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

# Assessment of Irrigation Performance Using NOAA Satellite Imagery

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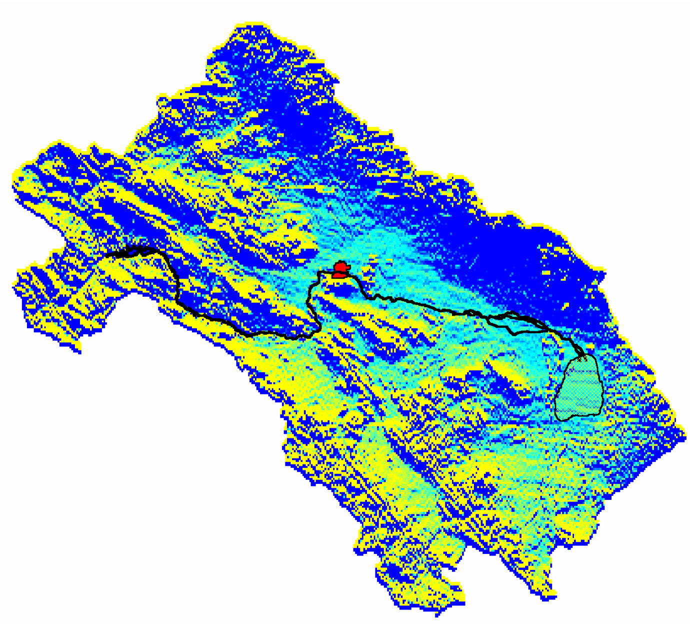

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The IAERI-EARC-IWMI collaborative project is a multi-year program of research, training and information dissemination fully funded by the Government of the Islamic Republic of Iran that commenced in 1998. The main purpose of the project is to foster 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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# Assessment of irrigation performance using NOAA satellite imagery

**P. Droogers, W.G.M. Bastiaanssen, A. Gieske, N. Toomanian, M. Akbari**

## Abstract

*Performance of four irrigation systems in the Zayandeh Rud Baisn, Iran, was assessed for the systems as a whole, rather than on only official registered water extractions and uses. NOAA satellite images were analyzed using the SEBAL (Surface Energy Balance Algorithm for Land) algorithm to obtain evapotranspiration, biomass production, and soil moisture contents. The missing term in the water balance was used to estimate groundwater extractions and unaccounted extraction from the river. For Abshar-Left groundwater extraction surpassed surface water applications, while for Nekouabad-Left groundwater extractions were very low. For Abshar-Right a large amount of water was pumped directly out of the river. The assessment of the systems was expressed by the Productivity of Water, defined as kg biomass over* $m^3$ *water evaporated. Productivity was higher (~0.72 kg* $m^{-3}$*) for the systems relying on surface water (Nekouabad-Left and Abshar-Right) than for the conjunctive systems, reflecting the difference in water quality between groundwater and surface water. Finally, it was concluded that the advantages of the methodology presented here over the traditional assessments are: (i) most data is readily available, (ii) all water users are included, (iii) groundwater extraction can be estimated, and (iv) a real time assessment can be set up using this approach.*

# Introduction

Increasing pressure on water resources requires a sound knowledge of where, when and how much water is used. Agriculture, and especially irrigated agriculture, is the main global water consumer and, consequently, a more productive use in this sector will have a large impact. Moreover, it is estimated that by 2025 cereal production will have to increase by 38% to meet world food demands (Seckler et al., 1999), putting even more stress on the scarce water resources.

Traditionally, performance of irrigated agriculture has been expressed in terms of efficiencies based on observed flows in different points in the water distribution system, such as reservoir releases, main, secondary and tertiary canal, field, and plant. The ratio of the flow at a lower level to the flow at a higher level defines the efficiency of that particular part of the system. For example, the ratio of total water received at the field by farmers over the releases of a reservoir is defined as the system efficiency. Similar, the ratio of total evapotranspiration on a particular field over water delivered to that field is defined as the application efficiency. The main objective of irrigation engineering has always been to increase those efficiencies. A serious drawback of this approach is that water considered as a loss, indicated by a low efficiency, is not a real loss but is often used somewhere else. This "lost" water is likely to be used by downstream users, or percolating to the groundwater, or used for "illegal" irrigation activities. In other words, increasing efficiencies requires additional water deliveries to the previous users of this "lost" water.

To overcome these problems with efficiencies, Molden and Sakthivadivel (1999) described a conceptual framework for water accounting, based on inflows and outflows. The framework includes the assessment of system performance in terms of the Productivity of Water (PW), defined as the amount of water used to produce 1 kg of crop. Different PWs were identified, based on different definitions of water used. Here we apply only $PW_{process\ depletion}$, which refers to the amount of water evaporated to produce 1 kg of crop. A practical example of the use of other PWs can be found elsewhere (Droogers and Kite, 1999).

Recently, new technologies based on RS have been introduced to monitor several components of the water balance. Main advantage of this approach is that large areas are covered, and that data is easily obtainable without extensive monitoring networks in the field. The SEBAL (Surface Energy Balance Algorithm for Land) algorithm (Bastiaanssen et al., 1998) estimates the energy balance based on remote sensing (RS) images resulting in actual evapotranspiration. The algorithm includes additional features to estimate crop production and soil moisture contents. For the four main irrigation systems in the Zayandeh Rud Basin, Iran, the SEBAL algorithm was applied, using NOAA-AVHRR (National Oceanographic and Atmospheric Agency – Advanced Very High Resolution Radiometer) images, and results were used to assess the performance of these systems.

In summary the objectives of this study: (i) use satellite images to estimate evapotranspiration and crop yields, (ii) estimate the performance of irrigation systems based on this information, and (iii) estimate groundwater extraction as the closing term of the water balance.

# Materials and Methods

## Study Area

The four main irrigated areas in the Zayandeh Rud basin, 41,500 $km^2$, have been selected to analyze the performance of irrigated agriculture (Figure 1, Table 1). The main river, the Zayandeh Rud, runs for some 350 km roughly west-east from the Zagros mountains to the Gavkhuni Swamp. The majority of the basin is a typical arid and semi-arid desert.

The gross command area of the four systems is about 135,000 ha, while net command area is about 92,000. Cropped area is between 70 and 80%, but cropping intensities can be much higher as a substantial area is used to grow two crops. Main winter crops are wheat and barley (November-May/June), summer crops are rice (June-October) and vegetables (March-October). Perennial crops encompass orchards and alfalfa. Rainfall is very limited, around 130 mm $yr^{-1}$, most of it occurring in the winter months from December to April. Temperatures are hot in summer, reaching an average of 30°C in July, but are cool in winter dropping to an average minimum temperature of 3°C in January. Obviously, reliable irrigation is the only way to have any economic form of agriculture. Detailed description of the study area can be found in Salemi et al. (2000) and Murray-Rust et al. (2000).

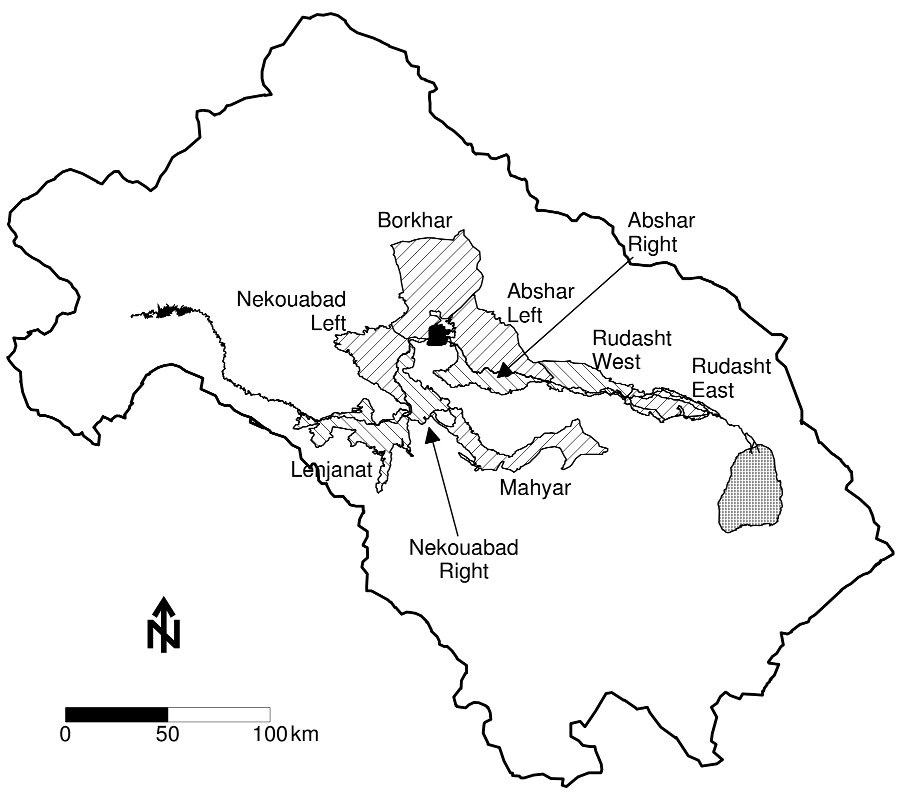


**Figure 1. Main irrigation systems in Zayandeh Rud Basin.**

**Table 1. Area of irrigation systems included in the analyses and total and cropped areas based on a NDVI criterion of 0.2 for April and September.**

| System | Designed | NOAA | Cropped | NOAA |
|---|---|---|---|---|
| | ha | ha | ha | % |
| NKB-R | 13,500 | 20532 | 16631 | 81 |
| NKB-L | 48,000 | 38863 | 30313 | 78 |
| ABS-L | 15,000 | 52370 | 38754 | 74 |
| ABS-R | 15,000 | 22565 | 16247 | 72 |

## NOAA images

Satellite images are more and more used to explore ways to optimize the management of natural resources. Landsat and SPOT images are used frequently as they provide high resolution images. However, overpass frequency is limited and, despite recent substantial price reduction for Landsat, still expensive to use as a monitoring tool. NOAA-AVHRR images are free of charge, are direct available, and overpass frequency is once a day. Resolution is limited to about 1 x 1 km at nadir. The recently launched MODIS satellite has the same features as NOAA, except that resolution has improved to 250 x 250 m. As this study emphasizes the use of satellites as a monitoring tool, and MODIS is still in a testing phase, we selected to use NOAA images.

Twelve NOAA images as well as some additional required meteorological data and streamflow data, were available for 1995. Images were radiometrically and geometrically corrected and geo-registered. Details of this procedure can be found in Gieske et al. (2000).

## Remote sensing algorithm SEBAL

The Surface Energy Balance Algorithm for Land (SEBAL) calculates both the instantaneous and 24-h integrated surface heat fluxes. The latent heat flux represents the energy required for ET, and is computed as the residual of the surface energy balance. Remotely sensed estimates of surface albedo, surface temperature and surface thermal infrared emissivity are used to compute spatial variations in reflected short-wave and emitted long-wave radiation away from the land surface. The incoming solar and atmospheric long-wave radiation are considered to be constant in the space domain during the moment of image acquisition (the atmosphere was cloud free). Combination of the short and long wave radiation yields the possibility to compute the net radiation absorbed at the surface for every pixel of a NOAA image. Net radiation is partitioned into soil, sensible and latent heat fluxes. The soil heat flux is the energy engaged to soil warming, and it is computed as an empirical fraction of the net radiation using surface temperature, surface albedo and the normalized vegetation index as the depending variables. The sensible heat flux is computed first for two specific land surfaces: one pixel with a high surface temperature where the latent heat flux is negligibly small and for a cold pixel where the sensible heat flux is negligibly small. Although the sensible heat flux might be negative during periods of intermittent cloud cover and when the upwind area is dryland, none of these conditions prevailed during the NOAA overpass days. The aerodynamic resistance is the transfer coefficient for heat transport and is calculated from the logarithmic wind profile between the blending height, where the wind speed is aerially constant, and the surface roughness length for momentum transfer. Combining the aerodynamic resistance with the extremes of sensible heat flux at the specially selected land surfaces, allows the assessment of the range of near-surface vertical air temperature differences. The surface temperature is thereafter applied to interpret the vertical air temperature differences over the region, assuming linearity between surface temperature and vertical thermal gradients in the air layer adjacent to the land-atmosphere interface. The first estimate of sensible heat flux is used to correct turbulent heat transport for buoyancy effects following the concepts of the Monin-Obukhov similarity theory. The resulting evaporative fraction describes the energy partitioning of the surface energy balance as the latent heat flux/net available energy fraction, with the net available energy being defined as the difference in net radiation and soil heat flux. The instantaneous evaporative fraction is shown in the literature to be similar to the 24-h evaporative fraction (Shuttleworth et al. 1989, Brutsaert and Chen, 1996), and this allows us to estimate the latent flux at a 24-h basis.

The surface temperature is a key parameter in the surface energy balance, and its magnitude directly affects the sensible and latent heat flux, the evaporative fraction and the ET. Surface temperature can be regarded as an ultimate indicator for root zone soil water conditions, without the need to model soil-physical processes and irrigation and rainfall events. A detailed description of the SEBAL algorithm is beyond the scope of this paper, but can be found in Bastiaanssen et al. (1998). Examples of applying SEBAL in other irrigation performance assessment studies are presented in Bastiaanssen et al. (1996), Roerink et al. (1997) and Alexandridis et al (1999).

# Results

## Spatial coverage April

Figure 2 shows an example of the results from SEBAL for April 1995. Irrigated areas can be clearly distinguished from the NDVI map with values of 0.20 and higher. High intensities can be found for the Abshar systems, reflecting the dominant cropping pattern with mainly winter crops. Interesting are also the relatively high intensities for the Rudasht-East system, indicating that during spring a reasonable amount of water is reaching this downstream area.

**Table 2. Annual water balance and Productivity of Water (biomass production / water supply). MCM is $10^6$ $m^{-3}$.**

| System | ETact | | Releases | | Precipitation | | Balance | | Biomass | | PWdepl |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | MCM | mm | MCM | mm | MCM | mm | MCM | mm | M kg | kg $ha^{-1}$ | kg $m^{-3}$ |
| NKB-R | 243 | 1183 | 181 | 882 | 25 | 123 | -37 | -178 | 193 | 9388 | 0.79 |
| NKB-L | 459 | 1180 | 477 | 1227 | 48 | 123 | 66 | 170 | 409 | 10528 | 0.89 |
| ABS-L | 484 | 924 | 230 | 439 | 64 | 123 | -190 | -362 | 356 | 6806 | 0.74 |
| ABS-R | 246 | 1088 | 201 | 891 | 28 | 123 | -17 | -74 | 223 | 9894 | 0.91 |

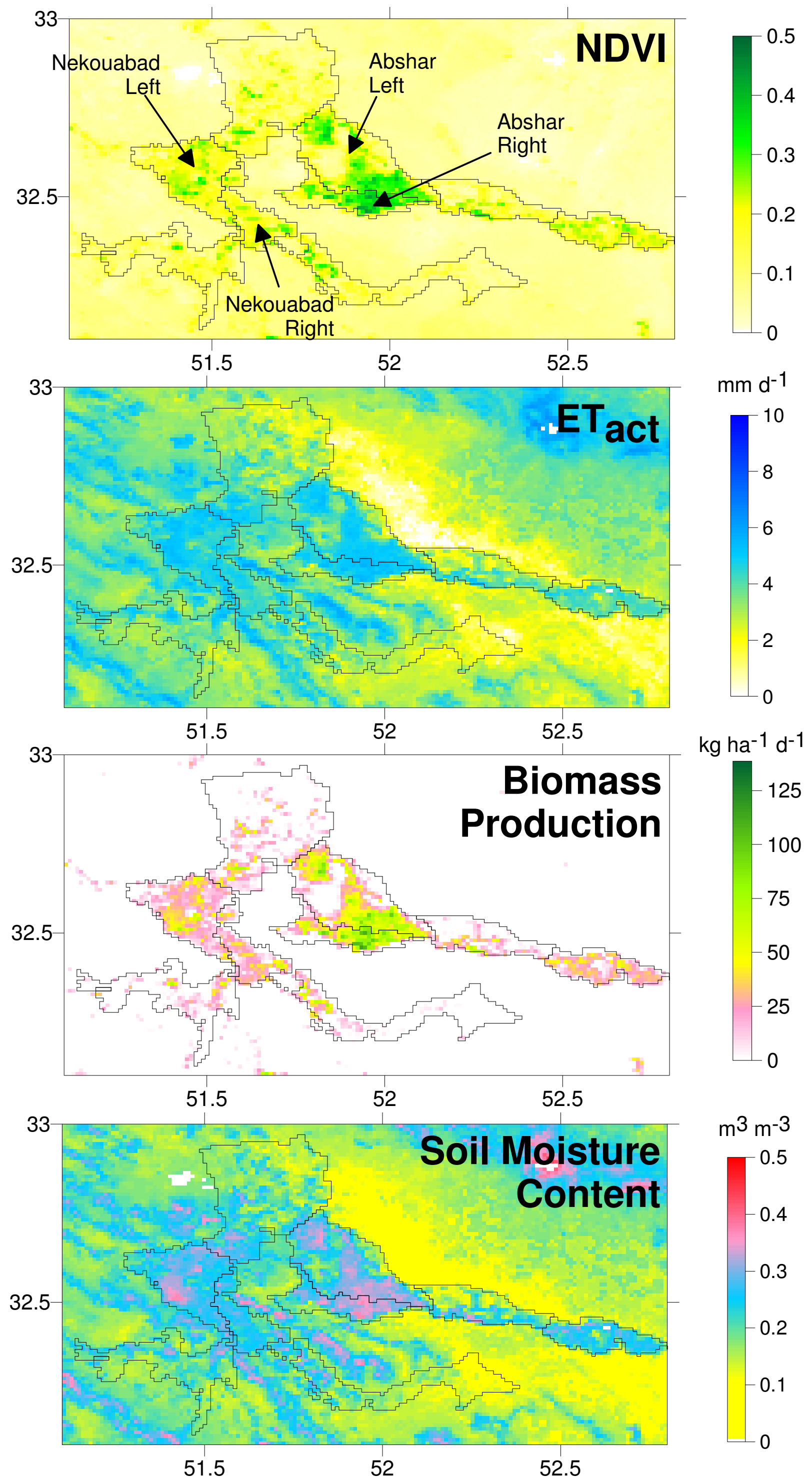


**Figure 2. Result of the SEBAL analyses for April 1995.**

$ET_{pot}$ (not shown in figure 2) values are about 6 mm $d^{-1}$ and are quite constant over the area as spatial variability in the prevailing weather conditions is low. Some lower values can be seen for the mountainous areas north of Abshar-Left as temperatures are lower resulting in lower $ET_{pot}$. Values of $ET_{act}$ show the same trend as NDVI levels in the irrigated systems: high NDVI values, correspond to high $ET_{act}$. However, in the mountainous areas outside the irrigation systems, also high levels of $ET_{act}$ show up. Probably, some of these could be explained by the limited rainfall in April, but in September, without any rain, also quite high values of $ET_{act}$ were found for these barren outcrop areas in the mountains. As described before, SEBAL is based on the energy balance where sensible heat flux is related to temperature. However, for hill-sloops surface temperatures can deviate substantially from the equivalent temperature for flat areas, and so the SEBAL results are unreliable for undulating areas. Therefore, the analyses will be only focussing on the flat irrigated areas.

The estimated crop productions can be considered as the integrating parameter of water and crop management. The Abshar system is clearly the most productive system in April, with daily biomass production values for some areas of 100 kg $ha^{-1}$ $d^{-1}$. For a crop with an active growing period of 120 days this translates to 12,000 kg $ha^{-1}$ biomass. The conversion factors from biomass to harvested product depends on crop, variety, and plant physiological condition, and values ranges from 10-30%, resulting in a actual yield of 1200 – 3600 kg $ha^{-1}$.

Finally, the estimated soil moisture contents show that most soils are reasonable wet, even soils without any crop (low NDVI). Also areas with an intensive cropping pattern (high NDVI) but a moderate soil moisture content can be seen, indicating that irrigation is required for these areas.

## Monthly values

Monthly NDVI values for the four main systems are shown in Figure 3. The dual cropping pattern can be observed with high NDVI values from March to May and from August to October. Lower values in June and July are the result of the end of the growing season for spring crops (wheat) and the start of the summer crops (rice). For Abshar-Right, and especially Abshar-Left, the peak for summer crops is lower as a result of the smaller area cultivated with rice.

$ET_{pot}$ is similar for the systems (Figure 3) and peak values for mid-summer are around 8 mm $d^{-1}$. $ET_{act}$ reflects again clearly the difference between the Nekouabad and the Abshar systems, with the latter one having a cropping pattern existing mainly out of winter crops harvested in June.

Crop growth peaks in May when climatic conditions in terms of radiation are optimal and sufficient water is available from precipitation, soil moisture storage, and irrigation. Soil moisture storage fluctuations can be seen in Figure 3, showing high values in May as a result of precipitation and irrigation. Low values can be seen for Abshar during the period July-October as a result of water extractions by crops.

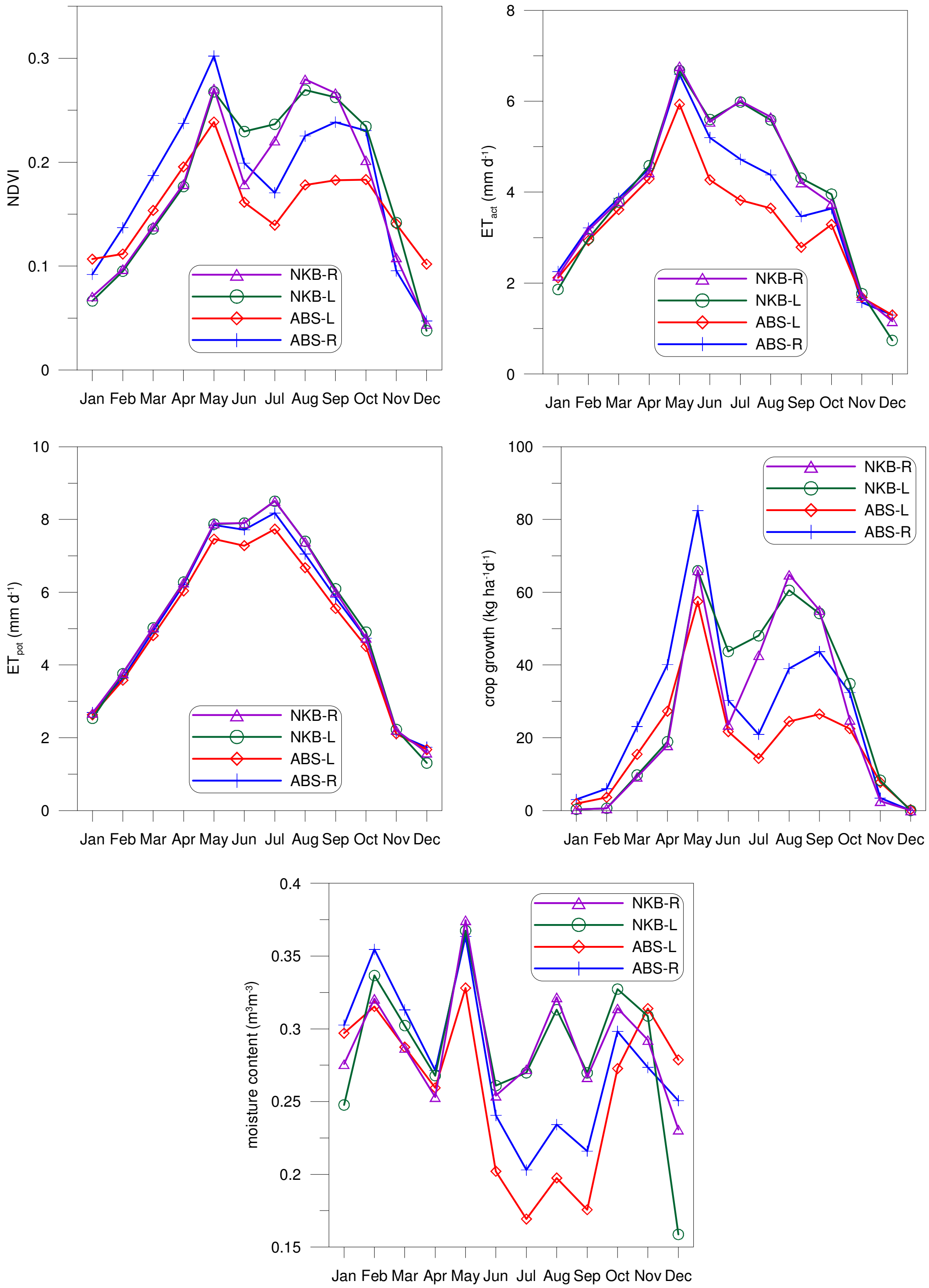


**Figure 3. Monthly values of NDVI, $ET_{pot}$, $ET_{act}$, biomass production, and soil moisture contents, for the four systems.**

## Annual values

For the four irrigation systems results were aggregated to annual totals (Table 2). Total areas presented here are gross command areas. This means that these figures include some non-agricultural areas but also some groundwater irrigated areas outside the actual command area, which enables making a total water balance of the systems rather than one based on only "official" surface irrigation. Cropped area was defined by taking the maximum NDVI value for each pixel in April and September and assuming that all values higher than 0.2 were cropped.

Releases for irrigation differ substantially from system to system. Figures presented here relate to the whole system area, rather than the areas served by surface irrigation. Converting these values to the official command areas leads to application rates between 1000 and 1500 mm $ha^{-1}$. Precipitation was considered to be similar for all areas, as distance between systems was limited, and, also, rates are low and thus less important on the whole water balance.

The overall water balances for the systems are not closed (Table 2) and three of the four systems show a water deficit. The apparent water surplus for Nekouabad-Left can be explained by the new offtake canal from Nekouabad-Left main canal to the new Borkhar system. It's unclear how much water was actually delivered to Borkhar, so the water supply to Nekouabat-Left only could not be determined.

The main question for the three water deficit systems is: "where is this other water coming from?" Two sources can be identified. First of all, a certain amount of water is extracted directly from the river, which is not included in the water balance. Second, groundwater irrigation is extensively applied in the area. Quantitative information about these two additional inputs in the systems is lacking, but can be estimated as the missing term in the water balance. For Abshar-Left this combined groundwater and unofficial water extraction is about 190 mm (Table 2). The designed command area of Abshar-Left is 15,000 ha, while the cropped area as determined by NOAA is almost 39,000 ha. It is clear that the additional areas are irrigated by groundwater. Nekouabad-Right and Abshar-Right show an annual deficit of 178 and 74 mm, respectively. Designed command area for these systems are 13,500 and 15,000 ha, while actual cropped areas are higher (Table 1). Using the data from the three deficit systems, a simple linear regression was developed ($r^2 = 0.87$) to assess the relationship between groundwater extractions, designed and actual cropped area:

$$Groundwater\ exraction = -132 \cdot \frac{designed\ area}{cropped\ area}$$

Finally, these results can be used to explore the productivity of the systems. As described before we used the Productivity of Water, expressed as the biomass production over the amount of water depleted by $ET_{act}$. Abshar-Left appears to be the least productive of the four systems. Groundwater quality in the Zayandeh Rud is much poorer than surface water, so for Abshar-Left, with its high percentage groundwater irrigation, this PW is low. For Nekouabad-Left, with limited groundwater irrigation, PW is high. Although groundwater extraction seems high for Abshar-Right, PW are not low. Probably, the negative values in the water balance for this system are mainly caused by unaccounted water extraction from the river rather than from groundwater.

**Table 3. Comparison between the current study (NOAA) and a supply and demand study based on Cropwat and cropping patterns (Sally et al. 2001).**

| System | NOAA | | Accounting | |
|---|---|---|---|---|
| | MCM | mm | MCM | mm |
| NKB-R | -37 | -178 | 34 | 166 |
| NKB-L | 66 | 170 | 66 | 170 |
| ABS-L | -190 | -362 | -74 | -141 |
| ABS-R | -17 | -74 | 75 | 332 |

# Conclusions

Recently, a water supply and demand study has been completed for the same irrigated areas (Sally et al., 2001), where supply was also based on observed extractions to the systems. Demand, however, was based on the cropping pattern and Cropwat calculations. So instead of the actual ET, the crop water demand was used. A major problem of the study was to get accurate data on cropping patterns. The first source was a huge database (only hardcopies) at village level, with many omissions and inaccuracies. The second database was at district level, which has different boundaries than the systems. The latter was used by overlaying these districts with the irrigation systems and assuming a homogenous distribution in cropping patterns. The study was based on a hydrological year rather than a calendar year as used in the current study. Comparison between the results from current study and this supply and demand study are shown in Table 3. In general the supply and demand study resulted in lower deficits, which is somewhat unexpected as potential ET (Cropwat) was used, rather than actual ET. On the other hand, the supply and demand study was based on reported cropped areas, which might be lower than the actual areas. Obviously, NOAA is based on the real cropped area. Further analysis should be done to compare the results of the two studies.

The main advantage of the methodology described here over the more traditional assessment methods is that the water balance of an entire system is considered. The traditional performance assessments use only the “official” areas and water extractions, resulting in biased conclusions. In many irrigation systems, the unofficial water users contribute substantially to the performance of the whole system, as they often rely on runoff or percolation losses from the “official” users, by using drain water or groundwater. In the methodology described here no distinction has to be made between these two groups and the entire system performance is assessed.

The methodology can also contribute to one of the most unknown factors in the management of irrigation water resources: groundwater extraction. As the method described here is based on the water balance of an entire system, the net groundwater extraction is obtained. Internal recycling within one system, percolation followed by pumping, cannot be determined. Although this figure of internal recycling might be important in terms of energy requirements, for optimizing water resources this is of no value.

The accuracy and validity of the SEBAL method has been demonstrated extensively (e.g. Bastiaanssen, 2000). The observed problems in undulating areas require more work, but as we have used only results from the flat irrigated areas, this does not interfere with the results presented. Estimates for cropped area have been derived by using a fixed threshold value for the NDVI. A more accurate method is presented by Gieske et al. (2000), but deviations appeared to be small.

Results from this study can be used as a Strategic Decision Support System (S-DSS); results from the past have been used to analyze the performance of the systems and can be used to make strategic decisions to improve this performance. Besides this S-DSS, the same methodology can be used in an Operational mode (O-DSS) where real time data acquiring can be used to make day-to-day decisions how to operate the scarce water resources. Such an approach is already semi-operational in some countries such as Sri Lanka and The Netherlands.

# References

Alexandridis, T., S. Asif, and S. Ali. 1999. Water performance indicators using satellite imagery for the Fordwah Eastern Sadiqia (South) Irrigation and Drainage Project. sensing data. IWMI Pakistan Research Report R-87. International Water Management Institute, Sri Lanka.

Bastiaanssen, W.G.M. 2000. SEBAL based sensible and latent heat flux in the irrigated Gediz Basin, Turkey. J. of Hydrology (in press).

Bastiaanssen, W.G.M., T. van der Wal, and T.N.M. Visser. 1996. Diagnosis of regional evaporation by remote sensing to support irrigation performance assessment, Irrigation and Drainage Systems 10, 1-23.

Bastiaanssen, W.G.M., M. Menenti, R.A. Feddes, and A.A.M. Holtslag. 1998. A remote sensing surface energy balance algorithm for land (SEBAL), 1. Formulation, J. of Hydr. 212-213, 198-212.

Brutsaert, W., and D. Chen. 1996. Diurnal variation of surface fluxes during thorough drying (or severe drought) of natural prairie, Water Resources Research, 32(7), 2013-2019.

Droogers, P., and G. Kite, 1999. Water productivity from integrated basin modeling. Irrigation and Drainage Systems 13: 275-290.

Gieske, A., N. Toomanian, and M. Akhbari. 2000. Monitoring NDVI of the main irrigation systems in the Zayandeh Rud Basin with NOAA/AVHRR during 1995. Trip report IAERI-EARC-IWMI mission 7, September 2000.

Sally. H., H. Murray-Rust, A.R. Mamanpoush, M. Akbari. 2001. Water supply and demand in four major irrigation systems in the Zayandeh Rud Basin, Iran. IAERI-IWMI Research Reports 8.

Murray-Rust, H., H. Sally, H.R. Salemi, A. Mamanpoush. 2000. An overview of the hydrology of the Zayandeh Rud Basin. IAERI-IWMI Research Reports 3.

Molden, D., and R. Sakthivadivel. 1999. Water accounting to assess use and productivity of water. Water Resources Development, 15, 55-71.

Roerink, G.J., W.G.M. Bastiaanssen, J. Chambouleyron, and M. Menenti. 1997. Relating crop water consumption to irrigation water supply by remote sensing, Water Resources Management, 11(6), 445-465.

Salemi H.R., A. Mamanpoush, M. Miranzadhe, M. Akbari, M. Torabi, N. Toomanian, H. Murray-Rust, P. Droogers, H. Sally, A. Gieske. 2000. Water Management for Sustainable Irrigated Agriculture in the Zayandeh Rud basin, Esfahan Province, Iran. IAERI-IWMI Research Reports 1.

Seckler, D., R. Barker, and U. Amarasinghe. 1999. Water scarcity in the twenty-first century. Water Resources Development 15: 29-42.

Shuttleworth, W.J., R.J. Gurney, A.Y. Hsu, and J.P. Ormsby. 1989. FIFE: the variation in energy partitioning at surface flux sites, remote sensing and large-scale global processes, Proc. Baltimore symp., IAHS Red Book Series, 186, 67-74.

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