CPWF Project Report

Karkheh Basin Focal Project

Project Number 57

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Program Preface:

The Challenge Program on Water and Food (CPWF) contributes to efforts of the international community to ensure global diversions of water to agriculture are maintained at the level of the year 2000. It is a multi-institutional research initiative that aims to increase the resilience of social and ecological systems through better water management for food production. Through its broad partnerships, it conducts research that leads to impact on the poor and to policy change.

The CPWF conducts action-oriented research in nine river basins in Africa, Asia and Latin America, focusing on crop water productivity, fisheries and aquatic ecosystems, community arrangements for sharing water, integrated river basin management, and institutions and policies for successful implementation of developments in the water-food-environment nexus.

Project Preface:

The Karkheh Basin Focal Project was designed to collect and organize baseline information for future researchers and to highlight future research needs. All collected data is available in the IDIS system. The specific research findings and recommendations for the basin are 1) The use of non-agricultural water measures is likely to be a more effective solution to remaining rural poverty in the Karkheh basin and Iran; 2) In the short to medium term, agricultural water policy and research should focus on improvements in physical water productivity so as to improve the use scarce water resources for given national food security priorities and 3) in the longer term, shift towards economic water productivity by moving water away from lower productivity grain production and towards higher value agricultural and other activities including hydropower generation and urban uses.

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EXECUTIVE SUMMARY

Development of the Karkheh's water resources has contributed in important ways to Iran's food security and underpinned the livelihoods of both basin farmers and urban consumers. However, the linkages between poverty and agricultural water use in the basin are now weak at best. Furthermore, there is now little if any additional water to develop. As a result, future water policy will need to increasingly focus on management and allocation of existing resources rather than development of new sources of supply. This new management focus should aim primarily at increasing water productivity to meet existing national priorities. In the short to medium term, this means focusing on improvements in physical water productivity, primarily the quantity of wheat output per unit of water input so as to improve the use scarce water resources for national food security priorities. In irrigated areas, this may be achieved, for example, through improved use of irrigation, an option which would also help to ensure groundwater sustainability. In the longer term, and if the international environment changes, the focus may be shifted towards increases in economic water productivity by moving water away from lower productivity grain production and towards higher value activities including hydropower generation and urban uses. Poverty is still an issue in the Karkheh and targeted water interventions may assist in poverty reduction. However, the water scarcity conditions of Iran, the country's other substantial assets, and evidence of the drivers of past poverty trends suggests that from a national policy standpoint, the use of non-agricultural water measures are likely to be the most effective solution to remaining rural poverty problems in the Karkheh basin. That said, scenario analysis shows that a combination of the right policies could minimize the tradeoffs between food self-sufficiency, sustainable water use and farmers' income.

INTRODUCTION

Iran is a land abundant and water short country. It has 1% of the world's population and 1.1% its land, but less than 0.4% of the world's freshwater. Already the country uses 74% of its annual total renewable freshwater, a figure placing it far into any definition of a water scarce state. The vast majority of current water use, 93%, is utilized for agricultural production. The food needs of rapidly growing population and strategic policy goals to move the country towards food self-sufficiency-from its recent position as one of the world's largest agricultural importers-will only further pressure water resources in the coming decades. Adding to these pressures will be even faster growth in industrial and domestic water demand for an urbanizing population and likely increased recognition of the values of environmental flows.

Given this situation, the agricultural water challenges for Iran are in the first instance related not primarily to the development of new water resources but rather to discovering ways to more effectively utilize existing resources for current needs, managing the competition for water between sectors, and determining the role of agricultural water use in future poverty reduction strategies. As in all countries, these challenges must also be considered in the light of environmental services naturally provided by water. And perhaps especially important for Iran, the goals of agricultural water management must also be viewed in the larger economic and geo-political objectives and context of the country.

The water challenges for Iran's Karkheh River Basin are in some senses exemplars of the water challenges facing the entire country and similar regions around the world. The Karkheh Basin is known as the "food basket of Iran" and is one of the main areas for the production of strategically important wheat in western Iran (Figure 0). Wheat production is facilitated by an irrigation system making up 9% of the country's total network. However, non-irrigated areas are also important sources for the production of both grains and, in particular, livestock products. In some cases, this production has resulted in degradation of lands and contributed to erosion problems impacting the operation of dams for hydropower and irrigation. As a key agricultural region, there is pressure to keep up agricultural production. However, the area has growing industry, is the home of important oil fields in the south and is experiencing a rapid demographic shift from agriculture towards cities. The use of the river also has important implications for environmental function, perhaps especially in the Hoor-al-Azim swamps.

This paper synthesizes the results of a 2.5 year study commissioned by the Challenge Program on Water and Food (CPWF) on agricultural water use, water productivity and poverty in the Karkheh basin. While the paper is focused on the Iran's Karkheh basin, many of the findings are applicable in similar regions, both in terms of agro-ecology and geo-politics.

To meet its objectives, the paper first looks at the physical side of the basin, providing estimates of water use and water productivity across scales. It then examines the human side, providing the first ever basin scale estimates of poverty in the Karkheh as well as a description of the institutional environment in which poverty, and water use, exist. From this content, policy recommendations related to water use, water productivity and poverty alleviation are derived. Finally, the paper uses the experience of the Karkheh project to suggest key research areas for future Challenge Program work.

Figure 0. Location of Karkheh River Basin in Iran

PROJECT OBJECTIVES

Basin Focal Projects (BFPs) are a new innovation designed to provide a more comprehensive and integrated understanding of the water, food and environment issues in a basin. In addition, they will develop a much more nuanced understanding of the extent and nature of poverty within each selected basin and determine where water related constraints are both a major determinate of poverty and where those constraints can be addressed. The Karkheh river basin of Iran has been selected as on the BFPs. This document summarizes the outcomes of the research done to meet the objectives and the resulting recommendations for both those directly involved in the Karkheh and those involved in setting future CPWF research policy.

1 Water use

Assessing the availability of water resources has been one of the key focuses of the Iranian government for all river basins of Iran. A comprehensive study was conducted by JAMAB (1999) for the Karkheh river basin with the main motivation of development planning of available renewable water resources in order to expand irrigated lands, provide water to increasing populations and industry, control floods and produce hydroelectricity. From this work, JAMAB produced basin level estimates of Karkheh water resources for the year 1993-94 (Table 1). The year 1993-94 represents the average water availability in the basin and is considered as a reference year for future planning and allocation of water resources.

Using the information from JAMAB (1999), the water accounts of the Karkheh basin for the water year 1993-94 are estimated by Masih et al. 2008 (Figure 1). The gross inflow, net inflow and total depletion are 24.96×10^9 m^3/year, 25.08×10^9 m^3/year, and 19.94×10^9 m^3/year, respectively. Direct depletion from precipitation constitutes 82% (or 16.39×109 m^3/year) of the total depleted water (19.94×10^9 m^3/year) in the Karkheh basin. This water is mainly depleted through cropped areas, pasture, forests and bare lands. Usually this portion is not well accounted for in hydrological studies, planning of basin water resources and accounting for basin water productivity.

Table 1. Water Use estimates for the Karkheh Basin, 1993-94 and planned use in 2021 (source: JAMAB 1999)

Description	Water availability/use(m^3/year)
Precipitation	24.96×10^9
Renewable water resources	8.60×10^9
Agricultural water use	3.95×10^9
Surface water use (63% of agricultural water use)	2.49×10^9
Groundwater use (37% of agricultural water use)	1.46×10^9
Domestic and Industrial use	0.23×10^9
Agricultural water use in 2021 (planned)	7.43×10^9
Domestic and industrial use in 2021 (planned)	0.46×10^9

To add greater detail in terms of both the nature of water use and the distribution of that use, the Karkheh BFP also undertook an additional analysis to estimate actual evapotranspiration using Surface Energy Balance Systems-SEBS (Su 2002; Su and Jacobs 2001; Su et al., 2003) for 2002-03, the period with most complete data (Mutuwatte et al.,2010). The spatio-temporal distribution of precipitation and actual evapotranspiration was assessed at 1km grid cell resolution with results aggregated to 16 sub-catchments as shown in Figures 2 & 3 (details given in Annex's 1 and 2). Analysis behind this information reveals that, during the study period, the Karkheh Basin received 18.5×10^9 m^3/year of inflows as precipitation out of which 16.7×10^9 m^3/year were outflows as evapotranspiration. Annual ET_a varies from 41 mm to 1681 mm, with the highest values found in the Karkheh dam and the lowest in the bare land/desert areas below the Karkheh dam.

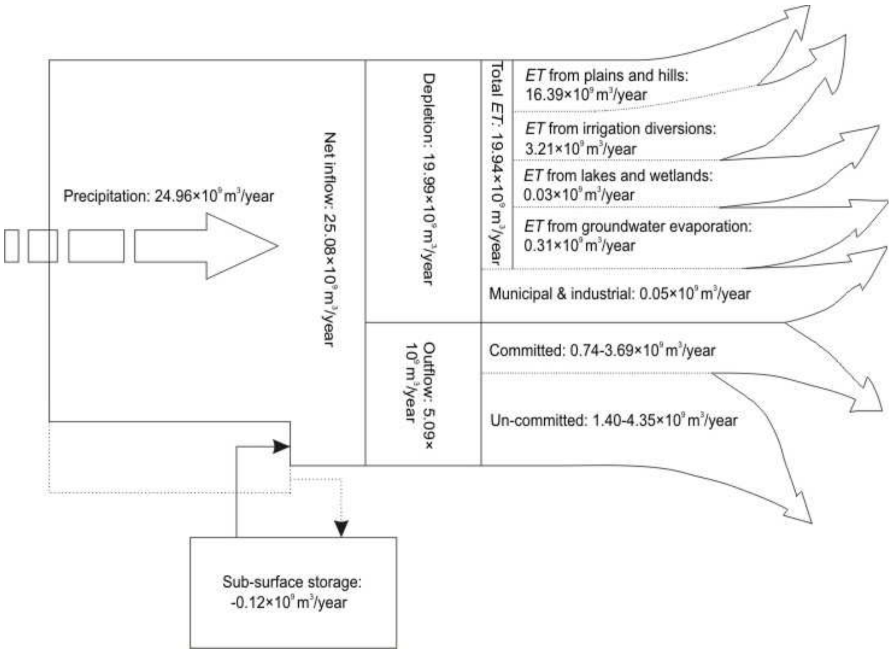

Figure 1. Representation of the basin level water accounting of the Karkheh Basin (1993-94).

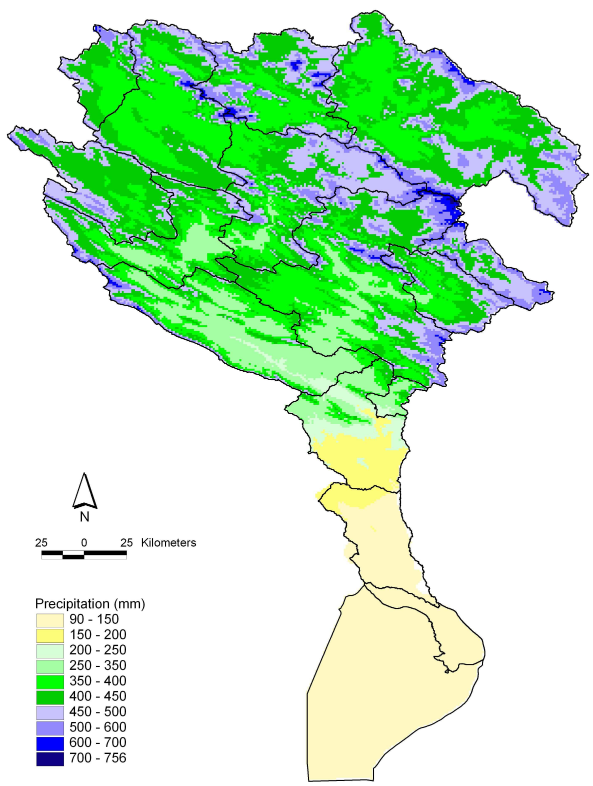

Figure 2. Spatial variation of annual precipitation (P) in the Karkheh river basin from November 2002 – October 2003

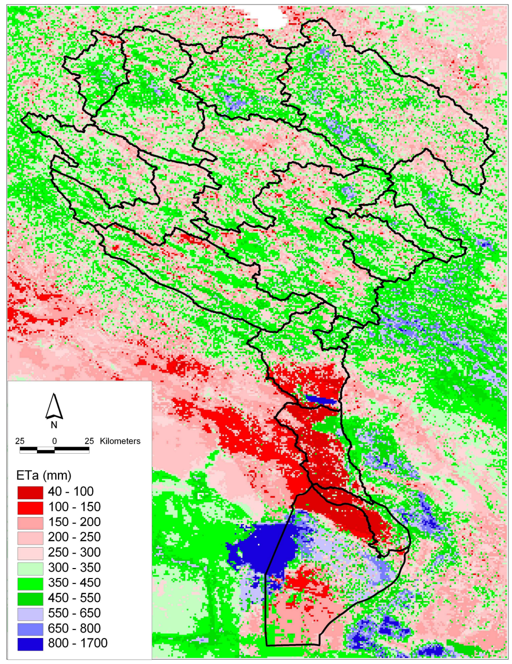

Figure 3. Annual actual evapotranspiration (ET_a) in the Karkheh basin – November 2002 – October 2003.

The analysis further reveals that, overall, irrigated areas (578,100 ha or 11 % of total basin area) consume 14% of total basin precipitation while rainfed areas (1,163,000 ha or 23 % of the total basin area) consume 20%. Rangeland and forests consume 18% and 11% of total rainfall respectively. However, there are significant differences in water use patterns between the upper and lower basin as shown in **Figure 4.** Rainfed crops and rangeland dominate the upper Karkheh while irrigated crops, wet soil, water bodies and bare land/urban evapotranspiration dominate the lower basin. Further highlighting the physical differences within the basin, two-thirds (75%) of annual precipitation in the upper Karkheh is consumed as evapotranspiration whereas in the lower Karkheh evapotranspiration is three times higher than precipitation. High levels of use in the lower Karkheh are made possible by irrigation supplied from dam releases and direct pumping from river. Information on water use is again used in computing water productivity estimates in the next section.

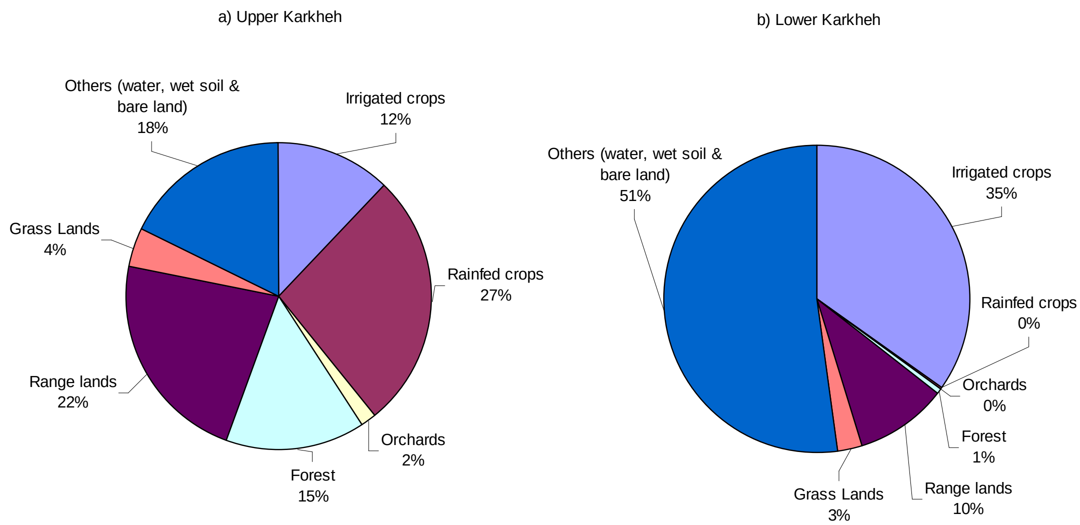

Figure 4. Percentage distribution of ET_a for different land classes for the upper (a) and lower (b) Karkheh basin, November 2002 – October 2003.

While both sets of water accounts are useful for understanding the current state of water use in the Karkheh, they are insufficient for understanding the relationship between these average figures, sustainability of use, and variability in supplies or for understanding the tradeoffs between changes in allocation and basin scale water productivity change or poverty reduction[1].

In terms of sustainability, an additional analysis conducted by JAMAB (2006 a & b) as part of Karkheh Basin Focal project has shown that water resources are coming under increasing pressure mainly due to growing demand and persistent drought. At the basin scale, a negative water balance of $144x10^6$ m^3/year was reported for 2000-01, a drought year, indicating increasing stress on the groundwater storage in the basin. Groundwater withdrawals in Gamasiab and Qarasou sub-basins in fact have already exceeded the safe limits (JAMAB, 2006b) and further groundwater development has been prohibited in the plains of Malayer, Asadabad, Toyserkan and the Nahavand plains of Gamasiab sub-basin. Ongoing water resources development strategies in the Karkheh basin are thus clearly coming into conflict with sustainable water use possibilities in the basin. A comprehensive literature review reveals that earlier studies which attempted to provide accounts of water resources availability and development potential ignored the implications on basin scale hydrology and did not take into account potential impacts on different users and uses of water.

Related, existing work including the 1999 JAMAB numbers used for planning have tended to ignore the issue of flow variability. Long term average flows at the key locations across the

[1] As mentioned, reallocation planning requires data on in stream flows. However, lack of data prohibits further downscaling of the analysis presented already to the level of tertiary and quaternary catchments. For instance, in the case of surface water measurements there were 50 stream flow gauging stations installed after 1950 out of which only 25 are continually measured and some of these have missing data. Similarly, while there are some 22 tributary streams discharging into the main rivers of Karkheh basin, discharge data at the outlet of their catchments is not available for half of them. Information on rainfall-runoff relationships is also lacking in the basin in general. Hydrological models can be used to partially remedy this problem. Models can be calibrated for catchments where discharge and other data (such as climate) are available. One key challenge however is the extrapolation of hydrological information from gauged to ungauged catchments (Sivapalan et al., 2003). This is a key issue in Karkheh basin. A methodology has been developed for Karkheh basin and is being tested and applied (work in progress, Masih et al., forthcoming), but results are not yet available. If it performs as hoped, it will serve as a tool for conducting reach by reach analysis of water balances which can then be used to analyze water productivity or poverty trade-offs under different allocation scenarios. Similarly, surface and ground water interaction in Karkheh basin are not well understood due to complex geological formation and requires detailed investigations.

Karkheh river system are shown in **Figure 5** for the period from 1961-2001 (Masih et al., 2008). Large seasonal variability is clear from the figure as is the similarity in high and low flow patterns over all areas simultaneously. What is not clear is the variability in flow between years. The maximum flow (at Paye Pole) of 12.59x10^9 m^3/year occurred in 1968-69 and the minimum of 1.92x10^9 m^3/year correspond to drought year 2000-01. These large temporal variations indicate a high level of supply insecurity for current and further withdrawals for human uses.

The government of Iran has also started an inter-basin water transfer project and a dam, Suleman, has been under construction since 2002 with the aim of producing hydro-electricity and the transfer of water to the Karkheh for agriculture. This project will certainly have impacts on productivity and water availability in Karkheh basin but exact quantification is not possible by the Karkheh BFP due to lack of information.

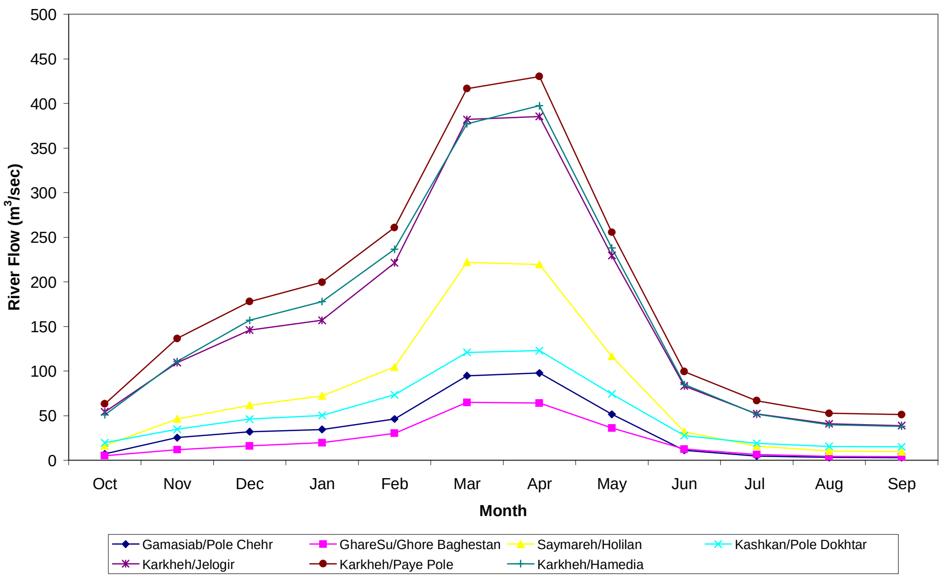

Figure 5. Mean monthly discharge at selected stations of the Karkheh River system, 1961-2001

To quantity this insecurity, flow duration analysis was conducted relative to mean annual availability of surface water as shown in **Table 1**. The analysis of the derived flow duration curves shown in **Figure 6** clearly suggest that planning on the basis of mean annual flows can only provide a supply security of 35-50 %. Furthermore, due to construction of the Karkheh dam and downstream irrigation schemes, one can anticipate that during below average/low flow years, conflicts will increasingly arise between the desire to retain water in the Karkheh dam for hydropower generation and the need to supply downstream agricultural users with irrigation water. The issue of irrigation supply will likely be further exacerbated by soil salinity problems. However resolved, both of these uses will also be accompanied by the diminished flows to riverine ecosystem and floodplains as well as to Hoor-al-Azim swamp further downstream (Masih et al., 2008).

Table 2. Various probabilities of annual river flows (in 10^6 or million cubic meters per year) at selected stations of the Karkheh River system

River/Station	Q5	Q10	Q25	Q50	Q75	Q90	Q95
Gamasiab/Pole Chehr	2416	1684	1303	1022	766	549	294
GhareSu/Ghore Baghestan	1844	1183	957	716	419	353	268
Saymareh/Holilan	6042	4250	2977	2343	1499	1168	871
Kashkan/Pole Dokhtar	3081	2455	2064	1645	1113	854	778
Karkheh/Jelogir	8958	8227	6193	4836	3562	2601	2230
Karkheh/Paye Pole	10755	9280	7756	5651	4082	3020	2404
Karkheh/Hamediah	9280	8641	7555	4873	3447	2254	1648

(Note: Based on the data for the period of 1961-2001)

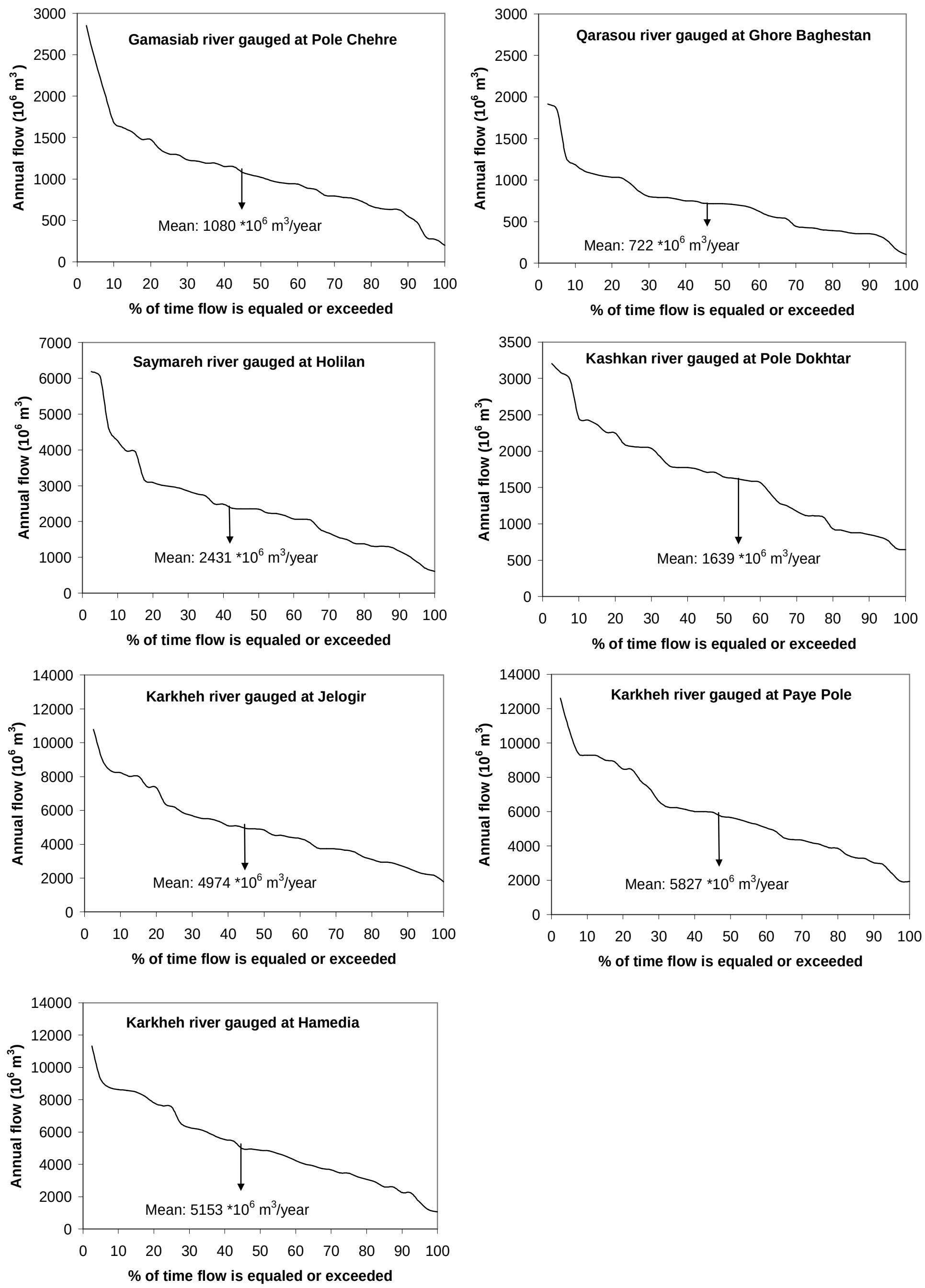

Figure 6. Flow duration curves at the main stations of the Karkheh River system based on 1961-2001 data. (note the difference in scales of the y-axis).

2 *Water Productivity*

Water Productivity analysis is essential to evaluate the performance of current water use at river basin and other scales and to identify opportunities to improve the net gain from water by either increasing the productivity for a given quantity of water consumed, or by reducing the quantity consumed without decreasing production. A review of existing literature and understanding revealed that the information on water productivity in Iran in general and the Karkheh basin in particular is limited.

At present, there are some estimates of field scale physical crop water productivity. However, the basis of the estimates (i.e. productivity in terms of gross inflow, irrigation applied or water consumed [evapotranspiration]) are unclear. Water productivity estimates beyond the field scale also appear to be non-existent. This is the major bottle neck for water policy makers to identify the possible and viable options to enhance water productivity in a sustainable manner and to understand how changes in water use in one location may have impacts on productivity in other locations and across scales. The major goal of this component of the Karkheh Basin Focal Project was thus to fill these information gaps by providing explicit estimates of water productivity using both physical measures at basin, sub-basin and farm scales and economic measures at sub-basin scale (see Ahmad et at. 2009 for more details). The analysis is conducted in two ways. First, physical water productivity estimates at a range of scales are made based on field scale measurements and farmer response, water availability and consumption surveys. Second, economic water productivity at the sub-basin scale is calculated mainly using secondary data from meteorological, hydrological and agricultural statistics.

For the entire Karkheh basin, physical water productivity in terms of yield over gross water inflow for major crops and by irrigated and non-irrigated area are shown in **Table 3**. While comparisons across countries are problematic because of differences in basic physical conditions, it can be generally said that the physical water productivity numbers for the Karkheh are low by global standards. This is discussed further below in the context of economic water productivity and at least suggests scope for improvement.

Table 3. Yield, water use, and water productivity estimates for major crops of the Karkheh Basin and sub-basins, 2006. (Data source: IWMI Water Productivity Survey, 2006)

Crops	**Gamasiab**	**Qarasou**	**Kashkan**	**Saymareh**	**Lower Karkheh**	**Karkheh basin**
			Wheat Irrigated			
Yield	4860±1300	4030±970	3420±1020	2680±1070	2490±1200	3320±1510
Gross inflow	7550±1530	6970±1380	7250±1960	6630±1250	4500±1140	6050±1920
WP	0.65±0.16	0.59±0.16	0.48±0.12	0.41±0.15	0.55±0.23	0.55±0.20
			Wheat Rainfed			
Yield	1820±570	1730±550	1410±580	1290±480	1220±620	1460±580
Gross inflow	3100±240	3190±300	3580±140	3650±450	1840±260	3320±610
WP	0.59±0.19	0.55±0.18	0.39±0.16	0.35±0.12	0.69±0.41	0.46±0.22
			Barley Irrigated			
Yield	4050±896	4250±1060	2250±350	1500±710	1460±830	2640±1530
Gross inflow	6760±1490	7270±1530	5820±290	5420±60	4030±1040	5320±1800
WP	0.60±0.08	0.61±0.27	0.39±0.08	0.28±0.13	0.37±0.18	0.470±0.19
			Barley Rainfed			
Yield	1870±590	1590±650	1450±500	1130±507	900±200	1410±610
Gross inflow	3240±240	3320±390	3600±130	3540±340	1750±280	3380±480
WP	0.58±0.18	0.49±0.21	0.40±0.14	0.32±0.14	0.54±0.17	0.43±0.19
			Maize Irrigated			
Yield	8350±1380	8270±910	6000	5750±1320	6710±1450	7440±1560
Gross inflow	9820±2420	11260±5920	6570	6720±1800	10290±4550	9990±4400
WP	0.90±0.28	0.88±0.37	0.91	0.88±0.18	0.75±0.30	0.84±0.30
			Chickpea Rainfed			
Yield	590±210	750±260	430±110	610±150	-	620±210
Gross inflow	1090±650	1040±250	1420±746	1250±540	-	1200±530
WP	0.54±0.44	0.76±0.34	0.44±0.32	0.57±0.26	-	0.70±0.84

Note: Units for yield, gross inflow and water productivity are kg per ha, m^3 per ha and kg per m^3 respectively.

Analysis at the sub-basin scale can provide additional insights into where any efforts to increase physical productivity might best be targeted. As shown in **table 3**, the basin averages mask variation in physical water productivity across sub-basins. The two upper sub-basins, Gamasiab and Qarasou, have the highest physical water productivity for all crops while the lowest figures tend to be found in Kashkan and Saymareh sub-basins. These water productivity patterns are largely similar to yield patterns, highlighting water productivity-yield relationships.

Because of vast differences in physical conditions within a single basin like the Karkheh, one must be cautious in assuming that differences in water productivity across the basin indicate gaps which might be closed. To get a better feel for gap closing potential, an analysis of individual farmer water productivity was performed. The results for wheat are shown in **Figures 7a** and **7b**. They reveal substantial variation even between farmers within the same sub-basins. While the physical conditions on individual farms within a sub-basin can of course still differ substantially, these figures still give an indication that closable gaps exist. For example, the difference between the top 10% of cases and average water productivity in each sub-basin is about 0.40 kg/m^3. If that gap could be closed, wheat production could increase by approximately 1500kg/ha with almost no increase in water use. While probably an overstatement of the realistic possibilities in the short to medium term, it does give an idea of the possible targets.

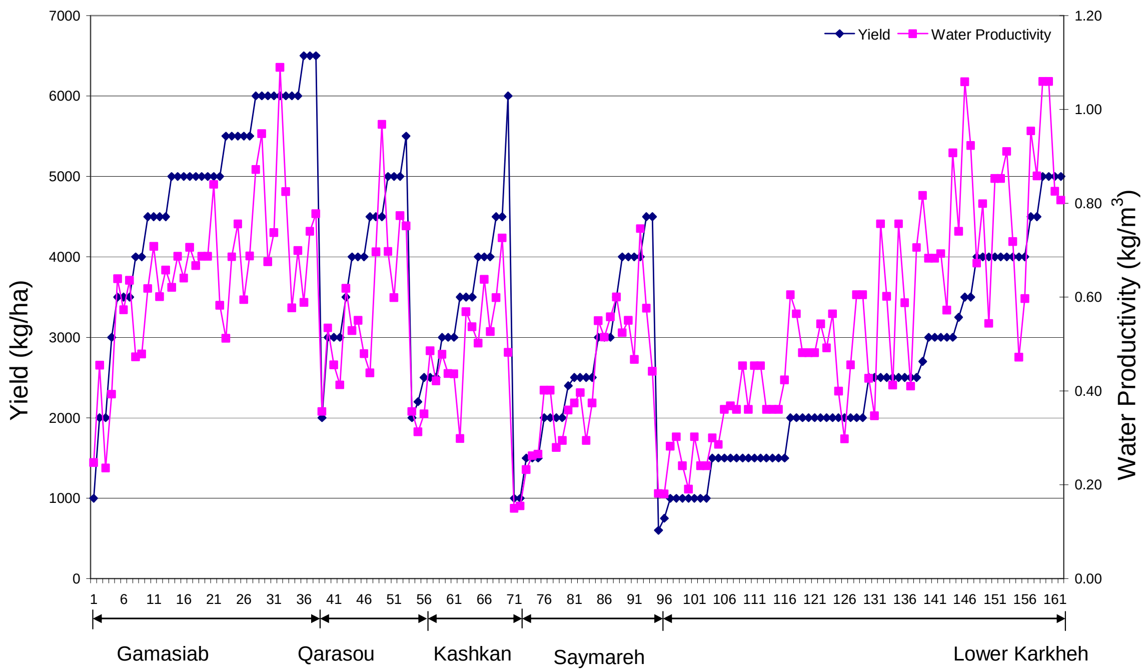

Figure 7a. Inter- and intra-subbasin variation in irrigated wheat land and water productivity. Water productivity is calculated in terms yield per unit of gross inflow. The large differences between farmers within a sub-basin gives an initial indication of the potential for improvement.

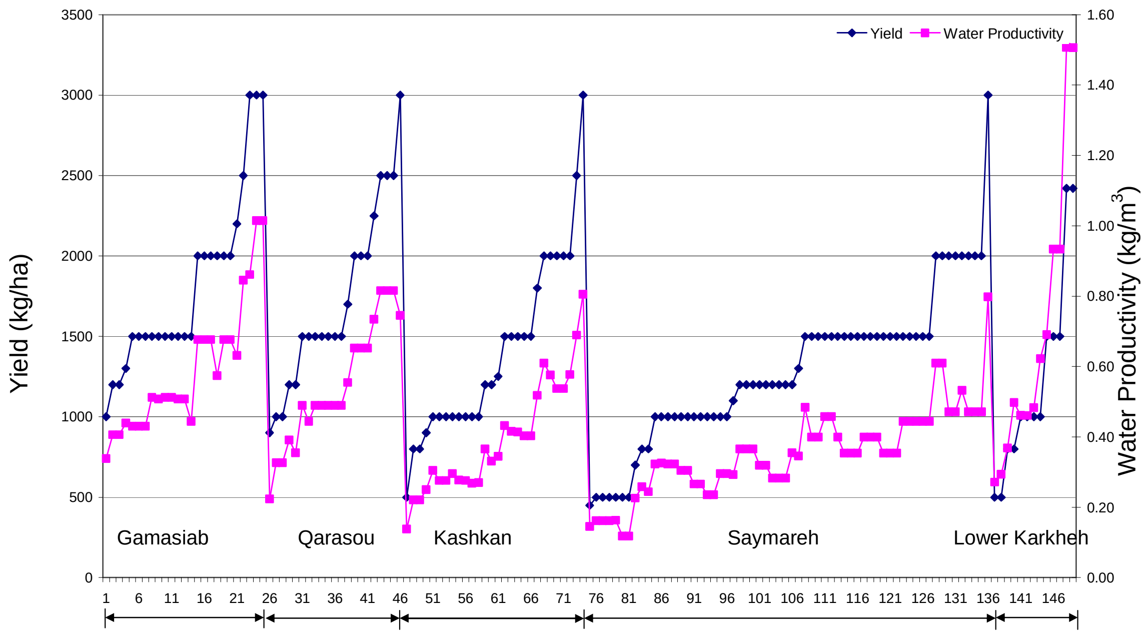

Figure 7b. Inter- and intra-subbasin level variation in rainfed wheat land and water productivity. Water productivity is calculated in terms yield per unit of rainfall. The large differences between farmers within a sub-basin gives an initial indication of the potential for improvement.

To develop some idea of the reasons for this gaps and therefore possible policy responses, production function analysis was performed. The tentative results showed that access to irrigation, pumped water (from either groundwater or streams), seed rate and nitrogen use are the major factor governing wheat yield. This highlights the importance of water and other inputs in improving farm scale yield and water productivity improvement.

For irrigated areas, the analysis also reveals that farmers apply 2-8 irrigations to wheat crops. Further segregation of data show that in most cases highest yield can be attained by 3-4 irrigations. While there may be valid reasons for "over irrigation", this suggests that extension work for farmer education might allow increased production at lower water input levels. Because all applied water is not used, the impact of the savings would not be proportional to the decreased application, but savings are possible.

For rainfed areas, the analysis shows that there is considerable scope for improving physical land and water productivity by exploring means of additional water application wherever possible. Rainfed yields tend to be only half that of irrigated and much of the difference can be associated with water use. However, the water productivity gap between rainfed and irrigated areas is minimal, because of both lower yield and lower well water use in rainfed systems. This stresses the need for comparing both land and water productivity while diagnosing the overall system performance. The data also show that the land productivity gains with respect to marginal increases in water use is higher for rainfed system than irrigated ones. For these reasons and because of higher precipitation and lower irrigation requirements, in spatial terms more scope exists in the upper than lower Karkheh for water productivity improvements.

To move thinking beyond a single crop to the best use for agricultural water overall requires a shift to economic water productivity concepts. Estimating economic water productivity, is an intricate task as it requires data on water use, production and economic value to be available at similar scales. As in most countries, data related to water use in Iran are collected within hydrological boundaries while production and economic data follow administrative boundaries. This mismatch was overcome for the Karkheh by transforming district level secondary data on agricultural, livestock and poultry production/economic value to the sub-catchment scale. For this transformation, first a land use map discerning non-vegetative areas, water bodies, irrigated crops, rainfed crops, and natural vegetation was prepared using field data, GIS coverage and signal processing of bi-monthly Moderate Resolution Imaging Spectroradiometer (MODIS) NDVI images for an annual cropping year. Then ratio of a particular land use area falling inside a sub-watershed and district was computed to transform district level data to a sub-watershed scale. Then the Gross Value of Production (GVP) from each land use at sub-catchment scale was calculated. Finally aggregated values of GVP and water consumption information in terms of actual evapotranspiration were used to calculate water productivity at sub-catchment scale (Ahmad et al., 2009). The analysis incorporated as many rainfed and irrigated agricultural production systems as possible. Separate calculations with and without livestock are presented to highlight the importance of mixed crop-livestock systems.

The overall water productivity of rainfed crops was 0.051\$/m^3 ranging from 0.027 to 0.071\$/m^3 (**Figure 8**) whereas average irrigated crop water productivity is 0.22 \$/m^3 ranging from 0.12 to 0.524 \$/m^3. The coefficient of variation (CV) for irrigated crop water productivity was 0.45, which is almost double than rainfed water productivity. High CV for irrigated crops than rainfed is largely attributed to large variation in cropping patterns between different sub-catchments. In rainfed systems wheat and barley are the main crops whereas in irrigated systems farmers grow a mixture of crops such as wheat, maize, barley, sugarbeat, and vegetables. Rainfed water productivity declines from the upper to the lower Karkheh. The apparent difference between upper and lower Karkheh is due to insufficient rainfall in lower Karkheh. Despite of similar precipitation patterns in upper Karkheh, rainfed water productivity shows quite large variability. This could be related to soils and other agronomic factor and requires further investigation. In contrast the higher irrigated WP values are concentrated in middle and lower reaches of Karkheh except South Karkheh sub-catchment which could be related to higher soil and water salinity. It is pertinent to note that although the highest irrigated water productivity is in Pole Zal sub-catchment but this could not be considered as a target value for improvement, given the high level uncertainties perceived in ET_a estimation, GVP and lower extent of irrigated area. Considering this Jelogir, Pole Dokhtar, Ghore Baghestan and Doab in upper Karkheh and Abdul Khan and Hamedieh in lower Karkheh could serve as the possible target values at least for medium term interventions in neighboring low performing sub-catchments.

In terms of comparison, Hussain et al., (2007) compiled recent estimates of water productivity from 40 settings in 23 countries and found a wide range of values (e.g, less than 0.01 to 0.45 \$/m^3). In Rechna Doab of Pakistan, Ahmad et al., (2004 a & b) reported values around 0.09, 0.12 and 0.124 \$/m^3 for rice, wheat and cotton crops, respectively. For the same system, the irrigation system level agricultural water productivity in terms of GVP per unit of actual evapotranspiration varies from 0.02 to 0.10 \$/m$^{3.}$ Higher water productivity values were attributed to good groundwater quality as well as adequate and reliable water supplies. Molden et al., (1998) compared the performance of 18 irrigation systems in 11 countries and reported that water productivity (output per unit of water consumed) varies from 0.03 to 0.91 \$/m^3. While comparisons across countries are problematic because of differences in basic physical conditions, it can be generally said that the physical water productivity numbers for the Karkheh are low by global standards. This is discussed further below in the context of economic water productivity and at least suggests scope for improvement.

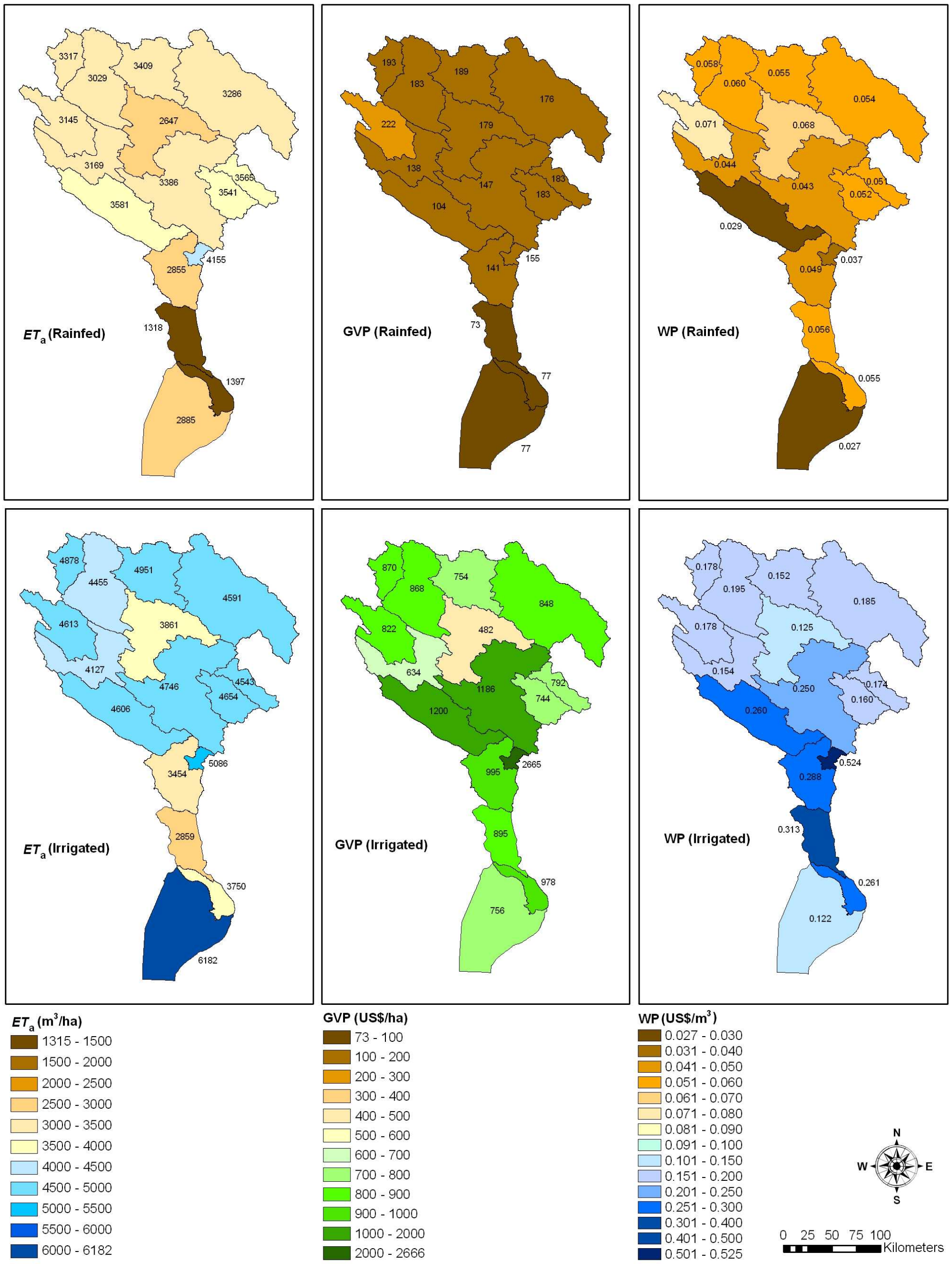

Figure 8. Water consumption (ETa), gross value of production (GVP) and water productivity (WP) from rainfed and irrigated crops for 2002-03 in Karkheh river basin. The values in each sub-catchment represent the average values for ETa, GVP and WP. (Note: 1 US$ = 8281 Iranian Rials in 2003).

Vegetative water productivity (WP of crops, horticulture and forest, not considering the contribution of livestock in the system) was 0.097 $/m^3. However, there was wide variation across sub-catchments and values ranged from 0.004 to 0.36 $/m^3 at the Pole Zal and Hamedieh sub-catchment respectively (**Figure 9**).

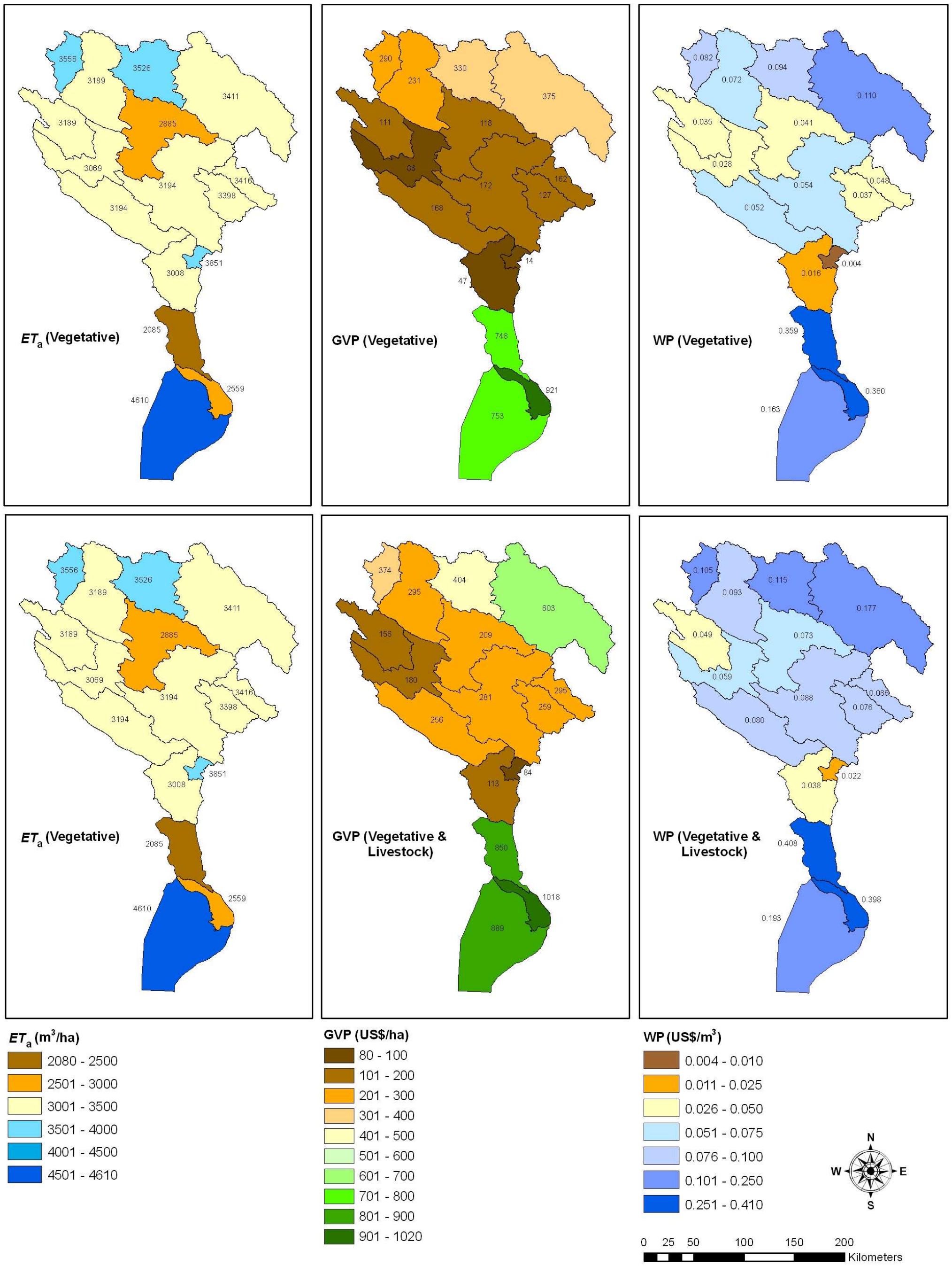

Figure 9. Water consumption (ETa), gross value of production (GVP) and overall water productivity (WP) from vegetative and livestock for 2002-03 in Karkheh river basin. The values in each sub-catchment represent the average values for ETa, GVP and WP. (Note: 1 US$ = 8281 Iranian Rials in 2003).

The higher values occur where there is a higher proportion of irrigated lands in a sub-catchment whereas lower values reflect the dominance of other land uses (i.e. range lands and forest and rainfed crops). It is important to note that the magnitude and distribution of agricultural economic water productivity changes substantially when livestock is included. The average value of overall vegetative and livestock WP becomes 0.129 $/m^3 which range of 0.022 to 0.408 $/m^3. The impact of including livestock in WP calculation is more prominent in case of upper Karkheh. The reasons include a high proportion of grass and rangelands as well as rainfed vegetation which is an important grazing source beside crop residue from irrigated and rainfed crops.

3 Poverty

Prior to this project there were few studies and little data available on the extent and distribution of poverty in Iran. As important for the goals of the CPWF, there were no poverty studies to our knowledge in Iran using anything other than administrative boundaries as the unit of analysis. As a result, it was necessary for the project team to both develop Karkheh specific data sources and undertake original analysis to describe the poverty situation in the Karkheh basin.

To do this, Iranian team members worked with the Statistical Center of Iran to obtain data from Household Income and Expenditure Surveys (HIES) for the years 1983, 1993, and 2004. The HIES is the most complete and consistent survey in existence within Iran related to poverty analysis. The 2004 survey for the first time included partially geo-referenced data which allowed us to reorganize the data away from traditional administrative boundaries and conduct analysis specifically on the Karkheh basin. As some indication of the surveys' scope, the most recent, for 2004, contains data for some 24,000 households across Iran and more than 2000 for the Karkheh.

While our primary goal was analysis of poverty within in the Karkheh, our data organization and procedures facilitated simultaneous analysis of the entire country. This also allowed us to put the Karkheh's poverty situation within the larger Iranian experience.

The first step in measuring poverty is defining a poverty line. To do this for Iran, we made use of the estimates of the cost of diet provided by Rahimi and Kalantary (1992). Based on this information, separate poverty lines were constructed for both rural and urban areas. Based on the Household Income and Expenditure Surveys, poverty estimates were then calculated using metrics standard in the literature including the Headcount, Income Gap, Poverty Gap Ratio and Foster, Greer and, Thorbecke Measures. While all measures follow similar patterns, each provides specific information and each has particular advantages and limitations. For the purposes of this synthesis, only the two most widely used measures, Headcount and Income Gap, are presented.

The Head-Count Ratio (HCR) is one of the most widely used poverty measures. The Head-Count Ration is simply the proportion of the population with income less than the poverty line. Its primary advantage is that it provides an easy to understand metric of the extent of poverty within a given population. One major disadvantage of the Head-Count Ratio is that it does not take into account the severity of the poverty among the poor. Thus someone with income 99% of the poverty line is counted the same as someone with income equal to only 10% of the poverty line. The Income Gap (IG) measure provides the average proportionate shortfall of income below poverty line. Thus it provides a measure not of the number of poor people, as in the Head-Count Ratio, but rather the depth of the overall poverty problem in terms of income shortfall.

To provide context for the Karkheh results, we first highlight the results national poverty levels and their trends as shown in **Table 4.** The most striking finding is the large and rapid changes in poverty levels which rose sharply from 1983 to 1993 before falling even more sharply by 2004. The reasons for these changes are complex. However, poverty is believed to have been relatively low in early period in part as a result of policy responses to the Iran-Iraq war. During that period, the government maintained tight controls over the economy and attempted to provide minimum subsistence to every household through a wide ranging rationing system. By 1993, economic adjustment and liberalization policies adopted by former president Hashemi Rafsanjani resulted in inflation rates of 40%, eroding income and throwing large numbers of people into poverty. By 2004, a stabilization policy had become effective, helped also by high oil prices due to conflict in the Persian Gulf, and the county's economy was growing at 5-6% per year with inflation down to 15%.

Table 4. Incidence of rural and urban poverty in terms of head-count ratio (HCR) and income gap ratio (IG) in Iran, 1983-2004.

	Rural		*Urban*	
Year	HCR	IG	HCR	IG
1983	0.391	0.384	0.187	0.342
1993	0.525	0.411	0.296	0.328
2004	0.334	0.362	0.236	0.331
	Percentage change in poverty			
1983-93	34.3	7.2	58.3	-4.4
1993-04	-36.5	-11.9	-20.3	0.9
1983-04	-14.7	-5.6	26.2	-3.4

The magnitude of these changes on poverty levels were higher in rural areas than urban, perhaps in part because the level of poverty was significantly higher in rural areas to begin with. While rural poverty is still higher in rural areas, the gap between the two is now substantially reduced.

As shown in **Table 5**, the overall trends in the Karkheh basin are similar to those for Iran as a whole. However, the decline in rural poverty has been even more rapid than urban. As a result, rural poverty levels in the Karkheh are actually now lower than urban levels. Furthermore, while the Karkheh basin was poorer than Iran as a whole in 1983, the reductions in poverty after 1993 have been even more rapid with the result that the Karkheh now has lower than average poverty rates in both rural and urban sectors.

Table 5. Incidence of rural and urban poverty in terms of head-count ratio (HCR) and income gap ratio (IG) in the Karkheh River basin, Iran, 1983-2004.

	Rural		Urban	
Year	HCR	IG	HCR	IG
1983	0.488	0.373	0.227	0.337
1993	0.593	0.376	0.404	0.347
2004	0.283	0.318	0.267	0.301
	Percentage change in poverty			
1983-93	21.6	0.8	78.0	3.5
1993-04	-52.3	-15.4	-33.9	-13.5
1983-04	-42.0	-14.7	17.6	-10.5

There is, however, substantial variation in poverty rates across the basin as shown in figure 10 for rural areas. Poverty rates in the south of the basin are more than double those of some more northerly districts and above those of the national as a whole. This contrasts with frequent assumptions that the incidence of rural poverty is highest in upland areas.

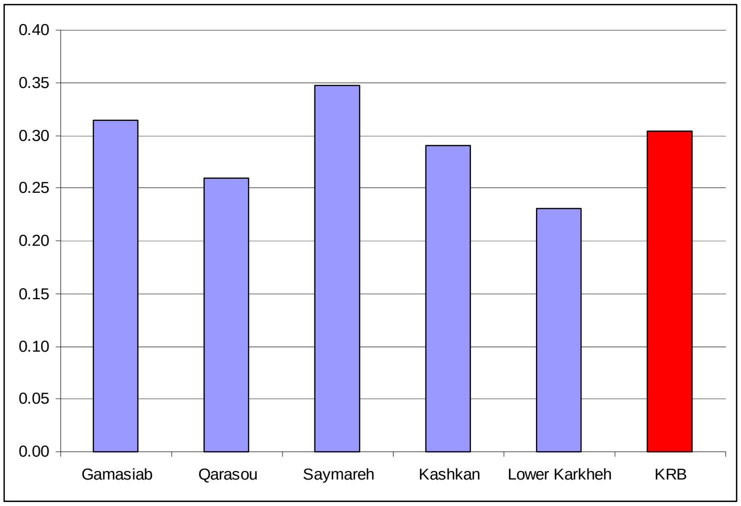

Figure 10. Sub-basin Breakdown of the Extent of Poverty in the Rural Karkheh River Basin, 2004.

4 Institutions and the Strategic Policy Environment

As in most countries, Iran develops and manages its water resources through a set of institutions. At the national level, there are three primary ministries in charge of water resources. These are the Ministry of Energy, the Ministry of Jihad-e-Agriculture and the Ministry of Jihad-e-Sazandagi.

The Ministry of Energy (MOE) is responsible for energy supply and therefore water via hydropower production. While hydropower plays a major role in the Karkheh management, the role of the MOE goes beyond just hydropower production and includes all major hydraulic works including dams as well as primary and secondary irrigation canals and drainage. Within the MOE there is a Water Affairs Department responsible for overseeing and coordinating planning, development, management and conservation of water resources. There are also 14 Regional Water Authorities (RWA), including one for the Karkheh, which report to the MOE and are responsible for water project feasibility studies and project management.

The Ministry of Jihad-e-Agriculture (MOA) is responsible for rainfed and irrigated crop development and thus indirectly influences crop water use. It is also in charge of subsurface drains, tertiary and quaternary canals as well as on-farm development and irrigation techniques. In addition, the MOA is involved with the setting of agricultural price and production policies which influence farmers' cropping decisions, water use and water productivity. The Ministry of Jihad-e-Sazandagi deals with watershed management and rural development.

Another set of organizations, both governmental and non-governmental, works to alleviate and prevent rural poverty. For example,

- The Komite-e-emdade Imam Khomeini (Emam Khomeini Relief Committee) which provides aid to needy and deprived families,
- The Red Crescent Society of the Islamic Republic of Iran which provides medical services,
- The Medical Services Insurance Corporation which provides medical services, including in rural areas,
- The State Welfare Organization, though focused primarily on urban areas, in some cases cover rural areas as well, and
- The Social Security Organization covers a variety of working groups, though not directly agricultural workers.

While there is certainly institutional overlap and imperfection, the key point, especially in comparison with many of the other CPWF basins, is that a set of functioning institutions exist to both manage water and address poverty. The primary institutional issues for the Karkheh thus have more to do with the setting and funding of policy priorities rather than the creation of new institutions.

This is perhaps exemplified by examining the physical and policy environment within the Karkheh over the last 100 years. This development can be divided into 4 phases including

1) "pre-development phase-1900-1950",
2) a "development and utilization phase-1950-1980,
3) a "GW exploitation and growing scarcity phase-1980-2000", and
4) an "over-exploitation phase-2000-2025".

During the 1st phase and before, wheat and barley were the dominant crops based on rain-fed agriculture, though evidence of irrigation is present. Starting in the second phase, the region shifted slowly towards irrigated agriculture and more than 10% of the area came under irrigation. Starting in the 3rd phase, groundwater began to grow in relative importance as surface supplies became more scarce. Due to self sufficiency program launched by the government in the 4th phase, wheat cultivation was given priority. As a result, the cultivation of other crops with less water demand and higher water productivity (in terms of units of water or value) were not considered as options.

Although these policies have helped close the self-sufficiency gap, natural resources including water in the basin came under extreme pressure. As highlighted earlier in this report, it is believed that these trends are not sustainable and more concerted efforts will be needed for the management of land and water resources if the Karkheh River Basin has to continue contributing its share in meeting country's overall food requirements. This highlights the interplay between physical outcomes and the policy environment and the role of each in finding future solutions to the basins water problems.

Understanding Iran's current water policy environment and choices related to water and poverty also requires an understanding of the countries broader national and strategic challenges and foreign policy challenges, in particular as related to its agricultural and foreign policy focus on self-sufficiency. The reasons for a self-sufficiency policy come from Iran's tumultuous past, two ongoing wars on the country's eastern and western flanks, and the fear that food supplies from the outside, in particular the west, could be cut off. Food self-sufficiency was in fact already a goal of the Iranian Revolution. The downside of the food self-sufficiency policy is that it encourages the production of grains in a water scarce areas which, from an economic and probably water productivity standpoint, would be better imported. Exacerbating the problem is a grain subsidy system aimed primarily at the welfare of urban residents. This subsidy system does not specifically target the poor but does encourages waste and pushes against Iran's own self-sufficiency goals.

5 Water, Poverty and Productivity: Current Policy Issues

As everywhere, the linkages in the Karkheh basin between water, agriculture and, in particular, poverty are complex. The control of water resources in the Karkheh has played a major role in the both the expansion of agricultural area and an increase in average yields over the last few decades. This has clearly contributed to Iran's strategic goal of food self-sufficiency.

At the same time, the increase in food production has not generally been associated with changes in rural or urban poverty levels in the Karkheh. As described already, poverty increased and then decreased sharply over the 20 year period ending in 2004 following a pattern similar to the country as a whole. For the Karkheh, this is despite a relatively steady increase in area harvested from 786,000 ha in 1983 to 1,272,000 in 1993 to 1,707,000 in 2004 (**Figure 11**). Clearly the direct driving forces behind poverty change in Iran in general and in the Karkheh in particular have more to do with larger economic, political and international relations issues than with agricultural production and, by association, water use. This same finding holds true for rural Iran and the rural Karkheh basin where poverty trends have been similar and one might hypothesize a closer connection between water use and poverty levels.

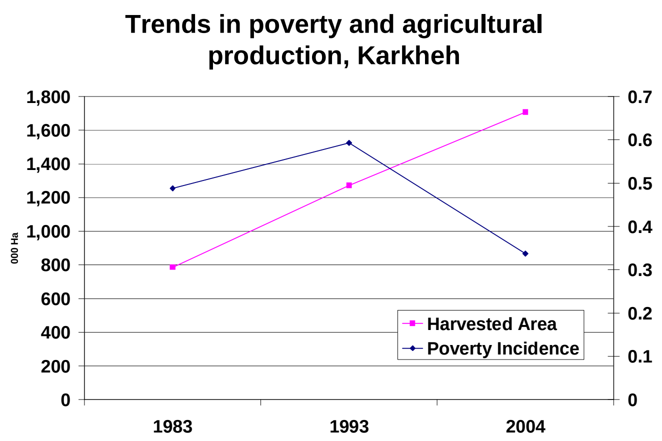

Figure 11. Trends in poverty and agricultural production, Karkheh basin, Iran

However, this is not to say that water, food and poverty are not linked in the macro environment in other, more indirect ways. In a market economy, increased food production translates into lower prices and has poverty impacts on the urban poor-impacts often estimated in other regions as large or larger than rural impacts. In Iran, the prices of many consumer staples are government controlled and so any price impact is more directly related to the cost of government subsidies. At least in theory, the decrease in implicit prices reduces the costs to the exchequer which can free government resources for other poverty reduction programs. While the Government of Iran and private organizations have established many poverty reduction programs, the extent to which they have been facilitated by increased food production is unknown and likely unknowable.

In the Karkheh basin, rural poverty levels are already relatively low, and agricultural workers are also not amongst the poorest of rural residents. Furthermore, the absolute number of rural residents in falling and the proportion of rural residents in the overall population rapidly declining. Given these demographics, the water scarcity conditions of Iran, the country's substantial other assets, and evidence of the drivers of past poverty, the use of non-agricultural water measures is likely to be the most effective direct solution to remaining rural poverty problems in the Karkheh basin and elsewhere in the country.

As an example of the possibilities, we can consider Iran's policy of providing subsidies to domestic energy, primarily petrol, users. These subsidies only indirectly impact water use and agriculture. However, their magnitude highlights how a change from a policy which does nothing to improve productivity could be used to improve the lives of the poor. Petrol in Iran sells at state controlled prices at only a small fraction of world market prices. The result is high levels of inefficiency in use as well as smuggling. Because Iran's petroleum refining capacity is limited and despite the fact it is one of the world's largest oil exporters, it now has to import nearly half its petrol which it sells internally at subsidized prices which have been estimated to include an implicit subsidy equivalent to 19% of GDP. Based on our analysis of the income gap measure of overall poverty in Iran, a targeted transfer of less than half this amount would move everyone in Iran now below the poverty line above the poverty line. While this might sound simple, the recent riots over the imposition of fuel rationing show the political difficulty in making any change to domestic energy policy. The same is would likely be the case for a change in food pricing policies. Nonetheless, the example highlights how changes in existing policy structures could be used to target poverty, likely much more effectively and with lower trade-offs than changes in agricultural water management or allocation.

In a related way, our analysis of poverty trends highlights how much impact the overall economic environment can have on both rural and urban poverty levels. Policies to foster overall growth including in industry and services in a stable macro economic environment again seem to be a more promising way to reduce poverty than changes in agricultural water management. However, such policies may actually increase competition for water between the agricultural and urban sectors and require careful overall planning to ensure that vulnerable rural groups are not disproportionately harmed.

This discussion should not be taken to mean that there is no work to be done in agricultural water management. In fact, our findings reveal that there are substantial gains to be made through improvements in water productivity. In the short to medium term, this means focusing on improvements in physical water productivity, primarily the physical quantity of crop output per unit of water input so as to improve the use scarce water resources for national food security priorities. For example, studies done for the project found that achievable increases in water productivity through reduced soil moisture loss and more efficient irrigation application could reduce irrigation requirements by 60 million m3 for the entire basin. Reduction in irrigation requirements will also help in controlling groundwater table decline. In the longer term, and if the international environment changes, the focus may be shifted towards increases in economic water productivity by moving water away from lower productivity grain production and towards higher value activities in and outside the agricultural sector including hydropower generation and urban uses.

To better understand these issues, scenario analysis was performed to illustrate the tradeoffs between food production goals, environmental protection and equitable distribution of production gains over the basin. The continuation of the government's wheat self-sufficiency policy – implemented because of the threat of international sanctions- will place heavy strain on water systems and likely lead to further degradation of the swamp downstream. On the other hand, strict adherence to environmental flow standards will lead to lower wheat outputs and missed production targets. But our scenario analysis shows that a compromise between food production, environmental goals and equity is possible. A further decline of water resources because of increased food demand is not inevitable. A combination of the right policies could minimize the tradeoffs between food self-sufficiency, sustainable water use and farmers' income. Scenarios analysis helps identifying tradeoffs and facilitates science based decision making.

It should be noted that the intention of the modeling effort was to show the use of scenario analysis as a tool in thinking about the future development of the Karkheh basin. The scenario quantification was based on lumped estimates of hydrological and agricultural variables. While the model provides a good first estimate, physically based hydrological modelling could add more detailed and precise estimates of the hydrological behaviour of the basin (and the interaction of the surface and groundwater in particular). Further, a more detailed modelling of the income distributional effects of the scenarios would enhance the analysis. While these activities were beyond the scope of the project, they would form a logical next step in basin work for the CPWF.

OUTCOMES AND IMPACTS

1 Impact Pathways for BFP Outputs

Outputs	Who will use the outputs?	Why? What is in it for them?	Change in Knowledge, Attitudes, Skills, Aspirations and Practice resulting from use	Indicator(s) of change
1) Karkheh BFP Project reports	CPWF, IWMI, AREO, MOE and other Iranian partners	To plan future research agenda and make better water management decisions in the light of the answers to the key BFP questions out spanning from the BFP research	Improved understanding of basin scale issues related to water productivity, poverty and tradeoffs	Research & development investments leading towards addressing key challenges in river basin management
2) IWMI research reports/working papers	CPWF, Policy makers, water managers, scientists/researchers, students, farmers	improving knowledge and understanding based on the scientific information and policy directions	Improved understanding and management of basin scale issues related to water productivity, poverty and water management.	Reference of this research in policy documentations, discussions, research papers
3) Conference papers/presentations/ Discussions	Participants	Sharing and learning from each others experiences	Extracting relevant lessons/messages for their local context	No. of workshops/conference organized
4) Journal papers	Researchers/scientists, policy makers, water managers, scientists, students, farmers and other stakeholders	New knowledge, methodologies and scientific facts	Improved understanding and management of basin scale issues related to water productivity, poverty and water management.	Reference of this research in policy documentations, discussions, research papers
5) PhD thesis	Researchers/scientists, policy makers, water managers, scientists, students, farmers and other stakeholders	New knowledge, methodologies and scientific facts	Improved understanding and management of basin scale issues related to water productivity, poverty and water management.	Reference of this research in policy documentations, discussions, research papers

Outputs	Who will use the outputs?	Why? What is in it for them?	Change in Knowledge, Attitudes, Skills, Aspirations and Practice resulting from use	Indicator(s) of change
6) Data	Researchers/scientists, policy makers, water managers, scientists, students, farmers and other stakeholders	Carry out analysis and research for making judicious water management decisions	Improved understanding and management of basin scale issues related to water productivity, poverty and water management.	Downloading of data from IDIS website

2 Outputs organized by Impact Pathway Plan

1) Karkheh BFP Project report

This report and related reports submitted to the CPWF

2) IWMI working paper

Marjanizadeh, S., Qureshi, A.S., Turral, H., Talebzadeh, P. 2009. From Mesopotamia to the thirdmillennium: the historical trajectory of water development and use in the Karkheh RiverBasin, Iran. Colombo, Sri Lanka: International Water Management Institute. 51p. (IWMI Working Paper 135)

3) Conference papers/presentations/ Discussions

Ahmad MD, Islam A, Masih I, Lal M, Karimi P, Turral H. 2008. Mapping basin level water productivity using remote sensing and secondary data In Karkheh river basin Iran. Paper presented at the 13th IWRA World Water Congress on Global Changes and Water Resources, "Confronting the expanding and diversifying pressures", Montpellier, France, 1-4 September 2008. 13p.

Ahmad, M.D.; M.A. Islam, I. Masih, L.P. Muthuwatta, P. Karimi, H. Turral 2008. Water productivity mapping to identify opportunities to improve agricultural water management in the Karkheh River Basin, Iran. In Humphreys, E.; Bayot, R. S.; van Brakel, M.; Gichuki, F.; Svendsen, M.; Wester, P.; Huber-Lee, A.; Cook, S. Douthwaite, B.; Hoanh, Chu Thai; Johnson, N.; Nguyen-Khoa, Sophie; Vidal, A.; MacIntyre, I.; MacIntyre, R. (Eds.). Fighting poverty through sustainable water use: proceedings of the CGIAR Challenge Program on Water and Food, 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, 10-14 November 2008. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food. Vol.I. Keynotes; Cross-cutting topics. pp.119-122. ISBN 978-92-990053-0-9

Masih I, Ahmad MD, Turral H, Uhlenbrook S, Karimi P. 2008. Understanding hydrologic variability for better surface water allocations in Karkheh Basin Iran. Paper presented at the 13th IWRA World Water Congress on Global Changes and Water Resources, "Confronting the expanding and diversifying pressures", Montpellier, France, 1-4 September 2008. 15p. Masih I, Uhlenbrook S, Ahmad MD, Maskey S. 2008. Regionalization of a conceptual rainfall-runoff model based on similarity of the flow duration curve: a case study from Karkheh river basin, Iran. Geophysical Research Abstracts, Vol. 10, EGU2008-A-00226, 2008 EGU General Assembly 2008. Poster presentation at EGU General Assembly meetings, Vienna, Austria, 13 – 18 April 2008.

Masih I, Uhlenbrook S, Ahmad, MD, Maskey S. 2008. Regionalization of a conceptual rainfall-runoff model based on similarity of the flow duration curve:

a case study from Karkheh river basin, Iran. Presentation at the Boussinesq Center Workshop on Hydrologic science for an ever changing world: search for new hydrologic concepts, theories, models and practices, held on June 23-25, 2008, at Delft University of Technology, the Netherlands. Available online at: http://www.boussinesqcenter.nl/act_masterclass_newtheorie.htm

Masih, I., M.D. Ahmad, S. Uhlenbrook, H. Turral, P. Karimi 2008. Overview of streamflow variability and water accounts for the Karkheh River Basin, Iran. In Humphreys, E.; Bayot, R. S.; van Brakel, M.; Gichuki, F.; Svendsen, M.; Wester, P.; Huber-Lee, A.; Cook, S. Douthwaite, B.; Hoanh, Chu Thai; Johnson, N.; Nguyen-Khoa, Sophie; Vidal, A.; MacIntyre, I.; MacIntyre, R. (Eds.). Fighting poverty through sustainable water use: proceedings of the CGIAR Challenge Program on Water and Food, 2nd International Forum on Water and Food, Addis Ababa, Ethiopia, 10-14 November 2008. Colombo, Sri Lanka: CGIAR Challenge Program on Water and Food. Vol.III. Water benefits sharing for poverty alleviation and conflict management; Drivers and processes of change. pp.32-37. ISBN 978-92-990053-2-3

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DATA

Data collection storage and sharing

1. Secondary data

1.1 Time series data on water and climate:

Climate

Sl	***Title***	***Country***	***Basin***	***Location***	***Time period***	***Source***	***Restriction***	***Data file***
1	Daily rainfall.	Iran	Karkheh	124 stations across Karkheh Basin	1951 January 01 to 2005 December 31	Iran Meteorological Organization	Restricted within project team	Loaded in IDIS
2	Hourly and mean daily humidity and dew point temperature	Iran	Karkheh	13 stations	1961 January 01 to 2004 December 31	Iran Meteorological Organization	Restricted within project team	Loaded in IDIS
3	Hourly and mean daily temperature	Iran	Karkheh	13 stations		Iran Meteorological Organization	Restricted within project team	Loaded in IDIS
4	Hourly Wind Direction and Wind Speed	Iran	Karkheh	13 Stations	1961 January 01 to 2004 December 31	Iran Meteorological Organization	Restricted within project team	Loaded in IDIS
5	Location of Meteorological stations	Iran	Karkheh	Karkheh Basin	1966 September to 2001 September	National database Iran	Sharable	Loaded in IDIS
6	Annual temperature map	Iran	Karkheh	Karkheh Basin	Time period used is not given	National database Iran	Restricted within project team	Loaded in IDIS

Water

SL	*Title*	*Country*	*Basin*	*Location*	*Time period*	*Source*	*Restriction*	*Data file*
1	Daily stream flow	Iran	Karkheh	33 Stations	1950 September 23 to 2004 September 21	Iran power and Water Ministry	Restricted within project team	Loaded in IDIS
2	Annual GW exploration statistics	Iran	Karkheh	Karkheh Basin	1998 to 2005	Iran power and Water Ministry	Restricted within project team	Loaded in IDIS
3	GW water decline data	Iran	Karkheh	Karkheh Basin	1960 to 1985	Iran power and Water Ministry	Restricted within project team	Loaded in IDIS

1.2 Statistical data on socio-economy, demography, agriculture, water, climate and environment

Agriculture

SL	*Title*	*Country*	*Basin*	*Location*	*Time period*	*Source*	*Restriction*	*Data file*
1	Statistics of production, yield and price of different crops (including forestry) at district level	Iran	Karkheh	Karkheh Districts	1999 to 2003	Ministry of Agriculture, Iran	Sharable within IWMI	Loaded in IDIS

Socio – economic

SL	*Title*	*Country*	*Basin*	*Location*	*Time period*	*Source*	*Restriction*	*Data file*
1	House hold income and expenditure survey data. (Code Sheet)	Iran	Karkheh	Gharasu, South-Karkheh, Saymareh, Gamasiab, and Kashkan sub-basins	1983, 1993, 2004	Statistical Center of Iran	Raw data are restricted. Aggregated data could be shared within IWMI	Loaded in IDIS

1.3 Base GIS/RS data on administrative boundary, transportation, hydrography, infrastructure, soil, land use, topography)

SL	***Layer name***	***Description***	***Geographic coverage***	***Format***	***Feature type***	***Data Source***	***Source scale/resolution***	***Data provider***	***Time period***	***Restriction***	***Data file***
1	GPS locations of gauge stations	Location gauge stations surveyed by GPS	Karkheh basin		Point	BFP GPS survey				Sharable	03-vect or-Gauge-Station-Locations\Data\gag_adjusted-to-srtm.shp
2	250m resolution Bi-monthly MODIS time series NDVI	Downloaded MODIS data	Karkheh Basin	ERDAS/img	Raster image	Downloaded from NASA web site http://modis.gsfc.nasa.gov/	250m	NASA	2005 and 2006	Publicly available	01-MODIS-250m-16day-NDVI-Mosaic-Single-date-2005\Data 01-MODIS-250m-16day-NDVI-Mosaic-Single-date-2006\Data
3	MODIS 250-m 16 day NDVI Data (Single date, single tiles) 2005-2006 Karkheh Basin, Iran		Karkheh Basin	ERDAS/img		Downloaded from NASA web site http://modis.gsfc.nasa.gov/			2005-2006		01-MODIS-250m-16day-NDVI-Single-date-Single-tiles-2005-2006\Data
4	90m SRTM DEM		Karkheh Basin	ESRI Grid		Consortium for Spatial Information http://srtm.csi.cgiar.org/				Publicly available	01-SRTM-DEM-90m\Data\demsrtm

5	30m Landsat Geo-cover image	Orthorectified Landsat Thematic Mapper Mosaics (nominal 2000's)	Karkheh Basin	Image/ERDAS		http://glcf.umiacs.umd.edu/portal/geocover/	30m	USGS	2000	Publicly available	01-Landsat-Geocover-30m-2000\Data\geo2000.img
6	Agro Climatic Zone map	Agro-climatic zones, Karkheh Basin	Karkheh Basin	Vector/Shapefile	Polygon	Ministry of Agriculture, Iran			Unknown		03-vector-Agro-Climatic-Zone\Data\acz.shp
7	District and provincial boundary map	Administrative boundary covering district, township and province boundaries	Karkheh Basin	Vector/shapefile	Polygon	Ministry of Agriculture, Iran			Unknown		03-vector-Administrative-Boundaries\Data\District\dist.shp 03-vector-Administrative-Boundaries\Data\Province\PrvnBnd.shp 03-vector-Administrative-Boundaries\Data\Township\Township.shp
8	Karkheh basin boundary	Karkheh Basin boundary	Karkheh Basin	Vector/Shapefile	Polygon	Iranian Ministry of Agriculture			Unknown		02-Basin-Bobundary\Data\basbnd.shp
9	City locations		Karkheh Basin			Iranian Ministry of Agriculture			Unknown		03-vector-City-Locations\Data\citybnd.shp
10	Dam locations		Karkheh Basin	shapefile	Point	Iranian Ministry of Agriculture			Unknown		03-vector-Dam-Locations\Data\damloc.shp
11	Lake areas		Karkheh Basin	shapefile	Polygon	Iranian Ministry of Agriculture			Unknown		03-vector-Lakes\Data\lake.shp
12	Land form (high-low) map		Karkheh Basin	shapefile	Polygon	Iranian Ministry of Agriculture			Unknown		03-vector-Landfrom\Data\landform.shp

13	Meteorological stations		Karkheh Basin	shapefile	Point	Iranian Meteorological Department			Unknown		03-vector-Meteorological-Stations\Data\metstn.shp
14	River network		Karkheh Basin	shapefile	Line	Iranian Ministry of Agriculture			Unknown		03-vector-River-Network\Data\river.shp
15	Road network		Karkheh Basin	shapefile	Line	Iranian Ministry of Agriculture			Unknown		03-vector-Road-Network\Data\road.shp
16	Soil types map		Karkheh Basin	shapefile	Polygon	ICAR			Unknown		03-vector-Soil\Data\soilicar.shp
17	Annual temperature map	Map shows the average temperature iso-line	Karkheh Basin	shapefile		Iranian Ministry of Agriculture			Unknown		03-vector-Temperature\Data\isotemp.shp
18	Location of village		Karkheh Basin	shapefile	Point	Iranian Ministry of Agriculture			Unknown		03-vector-Village-Locations\Data\village.shp
19	IKONOS 1-4m DNs Image, 20march 2000		Susa, Iron	Erdas Imagine	image	IWMI	1m	Digital imaging	March 20, 2000		01-IKONOS-MS-1m-2000\Data\susa_rgb.img
20	Landsat Enhanced Thematic Mapper (ETM+) Single Tiles		Karkheh Basin	Image/ERDAS	image	IWMI	30m	Land Sat	2000		01-Landsat-ETM-30m-Reflectance-2000
21	Landuse	Landuse data from AEZ	Karkheh basin	shapefile	polygon	Iranian Ministry of agriculture			1998		03-vector-Landuse-Agricultural-Ministry\Data\LUAEZ98.shp

22	Landuse 98	Landuse data of 1998	Karkheh basin	shapefile	polygon	Iranian Ministry of Forestry			1998		03-vector--Landuse-Forest-Ministry\Data\LULC98.shp

2. Processed data

Sl	Title	Description	Purpose	Geographic coverage	Resolution (for raster)	Format and type	Original data used	Process description	Access /use restriction	Data filename
1	Stream network derived from DEM	Stream network generated form SRTM 90 DEM	Hydrological modelling	Karkheh basin, Iran		Vector, line	SRTM 90 meter DEM	The DEM was processed using ArcGIS to fill sinks. Flow direction and flow accumulation was calculated and stream line generated using ArcGIS		02-Drainage-Network\Data\dr100.s hp
2	Sub-watershed boundaries derived by using DEM	Sub watershed generated form SRTM 90 DEM	Hydrological modeling	Karkheh basin, Iran		Vector, line	SRTM 90 meter DEM	The DEM was processed using ArcGIS to fill sinks. Flow direction and flow accumulation was calculated and sub-watershed generated using ArcGIS		02-Sub-watersheds\Data\watsd20k.shp
3	Vegetative coverage	Vegetative coverage classified from Landsat geo-cover image	Landuse mapping	Karkheh basin, Iran	ERDAS img	raster	LANDSAT ETM			02-Vegetative-Cover-Landsat-ETM-30m-2000\Data\vegcov.img

4	Land cover maps	Land cover maps at 2 different aggregation level (12 and 3 classes) classified by using time series MODIS NDVI with the help of GT survey	Landuse mapping	Karkheh basin, Iran	ERDAS img	raster	MODIS 250m image of 2005, 2006			02-Landuse-MODIS-3classes-250m-2005\Data\landuse 3cls 02-Landuse-MODIS-10classes-250m-2005\Data\landuse 10cls
5	Sub-watershed level GVP maps derived by using GIS based transformation method. District level GVP maps were also prepared									
6	Sub-watershed level water productivity maps derived by using GIS based transformation method.									
7	Slope Map, Karkheh Basin	Slope grid generated from sinkfilled 90 SRTM DEM								02-Slope-90m\Data\slopedeg
8	Flow accumulation	Flow accumulation grid generated from sinkfilled 90 SRTM DEM								02-Flow-Accumulation-90m\Data\flowacc
9	Flow Direction	Flow direction grid generated from sink filled 90 SRTM DEM								02-Flow-Direction-90m\Data\flowdir
10	NDVI of Landsat	NDVI of Landsat ETM		Karkheh Basin			Landsat ETM (nominal 2000),			02-Landsat-ETM-30m-NDVI-2000\Data

3. Primary data

SL	***Title***	***Country***	***Basin***	***Location***	***Time period***	***Source***	***Restriction***	***Data file***
1	Field scale data on soil moisture, irrigation and agronomic practices	Iran	Karkheh	Asadbad area	Feb-Oct 2007	Primary data	Sharable within IWMI	Loaded in IDIS
2	Water productivity Survey data	Iran	Karkheh	298 farmers from 113 villages Across Karkheh basin	May-October 2006	Primary survey	Sharable within IWMI	Loaded in IDIS
3	Groundwater survey	Iran	Karkheh	450 farmers across Gamasiab	June-September 2006	Primary survey	Sharable within IWMI	Loaded in IDIS

RECOMMENDATIONS

Karkheh Specific Recommendations

1. The direct driving forces behind poverty change in Iran in general and in the Karkheh in particular have more to do with larger economic, political and international relations issues than with agricultural production and, by association, water use.
2. Given current demographic trends, the water scarcity conditions of Iran, the country's substantial other assets, and evidence of the drivers of past poverty, the use of non-agricultural water measures is likely to be the most effective direct solution to remaining rural poverty problems in the Karkheh basin and elsewhere in the country.
3. In the short to medium term, agricultural water policy should instead be focused on improvements in physical water productivity, primarily the quantity of wheat output per unit of water input, so as to improve the use scarce water resources for given national food security priorities.
4. In the longer term, and if the international environment changes, the focus of agricultural water policy may be shifted towards increases in economic water productivity by moving water away from lower productivity grain production and towards higher value agricultural and other activities including hydropower generation and urban uses. However, additional work is needed to fully understand possible trade-offs in any reallocation.

Recommendation for future CPWF Research

1. Basic research to understand national and global impacts of food self-sufficiency policies, such as those caused by food embargo threats. This is especially applicable to the arid and generally water scarce states of the Middle East/North Africa. The purpose should be both to raise awareness of the water linkage, understand the potential for policy change to increase national and global water productivity via increased trade options, and prioritize future policy action at national and global levels. In some cases it is not unreasonable to hypothesize that water productivity gains from policy change in this arena could be as large or larger than those possible through technical intervention.
2. While the analysis presented here has argued that agricultural water use is probably not the most effective way to reduce general rural poverty in the Karkheh basin, it is still likely that in certain locations or for certain poor groups changes in agricultural water use may be a cost effective tool for poverty reduction-without major downstream tradeoffs. Additional research at much finer scale is needed to identify possible target groups and the agricultural water interventions which would most benefit them. Moving beyond the Karkheh, decision support systems for determining when and where (both within and across countries/basins) water is a cost effective poverty alleviation tool could be a major contribution of the BFPs and CPWF research.
3. The net value of any intervention to increase water productivity, or reduce poverty, in a given location or at a given scale requires an understanding of the impact of that intervention in other basin locations and scales. Similarly, planning for reallocation of water from low to high value uses-or even understanding the possible scope for reallocation-requires an understanding of in stream flows actually available for reallocation. A key constraint in the Karkheh for developing this understanding is a lack of hydrologic data, a problem which also exists in many other settings. The Karkheh Basin Focal project developed models to overcome data gaps and produce tools for trade-off analysis. However, additional research will be needed to ensure that the tools are truly appropriate for Karkheh managers. More generally, research into tool creation for regions without sufficient data may be an appropriate investment for the CPWF.
4. The inclusion of livestock in (average) economic water productivity calculations had a significant impact on estimates of the absolute level of water productivity as well as its distribution across the basin. Further work across basins to highlight the importance of livestock, fisheries, forestry and possibly other agricultural systems not traditionally included in water productivity estimates could be an important tool

for ensuring that productivity calculations are appropriately constructed for policy makers to base interventions for improving productivity through changes in production practices or through reallocation.

5. One goal of BFP research was to develop insights from individual basins which are applicable to other similar regions. Implicit in this goal may have been the idea of looking for similarity in comparable agro-ecological regions. As this focal project has shown, one of the driving factors in determining water outcomes and intervention possibilities in the Karkheh has been the geo-political situation in which Iran finds itself. While additional "research" on the topic of what the basis for basin comparison and cross-basin learning should be may not be required, additional discussion on ways to get cross-basin/region value beyond a focus on the physical may have high payoffs for the CPWF. This payoff could come in terms of generating additional value from existing research by BFPs and the overall CPWF project portfolio. One avenue may be to think of the changing marginal values of water productivity or poverty interventions as basin conditions change over time or space, e.g. in terms of water scarcity/development levels, income levels and/or within some typology of geo-political conditions.
6. Surface and ground water interaction in Karkheh basin are not well understood due to complex geological formation. Moreover, the impact of increasing groundwater use on downstream groundwater availability and in stream flows needs further investigation. This knowledge is also pre-requisite for planning and implementation of artificial recharge programs in the plains where groundwater has been mined. In addition, understanding how groundwater policy can be effectively implemented is a challenge not only in the Karkheh but around the world.

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ANNEX 1. Spatio-temporal distribution of precipitation in different sub-catchment of Karkheh Basin

Sub-catchment	Area (km^2)	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	*Sum*
Upper Karkheh														
Doab	7767	480	411	343	754	617	548	103	0	0	0	0	137	3393
Pole Chehr	3121	225	267	197	295	140	211	42	0	0	0	0	14	1391
Doabe Merek	1286	67	161	83	83	50	83	17	0	0	0	0	0	544
Ghor Baghestan	4072	170	409	273	290	170	307	51	0	0	0	0	17	1687
Holilan	4371	326	268	211	460	211	249	38	0	0	0	0	153	1917
Dartoot	2613	152	265	207	219	161	127	12	0	0	0	0	12	1154
Tang Sazin	2889	175	257	187	246	140	129	23	0	0	0	0	12	1170
Kaka Reza	1137	51	96	57	125	100	108	17	0	0	0	0	11	564
Cham Anjir	1637	78	128	71	171	107	136	21	0	0	0	0	7	721
Pole Dokhtar	6767	428	428	285	656	342	428	57	0	0	0	0	200	2823
Jelogir	4116	247	290	160	320	160	218	29	0	0	0	0	15	1438
Pole Zal	335	15	15	11	22	17	25	2	0	0	0	0	2	110
Paye Pol	2707	98	92	59	124	105	151	13	0	0	0	0	7	648
Lower Karkheh														
Abdul Khan	1967	41	33	46	33	52	49	3	3	0	0	0	8	267
Hamidieh	931	5	19	36	12	15	11	1	0	0	0	0	0	100
Susangerd	5963	23	104	232	58	93	64	6	0	0	0	0	0	579
Overall Karkheh	51677	2582	3245	2458	3867	2480	2842	435	3	0	0	0	594	18507

Note: Location of these sub-catchments are marked on Figure 0.

ANNEX 2. Spatio-temporal distribution of actual evapotranspiration in different sub-catchment of Karkheh Basin

Sub-catchment	*Area (km^2)*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Sum*
Upper Karkheh														
Doab	7767	230	167	121	314	595	428	350	70	74	48	31	176	2604
Pole Chehr	3121	83	89	46	119	231	215	198	32	27	17	11	65	1093
Doabe Merek	1286	32	16	22	44	83	91	112	16	13	7	6	14	456
Ghor Baghestan	4072	103	58	69	143	263	262	275	37	27	14	10	47	1309
Holilan	4371	133	93	76	159	282	215	175	33	27	16	9	55	1274
Dartoot	2613	67	45	57	103	175	165	152	19	13	6	3	21	825
Tang Sazin	2889	82	59	62	114	184	164	150	25	11	5	5	23	884
Kaka Reza	1137	36	27	19	41	74	67	48	12	20	10	5	31	389
Cham Anjir	1637	50	40	30	58	97	102	88	23	18	11	5	34	555
Pole Dokhtar	6767	206	157	129	228	381	395	362	98	72	40	26	103	2198
Jelogir	4116	110	90	88	149	229	251	236	68	25	11	7	58	1323
Pole Zal	335	10	7	7	12	19	243	26	14	5	1	1	6	132
Paye Pol	2707	70	58	43	83	127	126	117	55	28	16	13	43	780
Lower Karkheh														
Abdul Khan	1967	48	43	14	36	50	48	38	14	14	6	2	17	330
Hamidieh	931	26	23	11	27	35	21	14	6	7	5	2	10	188
Susangerd	5963	182	162	172	318	486	290	214	172	106	56	67	118	2340
Overall Karkheh	51677	1467	1094	964	1946	3312	2863	2558	694	486	270	204	822	16680

Note: Location of these sub-catchments are marked on Figure 0.