 5 images seems to be best.

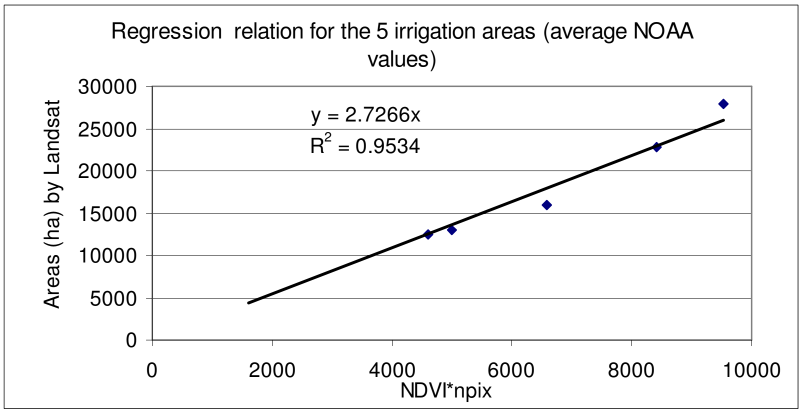

Figure 5. Regression relation for the 5 irrigated areas of Table 1 (average NOAA value).

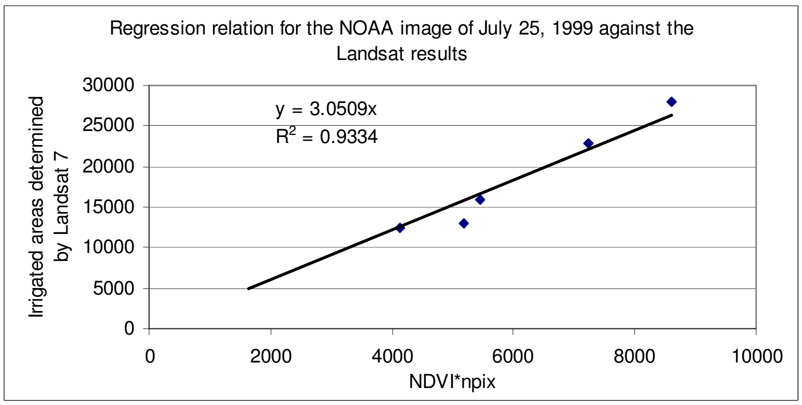

Figure 6. Regression relation for the 5 irrigated areas of Table 1 (NOAA, July 25).

The regression relation y=2.7266x was adopted to calculate the irrigated areas from the sum $S=\Sigma NDV_i*npix_i$. Table 2 summarizes the calculated areas. The table shows that there are large day-to-day differences in values. Note for example, the difference between July 7 and 8. In general, the errors are larger for Borkhar, Lenjanat and Mahyar where the choice of NOAA NDVI threshold (0.06 in this case) appears to be critical. These districts have less uniform surface water irrigation and large parts of these areas are irrigated with groundwater. The table shows that it is not advisable to make area calculations based on a single NOAA image. In this case, use of the image of July 7 would severely underestimate the areas.

Table 2 Irrigated areas from NOAA after calibration for the period July 7, 1999 to August 29, 1999 (all areas in ha).

	07-Jul	08-Jul	25-Jul	21-Aug	29-Aug	avg	Landsat 7
	7	8	25	52	60		(1/8/1999)
Borkhar	10397	19700	14893	21240	23670	17980	15915
Lenjanat	4204	16537	12172	16602	16741	13251	
Nekou-L	18249	26148	23473	31749	30249	25974	27912
Nekou-R	9311	12185	14107	16319	16120	13608	12922
Abshar-R	9030	11051	11294	15904	15498	12555	12382
Abshar-L	16869	21366	19727	27631	29145	22948	22874
Rudasht-W	4624	6748	4390	5554	6184	5500	
Rudasht-E	6718	8681	7490	9011	9450	8270	
Mahyar	1775	5919	4297	7861	8954	5761	

NOAA NDVI evolution during 1995

The results for the NDVI patterns of 1995 are summarized in Table 3 and the graphs are shown in Fig. 7. In general the pattern is clear. The NDVI values rise until May, and then there is a sudden drop, indicating that the winter crops are harvested, after which the values rise again in response to the summer crops. The most important outlier in the series corresponds to NOAA image of day 212. The time series shows that this image should be corrected or discarded. Probably the deviation is caused by atmospheric conditions, which have not been corrected for. There are some distinct differences for the individual irrigation areas, which are briefly discussed below. For an extensive discussion of winter and summer cropping patterns see Salemi et al. (2000) and Sally et al (2001). Results presented here are based on average NDVI values for the gross command area rather than cropped areas. This makes comparison between systems somewhat difficult.

<u>Nekouabad</u>

The pattern is uniform for both right and left bank systems. There is a steep rise in NDVI values and a sudden drop towards the end of May, indicating simultaneous harvesting of all winter crops (mainly wheat and barley) in the system, combined with flooding of areas in preparation for rice planting. After this, NDVI values rise again in response to the growth of the summer crops (mainly rice, corn, potato, onion). The background NDVI of about 0.1 is due to all year crops (orchards and alfalfa). Harvesting of the summer crops takes place more gradually, leading to a steady decline in NDVI values after August.

<u>Abshar</u>

The right bank system has consistently higher NDVI values than the left bank system. This is probably due to the large rock outcrop areas in the left bank system. The pattern is similar to that of the Nekouabad system, again with a sharp drop in NDVI values, indicating harvesting of the winter crops. However, NDVI values build up much more slowly for the summer crops and the maximum NDVI values for these crops are lower than for the winter crops. This is probably caused by the relatively more diverse cropping patterns (more corn and vegetables) as compared to the Nekouabad system (where rice is dominant).

Rudasht

Rudasht East lies closer to the tail end of the system (Gavkhoni salt marshes) than Rudasht West (see Fig. 1). Although one would expect NDVI values to be less in the eastern part where water quality is worse than in the western part, the opposite is found: NDVI values are consistently higher in the East than in the West. Perhaps the difference is due to variations in land suitability, caused by e.g. soil salinity and rock outcrop. The harvesting pattern in both areas is much more gradual than in the Nekouabad and Abshar systems.

Borkhar, Lenjanat and Mahyar

Borkhar NDVI values are consistently low around 0.1, reflecting the heterogeneous nature of this area. Irrigation traditionally took place by groundwater. Recently, an irrigation canal from the Nekouabad system was constructed. Large parts of this area remain fallow during the year, leading to low NOAA NDVI values because the large majority of the pixels consist of a mixture of bare soil and irrigated fields of relatively small size.

The Lenjanat NDVI values are also low. However, they show a more distinct pattern comparable to that of the Nekouabad system. The reason for this is that the Lenjanat district should actually be split up into two parts:

- The areas in the Zayandeh Rud Plain are irrigated with river water and the cropping pattern is similar to that of the Nekouabad system.
- Away from the river, irrigation takes place by groundwater and fields are scattered between vast areas of bare soil and rock outcrop.

Finally, the Mahyar system is similar in behaviour to the Borkhar system.

NOAA derived actual irrigated areas during 1995

The results are summarized in Table 4 and the graphs are shown in Figure 8. All areas were calculated according to the calibration procedure described above, with 2.7266 as value for the regression constant. It should be noted that the regression analysis was made for the period July-August 1999 using 5 NOAA images and a Landsat 7 image of 1 August 1999. The calibration is therefore valid for the summer crop period during the maximum NDVI period. It is not correct to assume that the calibration is valid for all times of the year. When the crop is in its initial stage, the relation between NDVI and irrigated area is not straightforward and needs further calibration against Landsat images of different seasons. It is probably best to interpret the maxima in the graphs of Fig. 8 as the actual irrigated areas.

The pattern of the graphs of Fig. 8 is of course very much the same as that of the graphs in Fig. 7. However, the differences in areal extent of the Left and Right Bank systems of Nekouabad and Abshar systems now show up very clearly.

Table 3. Average NDVI values of the irrigation systems along the Zayandeh Rud (1995).

day	Abshar left	Abshar right	Borkhar	Lenjanat	Mahyar	Nek left	Nek. right	Rudasht east	Rudasht west
53	0.112	0.137	0.087	0.053	0.089	0.095	0.097	0.094	0.080
81	0.129	0.161	0.080	0.046	0.073	0.116	0.102	0.132	0.090
91	0.196	0.237	0.108	0.118	0.113	0.177	0.179	0.176	0.123
119	0.205	0.280	0.093	0.104	0.101	0.217	0.246	0.243	0.174
128	0.229	0.298	0.130	0.130	0.091	0.267	0.259	0.255	0.179
137	0.232	0.297	0.123	0.129	0.091	0.272	0.256	0.263	0.177
138	0.249	0.306	0.124	0.134	0.097	0.269	0.283	0.248	0.168
146	0.205	0.241	0.088	-0.005	0.061	0.040	0.083	0.228	0.158
156	0.138	0.143	0.065	0.060	0.035	0.150	0.141	0.212	0.138
174	0.161	0.199	0.091	0.113	0.061	0.230	0.179	0.143	0.108
184	0.151	0.168	0.077	0.101	0.056	0.206	0.172	0.133	0.092
193	0.134	0.152	0.078	0.104	0.048	0.221	0.196	0.123	0.088
202	0.140	0.166	0.083	0.115	0.050	0.230	0.223	0.144	0.088
212	0.180	0.243	0.100	0.150	0.059	0.357	0.345	0.186	0.101
221	0.182	0.224	0.108	0.141	0.083	0.274	0.280	0.181	0.112
230	0.161	0.215	0.089	0.123	0.061	0.246	0.264	0.157	0.090
231	0.167	0.238	0.093	0.135	0.069	0.263	0.275	0.156	0.086
239	0.175	0.227	0.096	0.124	0.072	0.265	0.280	0.162	0.092
249	0.179	0.240	0.097	0.122	0.076	0.251	0.275	0.157	0.092
267	0.191	0.250	0.105	0.117	0.082	0.260	0.253	0.151	0.099
268	0.189	0.255	0.106	0.112	0.081	0.260	0.256	0.155	0.098
277	0.183	0.230	0.091	0.098	0.071	0.234	0.202	0.141	0.082
286	0.158	0.211	0.069	0.086	0.051	0.202	0.174	0.125	0.067
323	0.131	0.142	0.077	0.075	0.061	0.155	0.119	0.112	0.073
332	0.150	0.157	0.097	0.099	0.084	0.159	0.136	0.110	0.084
360	0.007	0.007	0.009	0.039	-0.014	0.016	0.012	-0.004	-0.003

Table 4. Irrigated areas from the NOAA NDVI (1995) values calibrated by Landsat 7.

day	Abshar Left	Abshar Right	Borkhar	Lenjanat	Mahyar	Nekouabad Left	Nekouabad Right	Rudasht East	Rudasht West
53	13819	8282	17749	2937	9091	9273	5086	5388	4309
81	15647	9245	13661	2330	6211	10994	4666	7254	4992
91	26281	13326	21245	12233	11694	17803	9352	9787	7364
119	27458	16789	17479	10310	10276	22702	13500	14476	10967
128	30457	18396	26538	13402	8740	28069	14317	14993	11484
137	30147	16968	24537	13174	7920	27138	13444	15246	11011
138	33927	18047	25570	14682	9001	28118	15562	14856	10786
146	26563	14050	15825	0	3862	2918	3708	13160	9601
156	17764	8200	10897	4553	1157	14221	7196	12347	8439
174	20642	11369	15595	11186	3540	23511	9373	8202	6482
184	20365	10379	13058	9504	2910	22067	9799	8126	5409
193	16934	9015	12360	9680	1749	22888	10744	7093	5042
202	18133	9622	13736	11068	1805	23531	12316	8503	4831
212	22985	14248	17907	14825	3723	36862	17889	10684	5904
221	24001	12877	20980	14585	7701	27004	14910	10368	6761
230	21287	12501	16441	12228	4032	25126	14570	8984	5095
231	21766	14092	17300	13589	5540	27254	15116	9270	4937
239	22836	13424	18071	12253	5891	27234	15123	9266	5305
249	23307	14125	18457	12333	6413	26084	14627	9233	5282
267	24839	14534	20272	11493	6966	26193	13502	8411	5643
268	25812	15955	22424	12409	7207	28240	14903	9519	6068
277	23421	13323	16299	9035	5097	23479	10376	7917	4341
286	21202	12818	10290	7704	2797	20898	9617	7007	3317
323	16775	8211	12474	6621	3622	15819	6285	6338	3636
332	20328	9411	19901	10603	8619	16276	7347	6164	4657
360	0	0	244	1819	0	321	0	0	0

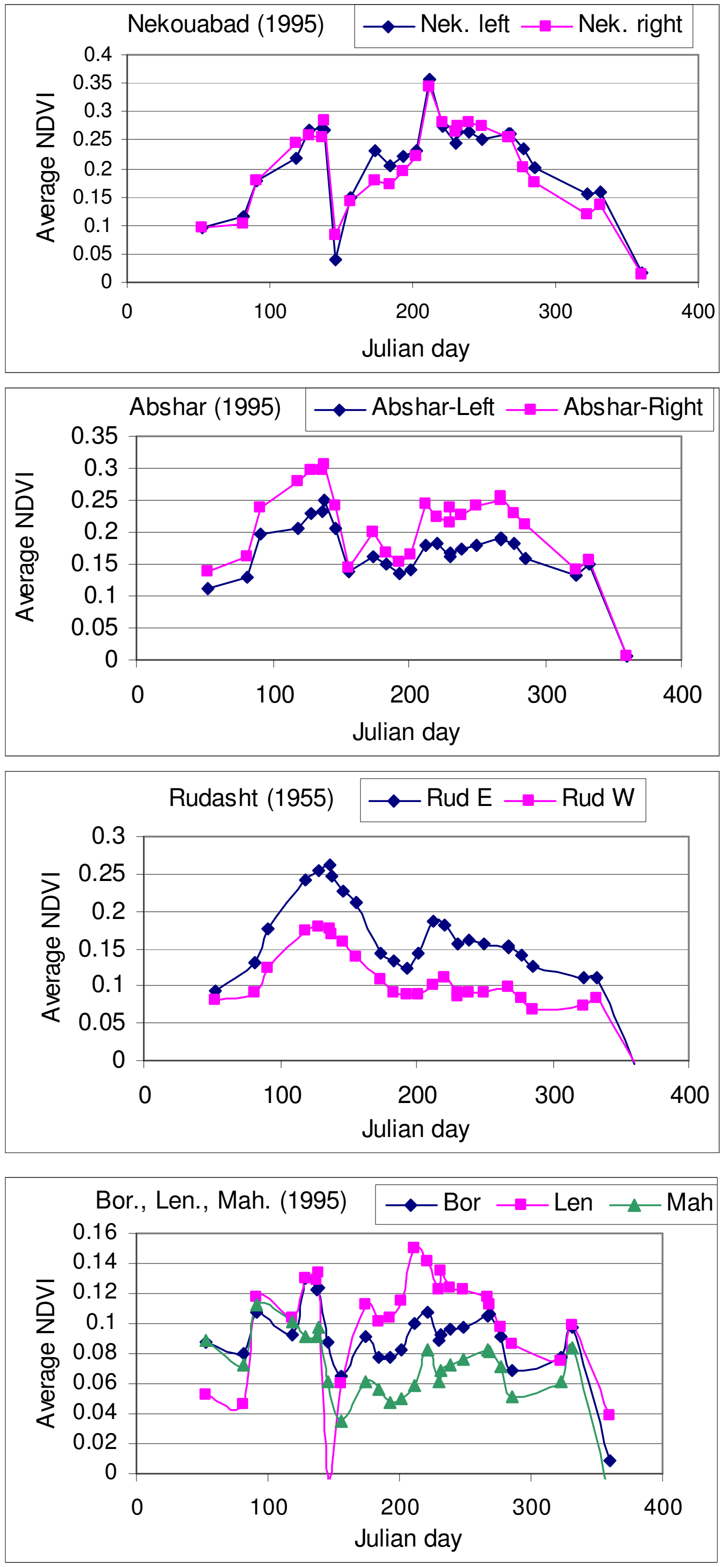

Figure 7. NDVI-time curves for 1995 (26 NOAA-14 images).

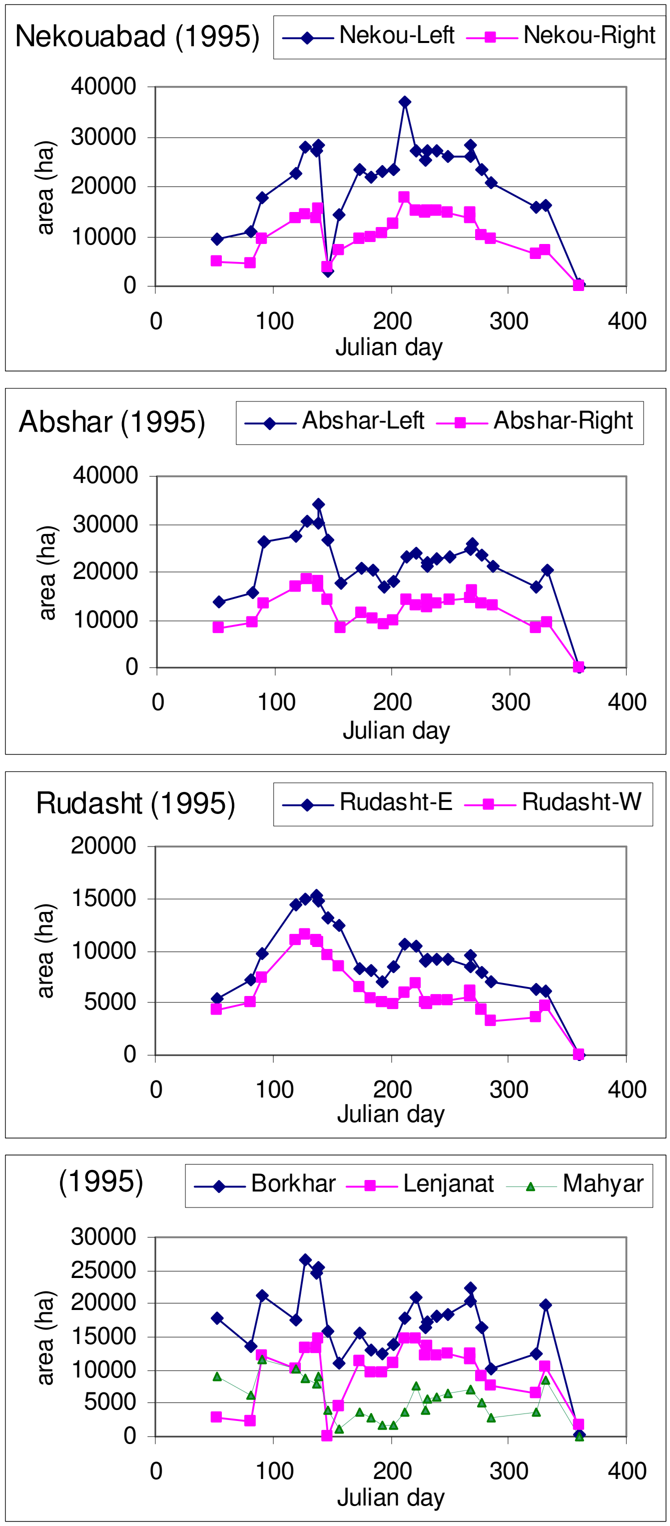

Figure 8. Area-time curves for 1995 (area derived from calibration of NOAA against Landsat7).

Table 5 shows that in general the calibration procedure seems to work well for the homogeneous areas of Nekouabad, Abshar and Rudasht, and less for the more heterogeneous areas of Borkhar, Lenjanat and Mahyar. In these areas NDVI values are generally low because of the more scattered and isolated fields. Under these circumstances the choice of an NDVI threshold (0.06 in the present case) becomes very critical to the area calculation.

Discussion

The procedures to download and process NOAA-14 images were discussed in this paper. In general, the technological developments with regard to Internet and the Satellite Active Archive (SAA) make it possible to download images of only several days old. Thus it becomes possible to monitor the agricultural situation almost real-time at very little cost. The disadvantage of course is the low resolution with 1 km pixel size at best. The pre-processing of the images was done satisfactorily with the packages NPR1b and ILWIS. However, some attention should be spent on atmospheric corrections, as some of the NOAA images showed significant reflection differences between successive days.

With regard to the calibration procedure, 5 NOAA images (July-Aug 1999) were used to calibrate the actual irrigated areas against a Landsat 7 image of 1 August 1999. The calibration is strictly speaking only valid for that time period, and can only be extrapolated to similar time periods of other years if crop patterns are not changing. Furthermore, a separate calibration is required for evaluation of the irrigated winter crop area. Finally, the calibration seems to work best for homogeneous areas, such as Abshar and Nekouabad. For heterogeneous areas such as Borkhar where irrigated fields are scattered in a predominantly non-vegetated background, NOAA NDVI values become rather low and consequently the regression relations are less reliable.

Comparison between different years, however, becomes possible. As an example a comparison is made between the actual irrigated areas of July-August 1995 (average of 7 images) and the areas of the corresponding time period in 1999 (average of 5 images), which was used in the calibration process. The results are summarized in Table 5 and Fig. 9.

Table 5 Comparison of the irrigated areas for the periods July-August 1995 (average of 7 images) and the calibration period July-August 1999 (average of 5 images).

		July-Aug 1995 (ha)	July-Aug 1999 (ha)	increase (ha)
Abshar	Left	20760	22948	2188
Abshar	Right	11701	12555	854
Borkhar		15992	17980	1988
Lenjanat		11844	13251	1407
Mahyar		4233	5761	1528
Nekouabad	Left	25015	25974	959
Nekouabad	Right	13225	13608	383
Rudasht	East	8801	8270	-531
Rudasht	West	5340	5500	160
	totals	116912	125847	8935

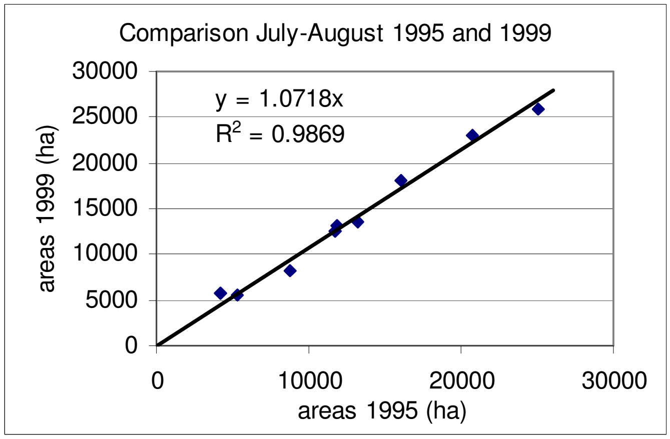

Figure 9. Comparison of the actual irrigated areas for the periods July-August 1995 and 1999.

Fig. 9 shows that the actual irrigated area was 7% higher in 1999 than in 1995, amounting to a total increase of 9000 ha. Comparison of the individual irrigation areas (Table 5) shows that the largest percentage increase is for Mahyar (36%), while the irrigated of Rudasht East has gone down compared to 1995 (-6%). The quality of the regression line of Fig. 9 is very good, which underlines the consistency of the methodology outlined in this paper.

Further work will concentrate first on processing more NOAA-14 images for the study area from 1995 to 2000 and make more calibrations against Landsat-7 images if available. Work on related applications, which also make use of the processed NOAA-14 time series, such as the determination of biomass, actual evapotranspiration, irrigation performance (Droogers et al., 2001) and crop pattern analysis (Sally et al., 2000) has been carried out as well.

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