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RESEARCH SUPPORT FOR
FORDWAH EASTERN SADIQIA (SOUTH)
IRRIGATION AND DRAINAGE PROJECT

WATER PERFORMANCE INDICATORS USING SATELLITE IMAGERY FOR THE FORDWAH EASTERN SADIQIA (SOUTH) IRRIGATION AND DRAINAGE PROJECT

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Abstract

Considering the need for the assessment of the performance of irrigation systems, the difficulties involved in data collection, and the non-availability of spatial information for the calculation of present performance indicators, a methodology using three indicators is presented. The performance is assessed in terms of water use, using adequacy, reliability and equity as indicators, which are described in statistical terms from a series of actual evapotranspiration and evaporative fraction maps of the Fordwah Eastern Sadiqia (South) project area. The maps were calculated using NOAA AVHRR satellite images that cover the period for rabi and kharif 93-94. Results reveal seasonal inadequacies of the water use based on target evaporative fraction values, as well as inadequacies in some distributary command areas. After a relative comparison of temporal fluctuations of the evaporative fraction, local unreliability is revealed. Considering the heterogeneity in the spatial distribution of the actual evapotranspiration as inequity, distributary command areas with uneven water use are indicated, and a decrease in the water use with an increasing distance from canals has been proved. Finally, a strong correlation between adequacy and equity has been determined, which leads to the conclusion that in areas where water is insufficient, management is a difficult task.

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to friends +

Abbreviations

AVHRR	advanced very high resolution radiometer
EF	evaporative fraction (Λ)
ETact	actual evapotranspiration over 24 hours
FES(S)	Fordwah Eastern Sadiqia (South)
GCA	gross command area
NOAA	national oceanic and atmospheric administration
SEBAL	surface energy balance algorithm for land

Part A: BACKGROUND

1. Introduction

Improved irrigation management is required for an increase in food production, since irrigated agriculture plays a major role in establishing the food security of most Asian countries. Performance assessment is considered a critical element to meet this target. Reasons for performance assessment of irrigation systems can be summarized with the following: to assess the general health of a system, to assess impacts or interventions, to compare actual results to planned targets, to improve system operations and to compare the performance of a system with others or with the same system over time.

Conventional surveys are based on overall estimates about the productivity of the total command area; they are rarely adequate to provide spatially distributed estimates within a command area. On the other hand, satellite remote sensing data can provide information on cropped area, cropping pattern and crop productivity in irrigation systems (Thiruvengadachari and Sakthivadivel, 1997). The ability of the satellite remote sensing to provide spatial data and monitor changes during a season and across years allow the performance of irrigation systems to be assessed effectively.

In this study, the spatial and temporal distribution of the total water used is described in statistical ways. This conjunctive water use approach is advantageous as it deals with the situation in view of the water that is evapotranspirated by the plants and fields, i.e. in view of the crop health. Therefore, the availability of water for the fields is checked independent of the source of the water (surface irrigation, groundwater irrigation, rainfall, canal seepage, capillary rise). The aim of the study is to assess the performance of the Fordwah Eastern Sadiqia (South) irrigation and drainage system, using as performance indicators the adequacy, reliability and equity in the spatial and temporal distribution of water use in the area, for rabi and kharif 93-94.

2. The Fordwah Eastern Sadiqia (South) Irrigation and Drainage System

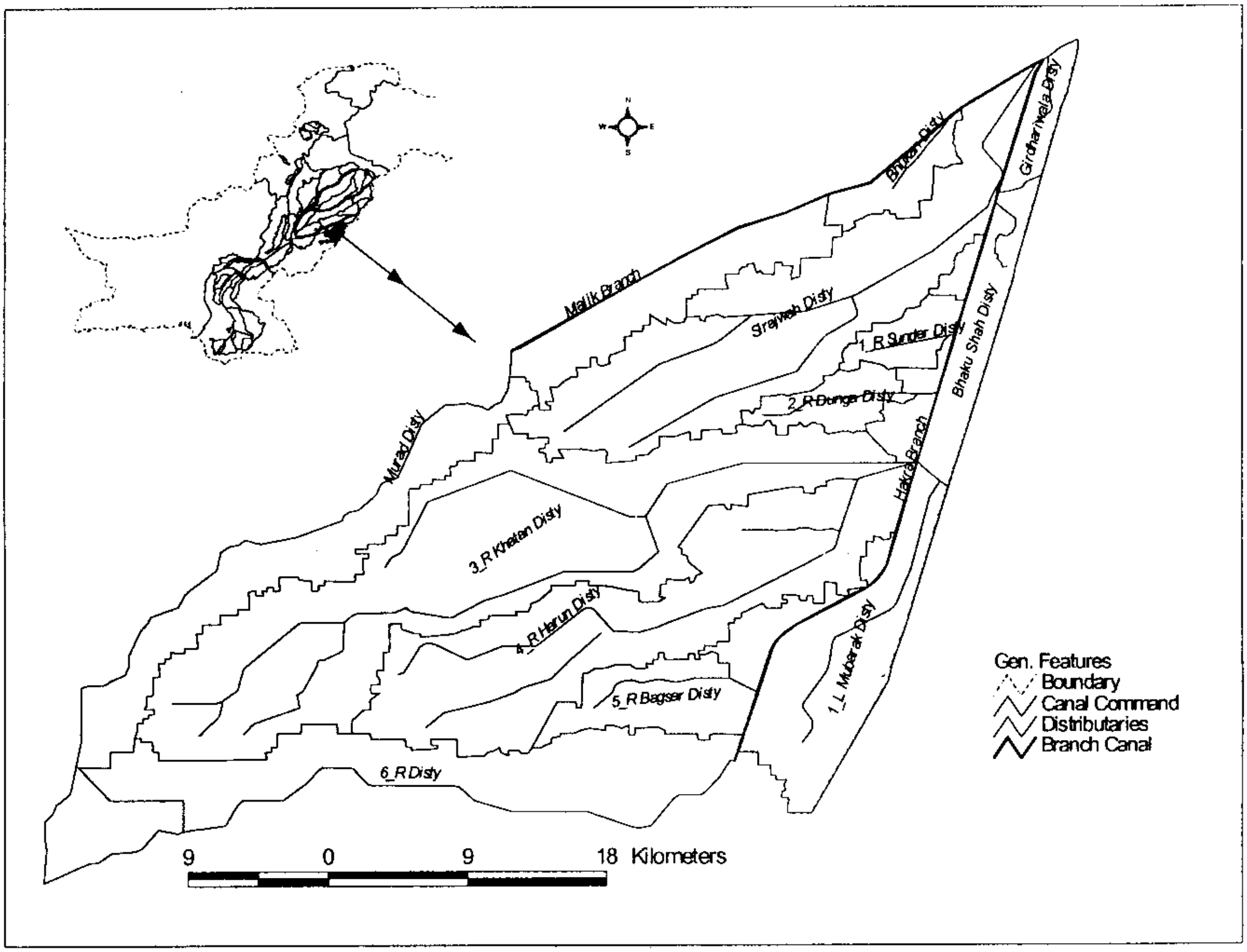
The Fordwah Eastern Sadiqia (South) (FESS) project area is located in the south-eastern Punjab Province, in the Bahawalnagar District. The area is bordered on the north-west by the Malik Branch Canal, on the south by the 6-R Distributary of the Hakra Branch, and on the east by India. The gross command area (GCA) under the FES(S) project is 137,000 ha. The surface water is distributed from distributaries from the Hakra and Malik Branches, from minors and direct outlets. The distributary command map is presented in Figure 1.

The area has an arid climate, except during the July to September monsoon season. The average annual rainfall is about 246mm. The area falls in the "Cotton-Wheat" agro-climatic zone, where conditions permit two growing seasons (rabi and kharif). The cropping pattern shows that wheat and cotton are the dominant crops for rabi and kharif, respectively, while the second major crop during both seasons is fodder. The topsoil is generally medium textured, and the topology is largely flat with no natural drainage. Sand dunes occupy about 6 percent of the area (WAPDA report, 1995).

The irrigation system follows the warabandi principle, and the irrigation turn time averages almost an hour per hectare. An overwhelming number of operators of the tail reach (90 percent) and 92 percent along the upper reaches reported an shortage of irrigation water during the survey year of 93-94. Mean number of irrigation turns applied to sugarcane, cotton, rice and wheat are 9, 4, 10 and 4, respectively. These are much lower than that recommended for sugarcane, but are comparable for the other crops.

About 50 percent of the project area is waterlogged with a water table within 5 feet. Waterlogging appears mainly in the central and north-east parts of the area. Waterlogging first appeared on lands in the upper reaches of the Hakra Branch and is gradually moving downstream. About 12 percent of the area is affected by soil salinity above tolerance levels of most crops. A comparison with previous surveys indicates an increasing trend over time (WAPDA report, 1995).

Figure 1 - Physical map and location map of the FES(S) project area



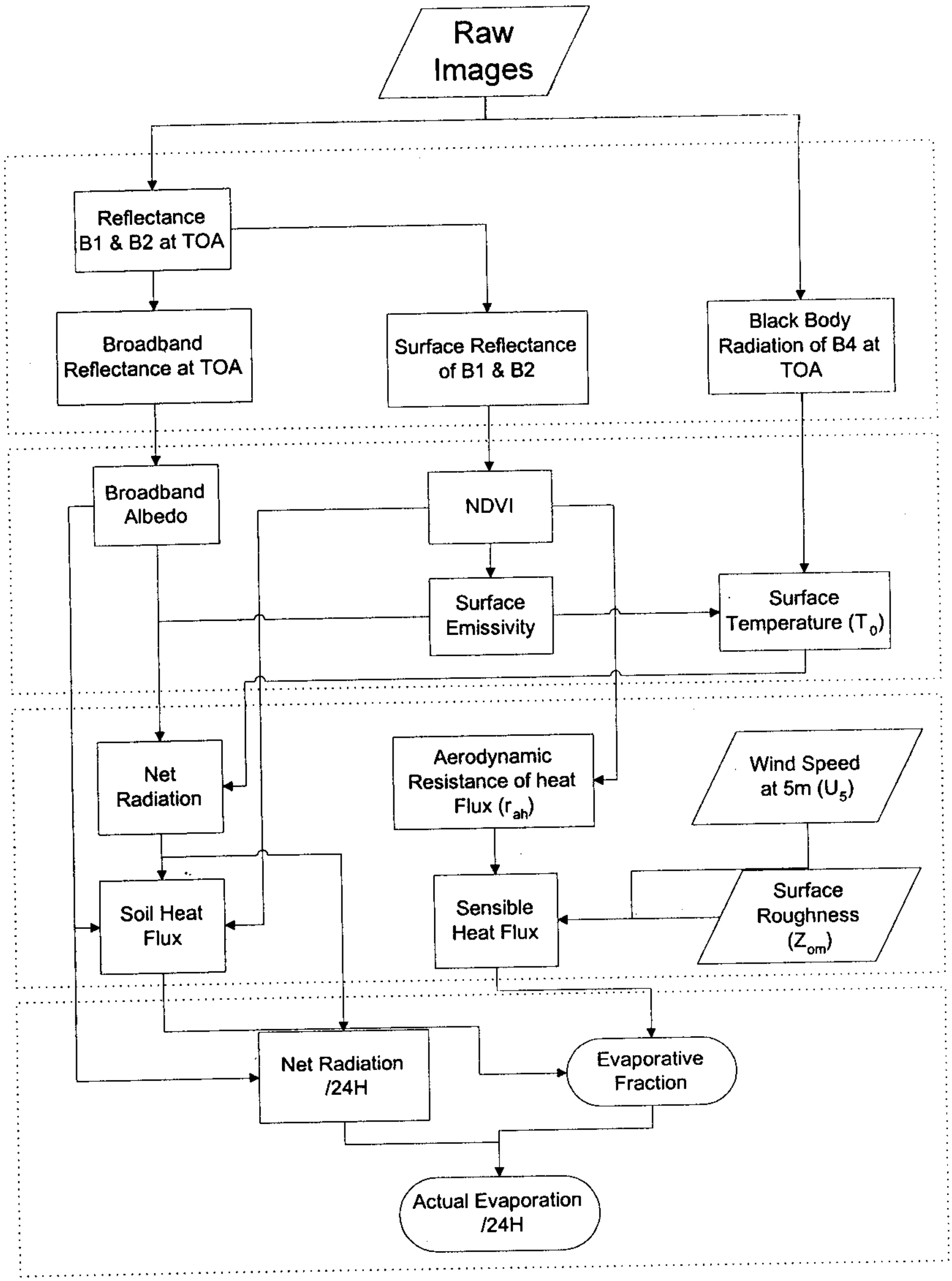
3. Materials Used

3.1 Image Processing

Satellite images were acquired for the period of October 1993 to September 1994, from the AVHRR sensor of the NOAA satellite. The spatial resolution of the sensor is 1.1 km at nadir, the radiometric resolution is 10 bits per word, and images can be acquired twice a day. The frequent overpasses make the AVHRR data useful for monitoring purposes, when compared with higher resolution satellites (e.g. SPOT, Landsat, IRS). The AVHRR images cover a total swath of 2,400 km and are adequate for national scale projects.

Reflected and emitted energy can be recorded from AVHRR in five spectral bands: band 1 in the visible range of the electromagnetic spectrum, band 2 in near-infrared, band 3 in mid-infrared, and bands 4 and 5 in thermal infrared. All spectral bands and other products were implemented in the Surface Energy Balance Algorithm for Land (SEBAL) model (Bastiaanssen, 1995) in order to estimate the actual evapotranspiration over 24 hours and the evaporative fraction, which were used in this study to express the performance indicators. The actual work is extensive and laborious, and the

Figure 2 - Flow chart for ETact and EF calculations



details are not in the realms of this study. The theory behind the estimations is summarized below. Details can be found in the work of Bastiaanssen et al. (1996), Moran et al. (1994) and Ud Din Ahmad and Chemin (forthcoming), in which all steps and calculations are described in detail. The flowchart, which describes the steps and the intermediate products, is shown in Figure 2.

The thermo-dynamic equilibrium between the moisture and heat flow in the soil-vegetation-atmosphere continuum is described in the land surface energy balance equation:

$$Rn = G_o + H_o + \lambda E \qquad (W\,m^{-2})$$

where Rn is the net radiation absorbed or emitted from the earth's surface, G_o is the soil heat flux to warm or cool the soil, H_o is the sensible heat flux to warm or cool the atmosphere and λE is the latent heat flux, which is the energy allocated for water evaporation. The values for G_o, H_o and λE are positive when directed away from the land surface, and Rn is positive when radiation is absorbed at the land surface. The physical attributes required to solve the surface energy balance are either directly measured by visible, near-infrared and thermal-infrared channels, or indirectly estimated using semi-empirical relationships.

The time integral of latent heat flux in a 24-hour period is equivalent to the actual evapotranspiration rate:

$$ET_{act}^{24} = \int_0^{86400} \frac{\lambda E(t)dt}{\lambda \rho_\omega 86400} \qquad (mm\,s^{-1})$$

where λ (J kg^{-1}) is the latent heat of vaporization and ρ_ω (kg m^{-3}) is the density of water.

Instantaneous values for potential evapotranspiration can be mapped from remote sensing observations without the involvement of crop factors such as:

$$\lambda E_{pot} = Rn - G_o \qquad (W\,m^{-2})$$

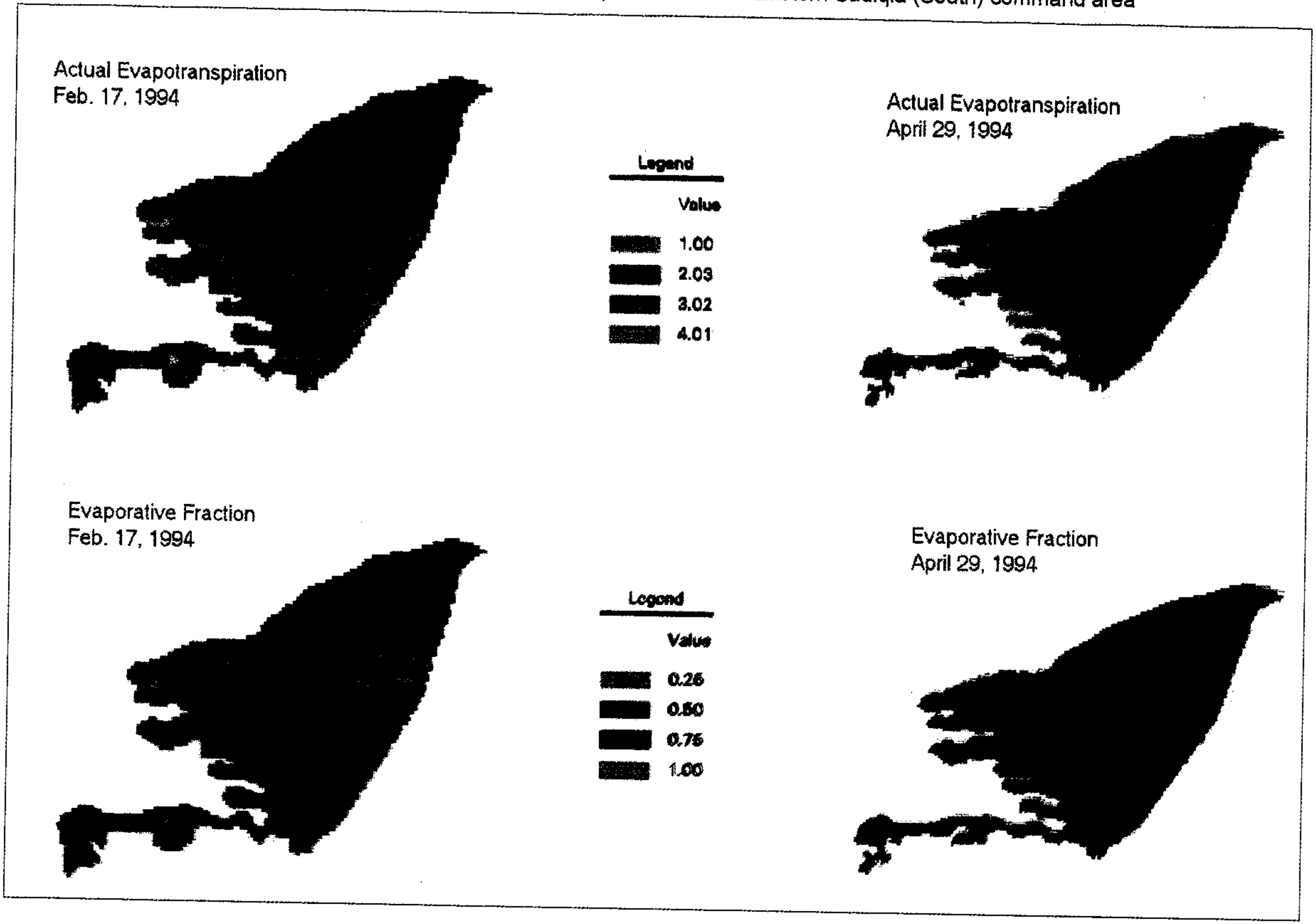
A combination of the surface energy balance equation and the previous equation provide the opportunity to define the relative evaporation as evaporative fraction Λ:

$$\Lambda = \frac{\lambda E}{Rn - G_o} \qquad (W\,m^{-2})$$

in which the numerator represents the actual evaporation and the denominator the available energy. Therefore, evaporative fraction is the portion of the available energy used for evaporation.

In Figure 3 are shown the actual evapotranspiration (*ETact*) and evaporative fraction (*EF*) maps of February 17 and April 29, 1994 for the Fordwah Canal command area. From these maps, the unirrigated area is masked out. The masks for rabi and kharif come from Alexandridis et al. (forthcoming).

Figure 3 - Actual evapotranspiration and evaporative fraction maps for Fordwah Eastern Sadiqia (South) command area

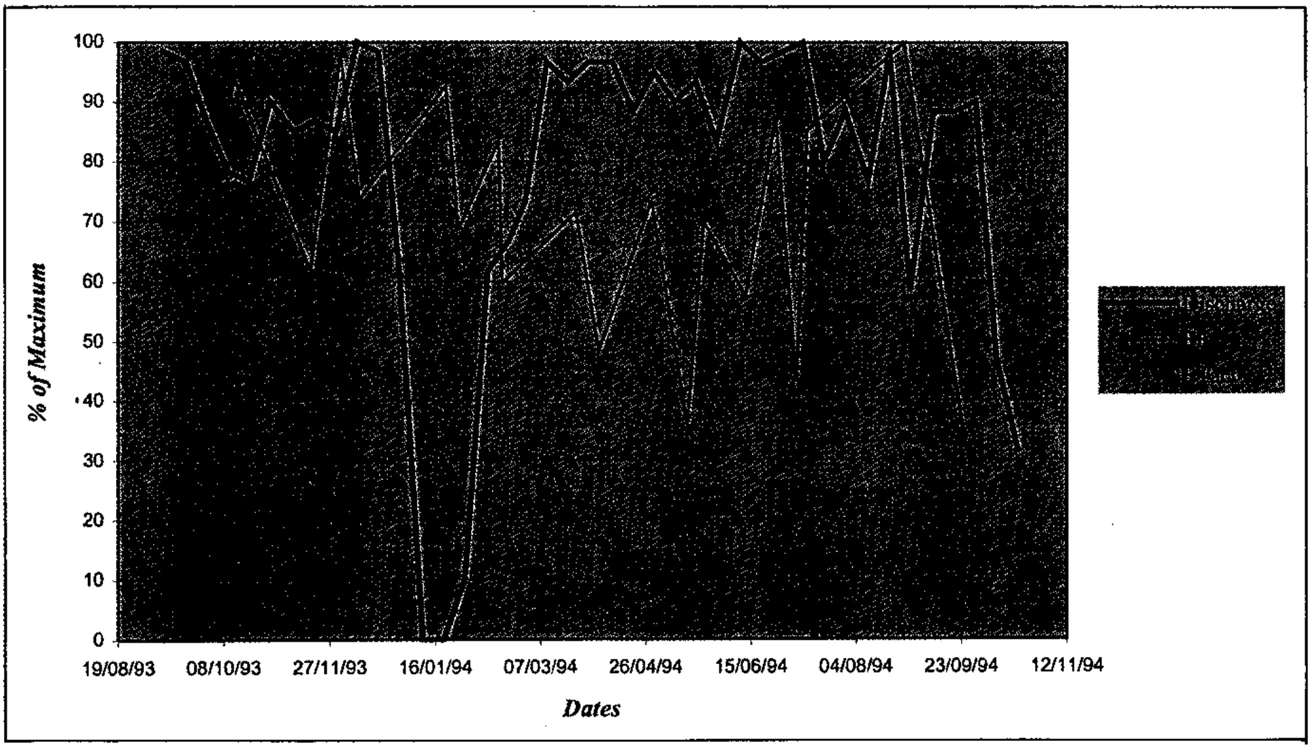


3.2 Extraction of Descriptive Statistics

The mean and standard deviations for all the distributary commands of the FES(S) project area were extracted from the 20 *ETact* and *EF* maps. The results and analyses are based on distributary command area instead of the pixel basis because: 1) this level of detail is considered to be satisfactory, and 2) due to possible mis-registration of the 20 images, pixel-to-pixel overlap cannot be guaranteed.

The time series of mean *ETact* and mean *EF* (for the whole FES(S) project area) is presented in Figure 4. The fluctuations in the discharge of the Eastern Sadiqia Canal, which is delivering water to the Hakra and Malik Branch Canals, are also plotted in the same graph. Factors that contribute to the high undulation of the *ETact* and *EF* values (for the whole FES(S) project area) are: 1) the fluctuation in the discharge of the Eastern Sadiqia Canal, 2) the daily atmospheric conditions (temperature, wind speed, rainfall) and 3) the phenological stage of each crop and its water requirement corresponding to its growth. The warabandi is not influencing the spatial-temporal distribution of *ETact* and *EF* since it is watercourse-based, and variations are not evident in the large area divisions, i.e. distributary commands.

Figure 4 - Time series of ETact, EF for the FES(S) project area, and the Eastern Sadiqia Canal discharge



Part B: PERFORMANCE ASSESSMENT

4. Performance Indicators

Many authors have proposed different indicators to measure irrigation system performance as summarized by Rao (1993), and have given examples for their use at particular irrigation systems (Molden et al. 1998, Sakthivadivel et al. 1999, Bastiaanssen et al. 1996, Thiruvengadachari and Sakthivadivel 1997). The indicators listed by Rao (1993) deal primarily with the quality of the irrigation service provided by the managers of the water delivery system, the agricultural production that is the output of the irrigated agriculture system, and to a limited extent, the economic benefits derived from the agricultural production (Table 1). The same table are also presents the indicators proposed by Molden et al. (1998). Other types of indicators deal with social aspects, processes and sustainability of the system.

Interesting features of these indicators, which also reveal their limitations, are: 1) they are based on a relative comparison of absolute values, rather than being referenced to standards or targets, 2) they are related to phenomena that are common to irrigation and irrigated agricultural systems, 3) they relate to outputs and are bulk measures of irrigation and irrigated agricultural systems, and thus, provide limited information about internal processes, 4) they are more efficient in irrigated agricultural systems where water is the limiting factor for the maximum yield (infertility, pests, weeds, etc), and 5) there are uncertainties in the source of data (secondary data) and uncertainties in the estimates (e.g. traditional methods of estimating crop evapotranspiration).

In this study, three indicators are analysed: adequacy, reliability and equity in water use. These are general indicators with the advantage of not being related to any specific output feature of the system. They show the hydrologic condition of the fields, which is the feature primarily related to water management and of interest to the water managers. These performance indicators can be related to information acquired from remote sensing, and therefore, allow the users to cost effectively monitor a large area over a period of time.

Adequacy is the quantitative component, and is defined as the sufficiency of water use in an irrigation system. An irrigation system, ideally, should have enough water to fulfill the crop needs. The relative evaporation provides direct information on the stress condition of crops. In this study, adequacy in water use is defined as:

Adequacy = Evaporative Fraction (*EF*)

Spatial analysis of the *EF* maps in the FES(S) project area is expected to reveal distributaries where water scarcity may be experienced. By this time, unfortunately, the remote sensing representations of adequacy (*EF*) are not well connected (quantitatively) with crop water requirements; therefore, only spatial (distributary level) and temporal (dates of image acquisition) relative comparisons were possible.

Reliability is the time component of the study, and is defined as the correspondence of water supply upon request. Also, it expresses the degree to which the irrigation system and its deliveries conform to the prior expectations of its users (Rao, 1993). A well administered irrigation system, should have water when crops are in need. Farmers should also be confident of receiving reliable water deliveries at scheduled times. Two aspects of reliability are global and local. When, for some reason, (canal breach, sudden demand to divert water for other uses) a general disruption of surface deliveries to all irrigators occurs, then it is global. Local reliability is when some areas of the command area receive a more stable water supply over time. This study assesses local reliability within the distributaries of the FES(S) project area. As revealed by previous reviews (Rao, 1993), reliability is difficult to monitor due to the difficulty and cost involved in secondary data collection over a long period of time. The use of remote sensing has made it possible to monitor a large area for the two growing seasons of 93-94. Time series analysis of *EF* maps can reveal distributaries with unstable water use:

Unreliability = Temporal fluctuation of *EF*

Temporal variations of *EF* will be examined, since *ETact* varies considerably throughout the year due to changing solar conditions.

Table 1 - Some performance indicators presented in literature

Rao (1993)	Molden et al. (1998)
a. Indicators of performance of water delivery system • Delivery performance ratio • Relative water supply or irrigation efficiencies for conveyance and distribution • Modified interquartile ratio • Reliability of water delivery as predicted by a delivery schedule • Fluctuations in groundwater levels	a. Indicators of irrigated agricultural output • Output per cropped area (\$/ha) • Output per unit command area (\$/ha) • Output per unit irrigation supply (\$/m^3) • Output per unit water consumed (\$/m^3)
b. Indicators of performance of the irrigated agriculture system • Yield per unit land compared to nearby rain-fed land • Yield per unit water • Percent of time in a potential growing season that a field is cultivating a crop (or crops)	b. Other comparative indicators • Relative water supply • Relative irrigation supply • Water delivery capacity (%)
c. Indicators of performance of the irrigated agriculture economic system • Profitability to farmers – net (income) return per unit land • Profitability to the system – net return on investment in the irrigation system	c. Financial indicators • Gross return on investment (%) • Financial self-sufficiency

Equity is the social component and is defined as the fairness in the spatial distribution of water use. Good management in water allocation is important when the water volume is not adequate to meet the demands of the full command area over the entire season. According to Levine and Coward (1989), a system that is considered fair by most farmers is more likely to be productive and efficient than one that the state has designed on the basis of productivity and efficiency, but which is considered unfair by the farmers. In this study, equity is considered the uniformity in the spatial distribution of water use:

Equity = spatial variation of *ETact*

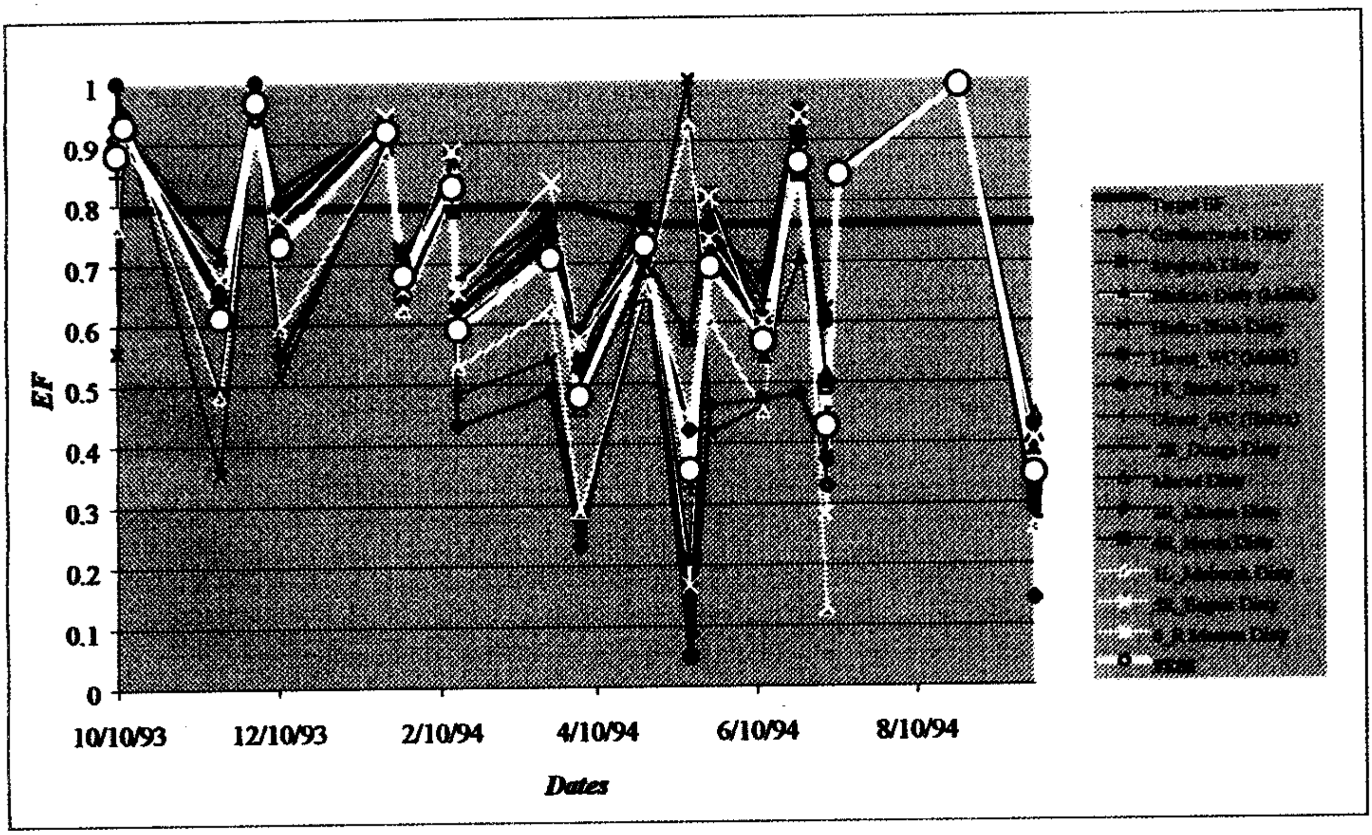
The analysis of the *ETact* maps can reveal distributaries where water use is not uniform, allow comparison among them, and show the time of the season when inequity is at a maximum.

5. Adequacy

The time series of mean *EF* values plotted for individual distributary commands (Figure 5) shows a tendancy for high *EF* values in the period of December 1993 to January 1994, which can be explained by the farmers' behavior to over-irrigate at the end of December in anticipation of the canal closure in January. The water table is rising due to these farming practices and adequate water is available for evapotranspiration even during the beginning of the canal closure (see Figure 4). Later, there is a distinct drop in water use during March to the end of April, which is conforming with the maturity of the wheat crop (major rabi crop for FES(S)), when no irrigation is necessary. After April, the high values of *EF* are explained from the irrigation for cotton germination (major kharif crop for FES(S)), followed by the monsoon rain season, which also implies a raise in the water table and therefore to the water available for evapotranspiration.

To the authors' knowledge, and as discussed in the previous section, papers presenting critical values of *EF* are not available. According to Bastiaanssen et al. (1996), crop growth reductions are tolerable as long as EF > 0.75. To improve this statement for this particular study area, target values for the major crops of the FES(S) project area are given as: rice 0.9, wheat 0.8, maize 0.8, sugarcane 0.7 and cotton 0.75 (Bastiaanssen 1999, pers. com.). Unfortunately, a crop cover map for 93-94 is not available for the study area, and therefore, an area-weighted average of the above values is calculated for each growing season, using the cropping pattern available from reported secondary data (source: Crop Acreage Data of Provincial Irrigation and Power Departments of the Punjab and Sindh). The area-weighted average target values of *EF* for the whole FES(S) project area are 0.79 for rabi and 0.76 for kharif.

Figure 5 - Time series of EF values for distributaries of the FES(S) project area, and target EF values



When comparing the time series curves of Figure 5 with the target values, it is evident that many distributaries do not meet the requirement for quite a long period. This is expected, and conforms with farmers' reports of water deficiencies (WAPDA report, 1995). The seasonal average *EF* value for each distributary, together with the average for the whole FES(S) project area, has been calculated in Table 2. Distributaries like Sunder (1-R), Baghsar (5-R), Dunga (2-R) and Harun (4-R) seem to have an overall adequate water use for rabi 93-94, while the pattern changes for kharif 94 when none of the distributaries is meeting the overall kharif target value. Harun (4-R) is again performing well, and this can be due to the existence of a number of tubewells in the south-west part of the distributary. Murad Distributary, as well as the area fed directly from the Malik Branch Canal (Direct WC Malik), are also performing well in rabi and kharif, possibly because the Hakra Branch Canal is less favored than the Malik Branch Canal in the case of water shortage.

Table 2 - List of distributaries in the order of inadequate water use for rabi and kharif 93-94

(a) **Distributary**	(b) **EF**	(c) **Difference from target**	(d) **Distributary**	(e) **EF**	(f) **Difference from target**
Sunder (1-R)	0.81	(2.4%)	**Target value**	**0.76**	**(0.0%)**
Baghsar (5-R)	0.80	(1.8%)	Harun (4-R)	0.69	(-8.8%)
Dunga (2-R)	0.80	(1.8%)	Murad	0.67	(-12.0%)
Target value	**0.79**	**(0.0%)**	Direct WC (Hakra)	0.66	(-12.6%)
Harun (4-R)	0.79	(-0.4%)	Mamun (6-R)	0.65	(-14.5%)
Sirajwah	0.78	(-1.0%)	Direct WC (Malik)	0.65	(-15.0%)
Direct WC (Malik)	0.78	(-1.3%)	**FES(S) (total)**	**0.65**	**(-15.0%)**
Bhukan (Malik)	0.78	(-1.6%)	Khatan (3-R)	0.64	(-15.3%)
Khatan (3-R)	0.77	(-2.4%)	Baghsar (5-R)	0.63	(-16.8%)
Murad	0.77	(-2.9%)	Dunga (2-R)	0.61	(-19.9%)
Direct WC (Hakra)	0.76	(-3.3%)	Sunder (1-R)	0.60	(-20.6%)
Mamun (6-R)	0.76	(-3.3%)	Sirajwah	0.60	(-20.6%)
FES(S) (total)	**0.76**	**(-4.3%)**	Bakushah	0.59	(-21.7%)
Mubarik (1-L)	0.68	(-13.7%)	Mubarik (1-L)	0.56	(-25.7%)
Girdhariwala	0.65	(-18.1%)	Bhukan (Malik)	0.55	(-27.9%)
Bakushah	0.64	(-19.4%)	Girdhariwala	0.38	(-49.4%)

On the other hand, Mubarik (1-L), Girdhariwala and Bakushah Distributaries have the most inadequate water use during rabi and kharif 93-94. The explanation can be the higher terrace that fields lie along the east of the Hakra Branch Canal, so that water is delivered with a greater difficulty and only when the level of the Hakra Canal is above a limit. Difficulties relating to cultivating the entire area because of military restrictions (proximity to the Indian border) may also occur.

In conclusion, there are water deficiencies for some periods in some distributaries, and sometimes in the whole of the FES(S) area. But, during the critical major crop growth periods (wheat: 27 October – 11 November and 6 December – 25 January, cotton: 1 May – 1 June and 19 July – 17 September) the water use appears close to the target values.

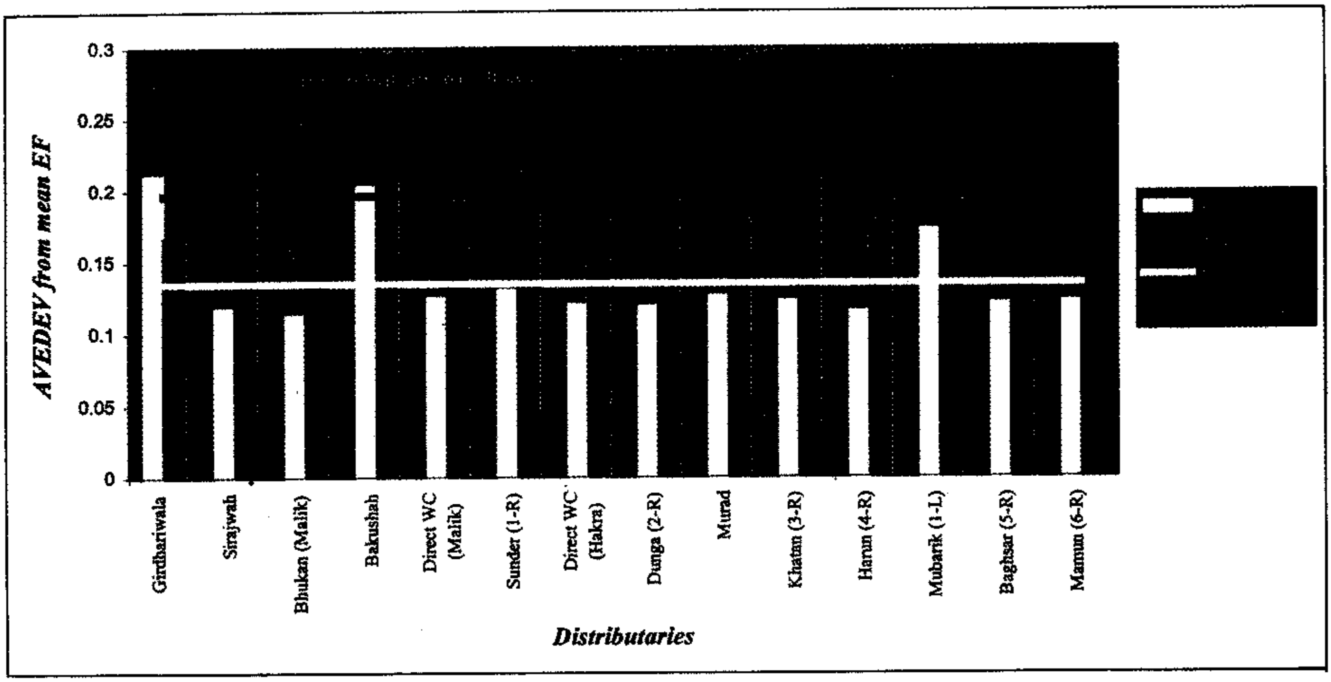
6. Reliability

The average of the absolute deviations of the data points from their mean (AVEDEV) is a measure of the variability in a data set. The equation for AVEDEV is:

$$AVEDEV = \frac{1}{n}\sum | x - \bar{x} |$$

Therefore, the temporal variability of *EF* for individual distributary commands can be described with this statistical parameter, which shows the magnitude of fluctuation, therefore, unreliability. The AVEDEV values of all the distributaries for rabi and kharif 93-94 are presented in Figure 6. In this study, the point that determines reliability is the AVEDEV for the whole FESS project area, and therefore the AVEDEV values for individual distributaries are compared with the value for the whole FES(S) project area. Distributaries that are more unreliable than the average of the FES(S) project area are listed in Table 3.

Figure 6 - Average deviation from the mean EF (AVEDEV) at the distributary command level



Evident is, that a larger area is reliable in water use during rabi than kharif. On the other hand, the percentage differences for rabi are bigger, which means that the magnitude of unreliability is big in the few distributaries that are unreliable during rabi. When examining these distributaries closer, they are lying on

Table 3 - Unreliable distributary commands during rabi or kharif 93-94

(a) Distributary name	(b) % difference of particular distributary AVEDEV from the value for FES(S) Rabi	(c) Kharif
Girdhariwala	57	
Sirajwah		10
Bakushah	51	7
Sunder (1-R)		8
Direct WC (Hakra)		4
Dunga (2-R)		30
Khatan (3-R)		7
Mubarik (1-L)	28	24
Baghsar (5-R)		21
Mamun (6-R)		3

the left side of the Hakra Branch Canal, where the terrace is at a higher level, and water cannot always be delivered easily. Lift irrigation is required for these areas, which is increasing the cost. Other distributaries that appear to be unreliable during kharif are Dunga (2-R) and Baghsar (5-R).

7. Equity

The spatial coefficient of variation of *ETact* is the statistical parameter that is used in this study to reveal high spatial heterogeneity, which is indicative of an uneven water use. The coefficient of variation of the values within each distributary command area is calculated for each *ETact* map (Figure 7). High values show distributaries with an uneven water use.

When comparing the coefficients of variation between distributaries in Figure 7, a higher heterogeneity in water use is observed on the left side of Hakra Branch Canal. As discussed before, the farmers in these distributaries experience difficulties with their surface water supply and some military restrictions may apply. Another reason that may add to the uneven spatial water use is the significant seepage from the Hakra Branch Canal, which decreases drastically close to the border, as the adjacent Indian area is dry with a low water table level.

When comparing the time sequence of the coefficients of variation, there is a trend towards increasing equity in water use during the canal closure (January) and during periods when water is not necessary for the major crop growth (end of each season, around harvesting). On the other hand, variation in water use is increasing with the beginning of the rice growing season (June), when more water is allocated to rice paddies. The beginning of the monsoon season in July does not seem to homogenize the spatial distribution of *ETact* as was expected, therefore, we conclude that irrigation water (surface or ground) and capillary rise are factors that influence the spatial distribution of *ETact* more, rather than the rainfall.

The spatial distribution of *ETact* with relation to the distance from canals was also studied. Buffer zones with an increasing distance from the canal system (branch canals, distributaries, or minors) were used to extract statistics from the average *ETact* and *EF* maps for the two seasons (Figure 8). The results show a distinct drop of *ETact* and *EF* as the distance increases, which is indicative of a lower water use away from the distributaries. The decrease in *ETact* reveals a possible change in the cropping pattern, restricting the cultivation of high water demanding crops close to the canals. This restriction indicates that farmers have unequal chances to grow the desired crop. The *EF* decrease reveals that despite farmers' restriction to grow low water requirement crops in the areas located away from the canals, these crops still suffer from water stress. The high value corresponding to the zone of 3,500m is explained due to waterlogging in the areas north of Mamun (6-R), where the zone mostly appears.

Figure 7 - Spatial coefficient of variation of ETact at the distributary level

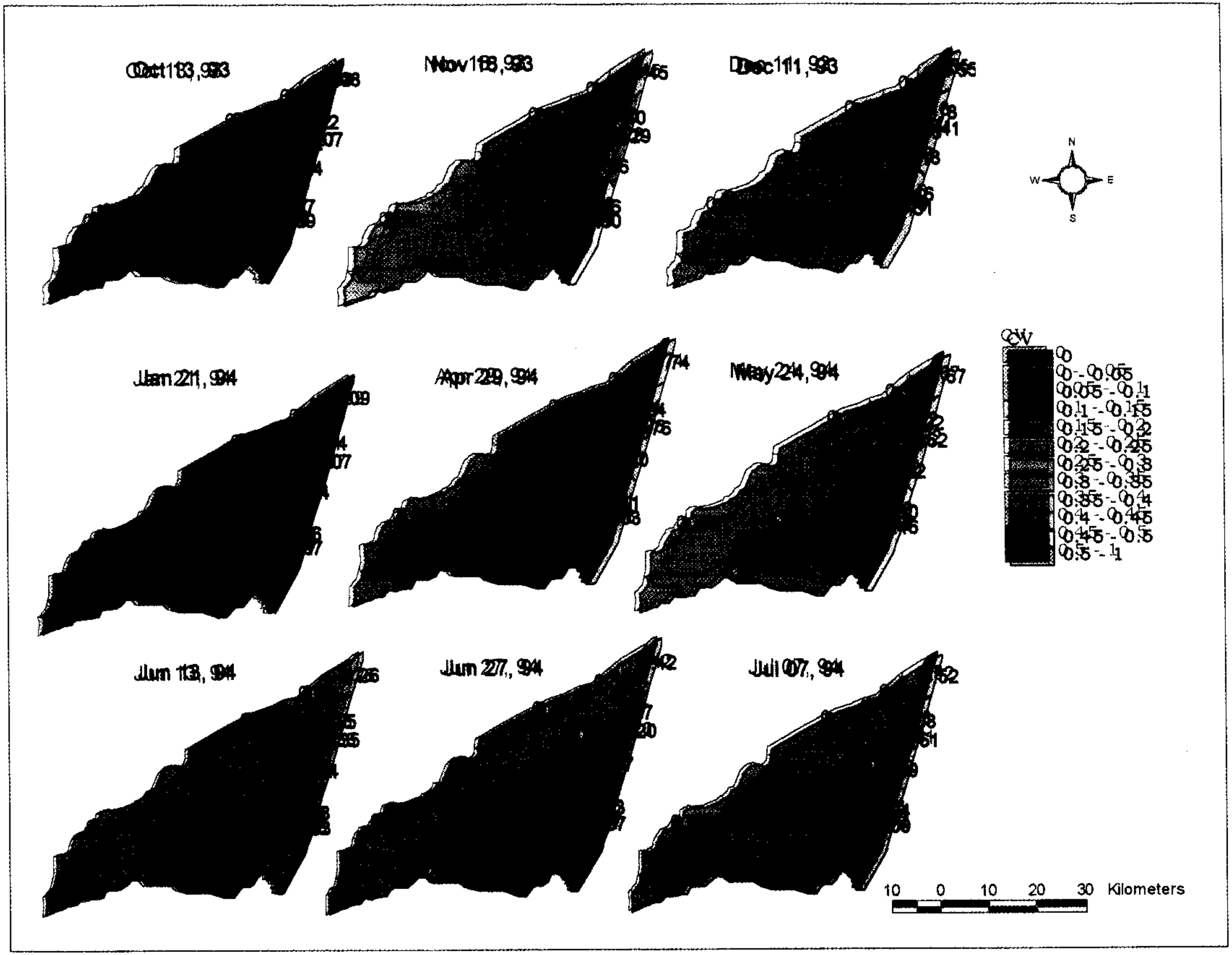
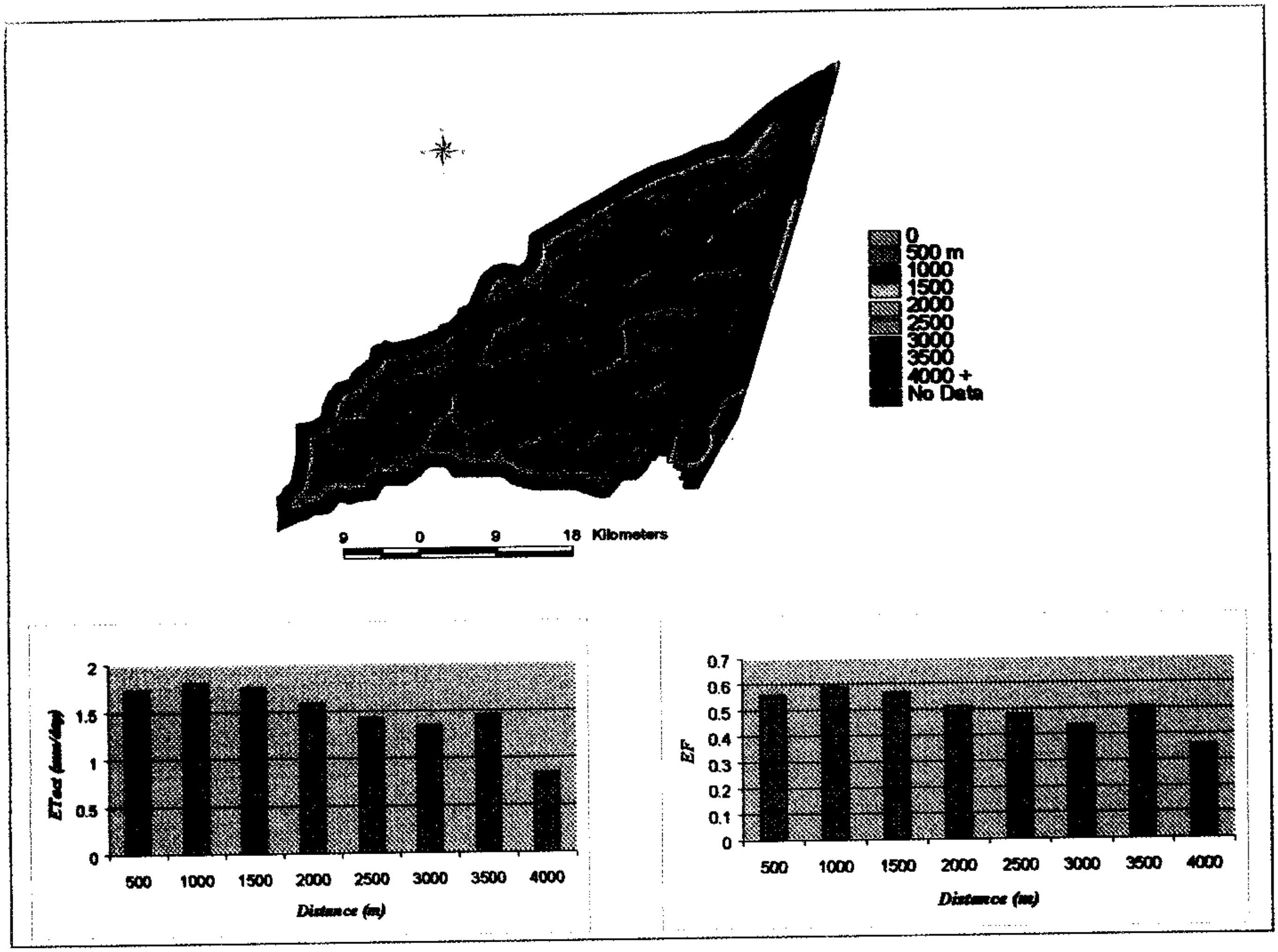


Figure 8 - Buffer zone map and relation of ETact and EF with the distance from canals



8. Relation of Three Indicators

In the previous sections unreliable and unequal distributaries have been indicated for and the occasions when the water use is inadequate. Of interest to water managers is to assess if water scarcity is followed by inequity in spatial water distribution, or by temporal unreliability. The relation between the three performance indicators is examined in the space domain, after the time influence has been eliminated by averaging for each season. The correlation coefficients between these time-averaged indicators, as well as for selected dates for the two seasons are listed in Table 4.

A strong positive correlation exists between adequacy and equity throughout the two growing seasons, while the relationship between reliability with the other indicators is not constant, and high correlations like for January 21 and April 04 may be due to chance. Therefore, in distributaries of the FES(S) project area where the water use is inadequate, the water use is also unequally distributed among the users.

From this example, it has been shown that there is a strong possibility that water scarcity also generates inequity and unreliability in spatial and temporal water distribution. As expected (from WAPDA Report, 1995) in irrigation systems where water deficiencies are frequent, management is a difficult task. In these systems, Levine and Coward (1989) prefer to use the term *administration* instead of *management*.

Table 4 - Correlation coefficients between the three performance indicators

Dec-02	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	-0.38	1	
equity	0.91	-0.40	1

Apr-29	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	0.05	1	
equity	0.73	-0.04	1

Jan-21	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	0.71	1	
equity	0.80	0.53	1

Jun-13	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	-0.02	1	
equity	0.94	-0.01	1

Apr-04	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	0.94	1	
equity	0.98	0.92	1

Sep-24	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	0.12	1	
equity	0.61	0.21	1

rabi average	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	0.95	1	
equity	0.95	0.90	1

kharif average	*adequacy*	*reliability*	*equity*
adequacy	1		
reliability	-0.20	1	
equity	0.60	0.21	1

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