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Water Productivity of Food Grains in India: Exploring Potential Improvements

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Introduction

“In broadest sense, water productivity reflects the objectives of producing more food, income, livelihoods and ecological benefits at less social and environmental cost per unit of water, where water use means per either water delivered to a use or depleted by a use. Put it simply, it means growing more food or gaining more benefits with less water.” In: ‘Water for food and Water for life’ of the Comprehensive Assessment of Water Management in Agriculture (Molden and Oweis 2007).

Growing more food and gaining more benefits with less water have received significant attention recently. Many countries in the world (Seckler et al. 1998; IWMI 2001a; Rosegrant et al. 2002; de Fraiture and Wichlens 2007) and regions within countries (Amarasinghe et al. 2005, 2007a) are reaching the thresholds of physical and economic water scarcities. Physical water scarcity is primarily due to inadequate water supply for meeting increasing water demands. Economic scarcity occurs when financial costs of new water resources development projects are prohibitively high for the prevailing economy. To ensure national food security, most developing countries tend to build additional water resources either through the allocation of larger domestic funds or through borrowings from international financial institutions. One option, perhaps the most feasible one, for increasing crop production under growing water scarcity is to increase the productivity in existing uses of water. So, like the campaign for ‘*more crop per unit of land*’ in the 1970s due to food scarcities, ‘*more crop or value per drop of water*’ due to water scarcities is also becoming an important topic in international and national discourses.

The concept of growing more crops from every unit of land gathered momentum in the 1970s due to increasing population and shrinking per capita agricultural land availability. Food and livelihood security of an increasing population were key drivers of the ‘Green Revolution’ in the 1970s. A significant outcome of this campaign was a remarkable increase in crop yield or land productivity. Irrigation combined with improved seed varieties, and increased fertilizer input and farm machinery use contributed to this yield increase. However, a significant scope still exists for many countries/regions to attain higher yields. For example, India, the world’s second most populous country and the largest food grain producer, still has one of the lowest land productivities. Doubling land productivity over the next five

decades, although a target far below what other major crop producing countries have achieved during such a time span by now, could help India to meet most of its additional food demand. So increasing land productivity is still relevant for many countries, and regions within countries. In fact, with the decreasing size of landholding per person, improving economic productivity per unit of land should be the primary concern for India now. But, unlike five decades ago, water, a critical input for agriculture and human well-being and ecosystems, has also become a constraint in sustaining the benefits achieved so far, and expanding the irrigated areas for enhanced crop production. As a result, increasing WP is also gaining new impetus.

Increasing WP is a relatively new concept. Seckler (1996), Molden (1997) and Koppen (1999) discussed different dimensions of enhancing WP, which included '*more crop or value or job per drop of water*'. Securing more 'crop per drop' is extremely important in today's context where climate change and the energy crisis are affecting vast populations, especially the rural poor in developing nations. The initial thoughts of Seckler (1996) and Molden (1997) were vigorously pursued by various international programs led by the International Water Management Institute (IWMI)—(Rijsberman, 2003). These programs culminated in a valuable collection of studies on opportunities and potential for improving WP in different livelihood settings, agro-ecological regions, cropping patterns etc. (Kijne et al. 2003). Our attempt here is to advance the knowledge on improvements of crop water productivity at the subnational level. This is especially important for a country like India with a significant spatial variation in climate, water availability and water use, and also where most river basins are fast reaching the threshold of water resources development (Amarasinghe et al. 2005).

The focus of this study is on the assessment and potential for improvement of WP of food grain crops in India. Cereals, mainly used for food, at present, occupied 65 % of the gross cropped area in 2000 (GOI 2007) and contributes to about 65 % of total calorie supply in daily diets (Amarasinghe et al. 2007a). With changing consumption patterns, feed grains, non-grain crops and livestock production also require more land and water. Thus, future food grain requirements will have to be met with lesser amount of additional land and water, which calls for increasing land and water productivity in food grain production. In fact, if land productivity (or yield) of grains increases at a rate of 1.04 % annually, India can easily meet the projected food and feed grain requirement of about 380 million tonnes by 2050 without any addition to the consumptive water use (CWU)—(Amarasinghe et al. 2007a). In other words, such growth pattern would require no additional or perhaps less irrigation water for food production. These national level scenarios are very appealing in light of the increasing water demand in and competition from other sectors (industrial, domestic and environment) and increasing water scarcities in many productive regions. But, how can we realize such goals in vast regions with varying water and land availability and climatic conditions? We explore some directions in this paper. The study presented in this paper assesses the extent and determinants of spatial variations of WP of grains at the district level and identifies pathways of increasing WP in irrigated and rain-fed areas. Thus, the present study is a continuation of the assessment WP at the national and state level provided in Amarasinghe et al. (2007a).

Unless stated otherwise, definition of WP in this paper is *food grain production from a unit of water depleted*. Indeed, there are many definitions of WP which are based on which

crop (numerator) or which drop (denominator)—(see Molden et al. 2003 for a detail discussion). Determinants of water productivity are scale-dependent, and also dependent on the objective of analysis. For crops, it relates to plant biomass per unit of transpiration, and between them there exists a linear relationship (Tanner and Sinclair 1983; Steduto and Albrizio 2005 cited in Molden and Oweis 2007). At field scale, farmers would like to know the physical production per unit of water allocated to different crops or the net return from the water delivered to the entire farm. At the level of an irrigation system, irrigation managers would be interested in knowing the value of production per unit of water delivered. Indeed, at the field or system scales, part of the water delivered is often reused within the field or system or elsewhere in the basins. Thus, for comparison between systems or between fields/farms at different locations, value of production per unit of consumptive water use (evapotranspiration) could be a better measure. The maximum of crop WP estimated in relation to evapotranspiration is close to the WP estimated in relation to transpiration under a given set of climate and soils. Thus, the difference between maximum yield and actual yield under a given agro-climatic condition shows the extent of increase in yield and WP possible through increased transpiration. For this purpose, we selected the definitions of WP of food-grains as the ratio of production and the crop consumptive use.

There are mainly two potential ways of increasing WP of food grains in India. First, is by increasing food grain yield with little or no additional CWU. There are a large number of low productivity areas having high potential for increasing crop yields by combining better water management, including improving reliability of irrigation deliveries in irrigated areas or providing a little supplementary irrigation in rain-fed areas, and agronomic practices and technology inputs. Second, is by reducing the amount of water depleted in irrigation with only little or no negative impacts on the yield. Water thus saved can be used for expanding the cultivated area and increase crop production or for beneficial uses in other sectors (Kumar and van Dam 2008). These are essentially areas receiving intensive irrigation and high dosage of crop inputs such as fertilizers and pesticides, and recording high crop yields, but with high incidence of overirrigation resulting in non-beneficial evaporation.

We have focused on potential contribution of higher crop yield and lower CWU in increasing the WP in different districts in India. It first identifies low productivity but high potential zones where a provision of supplemental irrigation could boost both the yield and WP significantly. It also identifies high productivity zones where there is a great possibility of water saving per unit of land, with little or no loss of production, or expanding production frontiers with no extra provision of irrigation water. In the next section, we discuss the methodology for achieving this and the data used for the study. In section three, we explore pathways of increasing WP and crop outputs. We conclude the paper with a discussion on policy implications.

Methodology and Data

Assessment and identifying determinants for improvement in WP of food grains is the main focus of this paper. Food grains consist of rice (milled equivalent), wheat, maize, other coarse cereals (sorghum, pearl millet, maize, ragi, barley and small millets) and pulses (gram, tur and other pulses)—(GOI 2007). Total food grain production per unit of CWU (kg/m^3) defines

WP in this paper. The CWU in irrigated areas is potential evapotranspiration (ETa)¹ during crop growth periods of different seasons and is given by

$$CWU_{ij}^{IR} = Area_{ij}^{IR} \times \left(\sum_{k \in \text{growth periods}} Kc_{jk} \times \left(\sum_{l \in \text{months}} Et_{ikl}^p \right) \right)$$

for the j^{th} crop in the i^{th} season. Where Kc's are the crop coefficients that vary over four growth periods and Et^p are monthly reference evapotranspiration. ETa essentially is the aggregate of effective rainfall (ERF) and the net irrigation requirement (NET).

CWU in rain-fed areas is only the effective rainfall during the season, and is estimated as

$$CWU_{ij}^{RF} = Area_{ij}^{RF} \times \sum_{k \in \text{growth periods}} \min \left(Kc_{ik} \sum_{l \in \text{months}} Et_{jkl}^p, \sum_{l \in \text{months}} ERF_{jkl} \right)$$

where ERF_{jkl} is the effective rainfall of i^{th} month in the k^{th} growth period. The total annual CWU of a district is estimated as

$$CWU = \sum_{i \in \text{seasons}} \sum_{l \in \text{crops}} (CWU_{ij}^{IR} + CWU_{ij}^{RF})$$

And the total WP is estimated by

$$WP = \frac{\sum_{j \in \text{crops}} \text{average yield}_j \times (Area_i^{IR} + Area_j^{RF})}{CWU}$$

where food grains consist of rice, wheat, maize, other coarse cereals and pulses (see Amarasinghe et al. 2005, 2007a for more details).

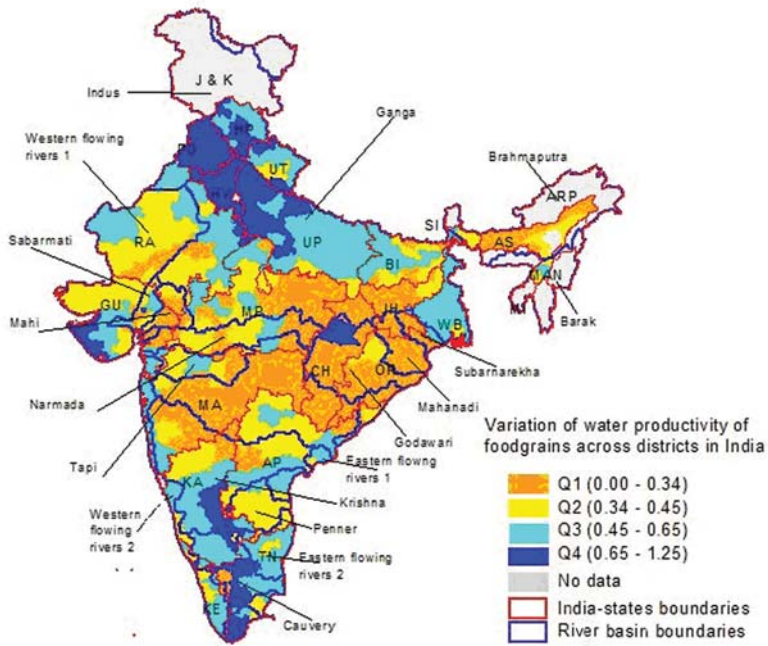
First, this study maps and gives a brief account of spatial variation in WP across states and districts in India (Figure 1).

Here we estimate the total WP across states and districts and assess the determinants of spatial variation. We use a multiple regression to assess implications of access to irrigation and other input use on spatial WP variation. We use total CWU as a proxy for availability of water supply for crop production, and percentage of groundwater irrigated area as a proxy for reliability of irrigation. In general, groundwater, with its easier control in operations, is more reliable than canal irrigation. However in some cases, pumping water in groundwater irrigation can be as unreliable as canal irrigation supplies because of the former dependency on an unreliable electricity supply for such pumping.

Second, it assesses pathways of increasing WP at the district level and their potential for irrigated and rain-fed land areas. This potential varies in different CWU regions (A, B and C in Figure 2). With increasing CWU, both maximum yield and WP increases in CWU region A, yield increases but WP decreases in region B and both yield and WP decreases in region C.

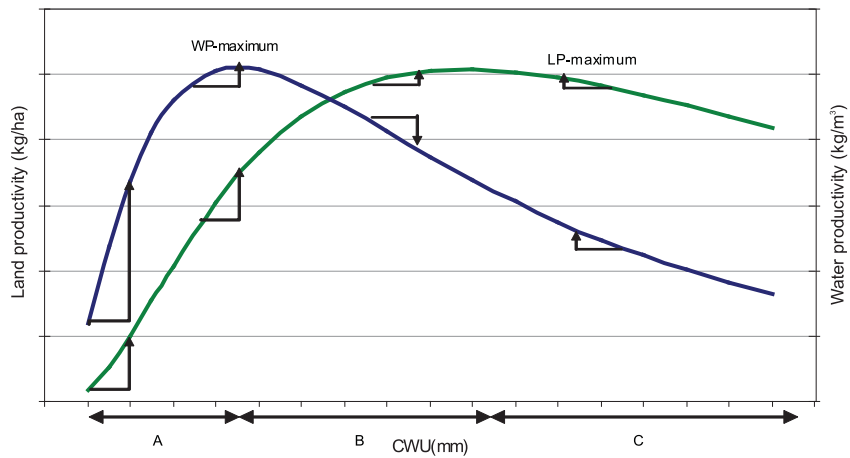
¹ In some areas, the actual evapotranspiration could be less due to deficit irrigation or nonoptimal field conditions.

Figure 1. State and river basin boundaries in India with variation in water productivity of food grains across districts.



Source: Based on authors' estimates

Figure 2. Pathways of increasing WP.



We hypothesize that a significant potential exists for increasing WP and production through:

- Bridging the gap between the actual and the maximum land productivity (yield). This can be done at any level of CWU in regions A, B and C in Figure 2, where a significant gap exists between actual and maximum yield. Maximum yield is the one that is attained under the current level of water and other agronomic and technological inputs.
- Providing additional irrigation to increase CWU in region A (Figure 2). These are mainly rain-fed areas, and a small increase in CWU can generate a large increase in land and water productivity and production. A comparable increase in CWU in region B would result in smaller growth in yield and hence production. However, additional CWU would decrease WP in region B. These areas need diversification of crop production or agriculture patterns to increase the economic value of water productivity.
- Practicing deficit irrigation for not meeting the full water requirement in irrigated areas. This potential exists in CWU region C (Figure 2). Reducing CWU in this region would, in fact, increase land and water productivity and, hence production. Many a time, these are the irrigated areas with large irrigation application and poor water management. Thus, deficit consumptive water use with proper water management can have large benefits in terms of irrigation demand and food production.

To explore these opportunities at the district level, we estimate the relationships between yield and CWU and WP and CWU. First, we estimate the maximum land and water productivity, which are attained at different levels of CWU. For this, we use two to three of the largest yield values at different CWU regimes (0-50 mm, 50-100 mm, 100-150 mm, etc.,) and estimate the maximum yield function. Next, we assess the potential for yield or WP improvements through additional, supplementary and deficit irrigation.

Data for the study consists of district level land use and crop production for 2000 (averages of 1999-2001). Three-year averages smoothen the deviations due to high short-term temporal climatic variations. For the analysis at district level, we look at the extent of irrigated and rain-fed areas of different crops, and the combined total production. These were collected from the Government of India and other sources (FAI 2003a-d; GOI 2002, 2007). Climate data (monthly potential evapotranspiration and rainfall) for the study was available from Climate and Water Atlas (IWMI 2001b). We consider 403 districts in 20 major states namely, Punjab, Haryana, Uttar Pradesh (UP), Himachal Pradesh (HP), Uttarakhand, Jammu and Kashmir (in the north); Bihar, West Bengal (WB), Assam, Jharkhand (in the north-east), Orissa and Andhra Pradesh (AP) —(in the east), Tamil Nadu (TN), Kerala, Karnataka (in the south), Maharashtra and Gujarat (in the west), Rajasthan (in the north-west) and Madhya Pradesh (MP) and Chattisgarh (in central India). These districts contribute to about 99 % of the consumptive water use and 98 % of the production of food-grains in India (Amarasinghe et al. 2008b).

Water Productivity of Food Grains – Present Status

At present, WP of food grains in India is significantly lower when compared to other major food-grain producing countries in the world (Molden et al. 1998; Rosegrant et al. 2002; Cai

and Rosegrant 2003). In 2000, WP of food-grains in India was only 0.48 kg/m³ of CWU. This was primarily due to low growth in yields. India's food grain yield was 1.7 tonnes/ha in 2000, which has increased only by 1.0 tonnes/ha during 1960-2000 (FAO 2005). Meanwhile, China with a similar level of yield in 1960 (0.9 tonnes/ha) has increased to about 4.0 tonnes/ha by 2000. The USA made vast strides by increasing food grain yield from 2.5 tonnes/ha in 1960 to 5.8 tons/ha over the same period. Also, India produces less grain in spite of having a large cropped area (205 million tonnes in 124 million ha), while China and USA have much larger production (using less water) from a significantly smaller crop area. Indeed, India has significant scope for raising the levels of WP by increasing its crop yield alone. Better water management can create additional increase in WP in many regions.

Variations of Water Productivity among States

WP varies from 1.01 kg/m³ in Punjab (the highest) to 0.21 kg/m³ in Orissa (the lowest) among states (Table 1).

These differences are mainly due to varying cropping and land-use patterns, yield levels and CWU. Among the large variations, we observe: Punjab, Haryana and Uttar Pradesh (UP) in the Indo-Gangetic basin (IGB) are having the highest water productivities. These states, with rice-wheat dominated cropping pattern, share 26 % of the total CWU in India, but contributing to 40 % of the total food grain production. Importantly, they contribute to 70 % of wheat and 26 % of rice production in India. A major part of the area under food grain in these states is irrigated. It is 67, 85 and 97 % in Uttar Pradesh, Haryana and Punjab, respectively, and contributing to 48, 72 and 75 % of the CWU.

Low share of irrigation to total CWU in Uttar Pradesh means that effective rainfall contributes to a significant part of CWU. In fact, substantial variation in WP too exists within Uttar Pradesh. For example, water productivity in 53 districts in Uttar Pradesh varies between 0.40 to 1.02 kg/m³. Western region with 20 districts has 34 % of the grain area, contributing to 40 % of the total food grain production. Average WP in the western region is 0.75 kg/m³. Eastern and Bundelkhand regions encompassing 23 districts have 48 % of the area under food grains, contributing to 42 % of the total food grain production. Average water productivity in these two regions is only 0.54 kg/m³. A key difference between the western and eastern and Bundelkhand region is in the irrigated area, where 82 % of the area is irrigated in western region against 54 % in the eastern and Buldelkhand region.

- Bihar, also in the IGB, with 82 % of the area under wheat and rice, however, has lower WP and share 6.2 % of CWU and 5.9 % of the food-grain production in India. Irrigation contributes to 60 % of the area and 33 % of the CWU in Bihar. Although a major part of the grain area is irrigated, effective rainfall meets much of the CWU in Bihar at present. Irrigated areas contribute to 65 % of total CWU in Bihar, but irrigation contributes to only 51 % of CWU in irrigated areas.
- Andhra Pradesh, Tamil Nadu, West Bengal and Kerala with rice-dominated cropping patterns (more than 80 % of grain area) have slightly higher WP. These states share 19 % each of total CWU and total grain production of India. While irrigation contributes to major part of CWU in Andhra Pradesh and Tamil Nadu (47 % and 58 %), it contributes to only 15 % and 26 % of the CWU in West Bengal and Kerala.

Table 1. Water productivity of grains across states of India.

Area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																		
ID	State ¹	Total						Irrigation						Rain-fed				
		CWU	NET	Area	Produce	Yield	CWU	WP	CWU	NET	Area	Prod-uction	Yield	CWU	WP	Yield	CWU	WP
		km ³	km ³	M ha	M Mt	tonne/ha	mm	kg/m ³	%	- % of total CWU	%	- % of total area	%	tonne/ha	mm	kg/m ³	mm	kg/m ³
	India	424	154	123	205.4	1.66	344	0.48	56	65	43	68	2.59	446	0.58	0.95	265	0.36
1	Uttar Pradesh	71.4	34.4	20.3	43.4	2.13	351	0.61	73	66	68	83	2.61	377	0.69	1.13	296	0.38
2	Maharashtra	36.1	6.1	13.3	11.3	0.85	272	0.31	26	66	15	22	1.25	461	0.27	0.78	238	0.33
3	Andhra Pradesh	33.5	15.8	7.3	14.3	1.96	460	0.43	77	61	56	82	2.86	628	0.45	0.81	243	0.33
4	Madhya Pradesh	31.3	14.3	11.2	11.1	0.99	278	0.36	51	90	34	48	1.39	417	0.33	0.78	207	0.38
5	West Bengal	29.5	4.5	6.6	15.2	2.31	447	0.52	44	35	42	50	2.73	461	0.59	2.00	436	0.46
6	Orissa	28.4	2.1	6.5	6.1	0.93	434	0.21	36	21	29	49	1.53	535	0.29	0.68	392	0.17
7	Bihar	26.3	8.7	7.1	12.1	1.71	373	0.46	64	52	60	72	2.06	400	0.51	1.19	332	0.36
8	Rajasthan	25.7	13.4	11.7	11.7	1.00	220	0.46	57	92	29	61	2.12	435	0.49	0.55	134	0.41
9	Punjab	25.4	18.9	6.3	25.5	4.07	404	1.01	99	76	97	99	4.14	411	1.01	1.79	184	0.97
10	Karnataka	20.3	5.7	7.5	9.9	1.32	272	0.49	42	66	23	44	2.51	495	0.51	0.96	204	0.47
11	Chattisgarh	18.3	2.2	5.1	4.8	0.94	362	0.26	30	40	21	32	1.42	513	0.28	0.81	322	0.25
12	Tamil Nadu	16.4	9.5	3.5	8.7	2.47	463	0.53	85	68	60	83	3.38	650	0.52	1.09	178	0.61
13	Haryana	15.6	11.2	4.3	13.4	3.13	363	0.86	92	78	85	95	3.51	395	0.89	0.98	185	0.53
14	Assam	13.9	0.1	2.8	4.1	1.45	492	0.29	8	7	8	13	2.51	522	0.48	1.36	489	0.28
15	Gujarat	10.6	4.4	3.8	4.2	1.11	280	0.40	55	76	29	47	1.81	533	0.34	0.83	178	0.47
16	Jharkhand	7.7	0.3	1.9	2.0	1.08	409	0.26	8	41	8	12	1.66	442	0.38	1.03	406	0.25
17	Uttaranchal	3.0	0.7	1.0	1.7	1.75	298	0.59	53	43	38	57	2.59	408	0.63	1.22	229	0.53
18	Jammu & Kashmir	2.4	1.0	0.9	1.2	1.38	271	0.51	63	64	37	40	1.48	455	0.33	1.32	161	0.82
19	Himachal Pradesh	2.0	0.2	0.8	1.5	1.78	245	0.73	27	34	19	21	2.03	353	0.58	1.73	220	0.79
20	Kerala	1.7	0.4	0.4	0.8	2.17	470	0.46	65	41	57	64	2.45	538	0.45	1.82	381	0.48
21	Others ²	5.3	0.4	1.3	2.2	1.68	404	0.42	34	7	31	45	2.43	443	0.55	1.35	386	0.35

Source: Authors' estimates

Notes: 1- states are ordered in descending order of total CWU

2- Others include Nagaland, Maipur, Meghalaya, Mizoram, Sikki, Tripura, Arunchal Pradesh and union territories (Andaman and Diu, Dadra and Nagar Haveli, Delhi, Goa, Lakshdweep, Pondicherry)

- Orissa, Chattisgarh and Jharkhand, in eastern India, have the lowest water productivities, and share 12.8 % of the total CWU, contributing to only 6.3 % of the food grain production. These are major rain-fed states where rice dominates the cropping patterns. In Orissa and Chattisgarh, 26 and 21 % of the area under food grains are irrigated, but irrigation contributes to only 8 and 12 % the CWU, respectively. The share of irrigated area (8%) and contribution from irrigation to CWU (3%) are even smaller in Jharkhand.
- Maharashtra, Madhya Pradesh, Karnataka and Gujarat with a mixture of cropping patterns (more than 50 % of the area under maize, other coarse cereals and pulses) have lower water productivity. They share 27 % of CWU and contribute to 21 % of food grain production in India. Irrigation in Maharashtra and Karnataka covers only 15 and 23 % of area, respectively, contributing to 17 and 28 % of CWU. However, irrigation in Madhya Pradesh and Gujarat covers 29 % of the area under food grains, contributing to 52 and 41 % of the CWU.

Extent of irrigation and cropping patterns partly explain the variation in water productivity among the states. Presence or absence of irrigation (irrigated and rain-fed areas) mainly explains the variation in total water productivity.² Additionally, the land use and cropping patterns of food grains significantly influence water productivity differences between states.

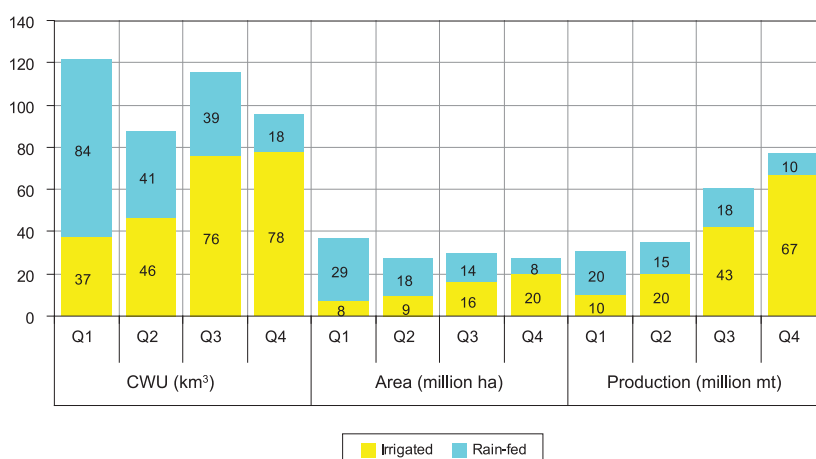
In 2000, irrigation covered 43 % of the area under food grains, but contributed only to 68 % of the total production. While many opportunities still exist in improving WP in irrigated and rain-fed conditions with the existing level of water use or with proper cropping patterns, shifting production frontiers of rain-fed food grain crops through new irrigation could also boost WP significantly. These regions require not only better water management but also better non-water input application. Depending on CWU and actual irrigation at present, improvements in WP with better water management require various interventions—from full irrigation to small supplemental irrigation, no additional irrigation to deficit irrigation. We discuss these in detail in the next section by assessing functional relationships of yield versus CWU at the district level. Before that we present the spatial variations of WP across the districts in India.

Variations in Water Productivity among Districts

District-wise water productivity values vary between 0.11 kg/m³ to 1.25 kg/m³ (Figure 1, Annex Table 1). WP in the first to fourth quartiles (Q1-Q4) vary from 0.11- 0.34, 0.34-0.45, 0.45- 0.60 and 0.60-1.25 kg/m³). Districts in the fourth quartile of water productivities account only 22 % of the total area under food grains and 22 % of total CWU, but contribute to 38% of total food grain production of all districts in this study (Figure 3). Irrigation provides water supply to 72 % of the total area under food grains in this group, and contributes 81 % of total CWU and

² $WP = 0.021 + 0.59 IWP + 0.37 RWP + 0.11 PCGRIRAR - 0.09 PCRIAR$, Adjusted $R^2 = 97\%$
(.029) (0.06) (0.05) (0.05) (0.02)

Values within parentheses are standard errors of estimates. TWP, IWP and RWP are total, irrigated and rain-fed water productivity, PCGRIRAR is irrigated grain area as a % of total grain area and PCRIAR is percentage of area under rice.

Figure 3. CWU, area and production of food grains.

Source: Authors' estimates

87 % of total food grain production. In irrigated areas, net evapotranspiration (NET) accounts for 72 % of CWU.

On the other hand, districts in the first quartile of water productivities account 30 % of total area under food grains and 29 % of total CWU, but they contribute to only 15 % of total crop production. Effective rainfall, the main source of water supply in this group, accounts 83 % of the total CWU.

These observations show irrigation is a major contributor to higher yields and hence to the production in these districts, and they in turn contributed to higher water productivity. Further analyses (Table 2)³ show that in districts with a substantial irrigated grain area (i.e., districts with percentage of irrigated grain area more than 25 %):

- 1) Relative increase in WP is significantly higher when actual yield is much lower than the maximum yield. Every 1 % increase in yield increases WP by 0.65 % (first regression in Table 1). Large potential of increasing WP exist in areas where both yield and CWU are significantly low or in areas where CWU is high but yield is significantly lower than the maximum. There are many districts with significantly high CWU, but with a significant gap between maximum and the actual yield. It is in these areas that there exists a high potential for reducing the yield gap and increasing WP with better water and input management. Part of the reasons for a low yield gap in areas with high CWU could be agro-climatic factors. In these areas, only a proportionate increase in CWU can increase the yield and WP (Molden and Oweis 2007).

³ Note: First regression in Table 2 assess the extent that variation of yield explains the variation of WP. The last two regressions assess the contribution of differences of CWU (mm), fertilizer application per gross cropped area, and groundwater irrigated area as a percent of gross irrigated area explain the variation of yield and WP. To some extent, fertilizer application/ha show the extent of application of non-water inputs. Ground irrigated area could be considered to indicate the reliability of irrigation water supply.

Table 2. Regressions of yield and WP of food grains.

Explanatory variable	Coefficients (standard errors) of explanatory variables (n = 255)		
	Ln (WP)	Yield	WP
Ln (Yield) (tonne/ha)	0.66 (0.027) *	-	-
Constant	-5.59 (0.19) *	356.0 (196.0) *	0.60 (0.1) *
Total CWU (mm)	-	1.5 (0.5) *	-0.0009 (0.0001) *
Fertilizer application/gross cropped area (kg/ga)	-	8.1 (0.6) *	0.002 (0.0001) *
Groundwater irrigated area - % of gross irrigated area	-	3.6 (1.1) *	0.0008 (0.0001) *
Adjusted R ²	59%	51%	41%

Note: *- Statistically significant at 0.001% level

- 2) Average yield increases, but WP decreases with increasing CWU. This indicates that at present, the rate of increase in average yield is lower than the rate of increase of CWU with an increase in irrigation inputs.
- 3) Higher fertilizer inputs are significantly associated with higher yields and WP. Groundwater irrigation contributes significantly to increasing yield and also WP. This perhaps indicates that, in spite of a negative relationship between WP and increasing CWU, reliable irrigation deliveries, in this case through groundwater, can have a significant positive effect in increasing both WP and yield.

Molden et al. (2003) suggest improvements of non-water inputs with better water management could be an effective strategy for increasing yield and WP in many regions. The above regression results also show that better management of irrigation and non-water inputs can substantially increase food grain yield and WP. In fact, we observe that significant variations exist in yield and WP at different levels of irrigated grain area (i.e., 0-10 %, 10-20 %, 20-30 %, 30-40 % etc., of the total area), where coefficients of variation (CV=standard deviation/average) of yield and WP vary from 20 to 51 and 23 to 50 %, respectively, and decreases with increasing irrigated area. The smallest CV of yield is in districts where the percentage of the irrigated area is between 70 to 80 %, while the largest CV of yield is in districts where the percentage of the irrigated area is between 20 to 30 %. This shows that there still is great scope for increasing the yield and hence WP at any given level of the irrigation patterns. However, opportunities for increasing yield through better management of water and non-water inputs are higher in districts with high CWU.

Additional irrigation could be a major boost for increasing yield in many districts with low CWU or low irrigated area. In fact, recent research (Sharma et al. 2006) indicates that providing a small supplemental irrigation of about 100 mm during critical water stress periods of crop growth can significantly increase crop yields in major rain-fed districts of India. Sharma et al. (2006) and

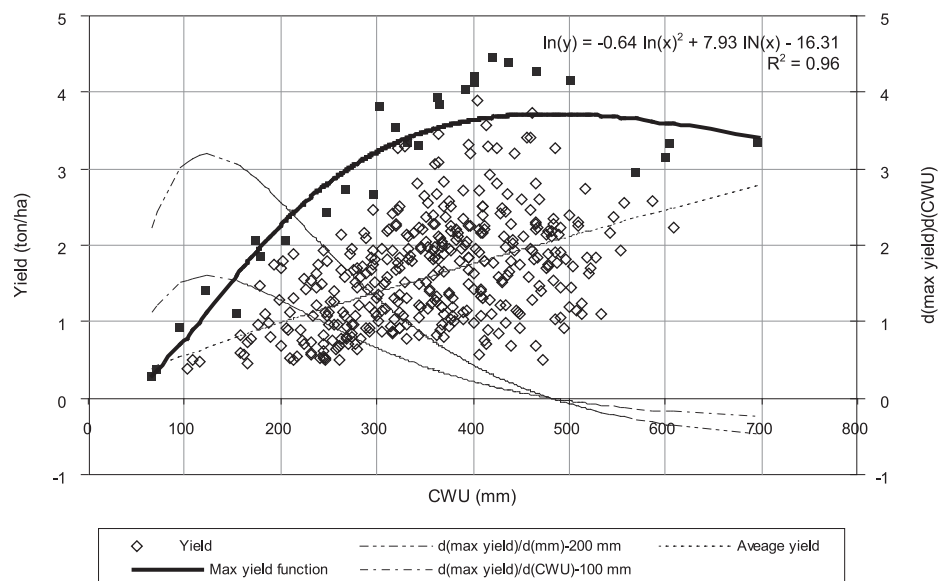
Wani et al. (2003) show that rainwater can be managed through in situ harvesting to provide supplemental irrigation to increase yields in rain-fed cropping systems. Significant scope also exists for increasing the yield and WP in many districts with moderate to high irrigation inputs. All these offer opportunities for increasing the numerator, i.e., production in WP estimation.

Is there scope for increasing WP by changing the denominator, i.e., the consumptive water use? In fact, many canal irrigation systems in water-scarce north-western parts of India are good examples where this is already happening (Malhotra 1982; Perry and Narayanamurthy 1998; Sakthivadivel et al. 1999). Due to water scarcity water delivery in these systems uses the *warabandi*⁴ principle. The farmers practice deficit irrigation in a larger area at the expense of meeting full requirement of a smaller area with a view to maximizing returns to a unit of water delivered and consumed. Deficit irrigation could be a good strategy for increasing WP where water is scarce but land is not (Molden et al. 2003; Kumar and van Dam 2008). And as shown by Oweis and Hachum (2003), such practices can result in significant increase in crop output too. We explore these in the next section.

Some Pathways of Improving WP in India

Figure 4 shows that several strategies exist for increasing WP in Indian districts. X-axis in Figure 4 represents consumptive water use (mm), while Y-axis represents food grain yield (1,000 kg/ha) and growth in yield (in 1,000 kg) per every additional unit of CWU. Average

Figure 4. Relationships of yield and consumptive water use (CWU) of food grains.



⁴ Warabandi, where 'wara' means turn, and 'bandi' means fixed, is a rotational system of irrigation delivery with turns are fixed according to a predetermined schedule specifying the day, time and duration of supply (Malhotra 1982). Warabandi promotes equity of water distribution in a larger area than adequate water supply to a small area.

yield function takes Cob-Douglas form ($\ln(\text{yield}) = 2.48 - .18 \ln(\text{CWU})$, $R^2 = 0.29$). We use 2-3 highest values of yield in each category of CWU (0-50, 50-100, 100-150, 150-200, etc.,) for estimating the maximum yield function. Figure 4 also depicts two marginal yield curves ($d[\text{max yield}]/d[\text{CWU}]$) for increase in CWU of 100 and 200 mm.

Figure 4 also shows that all three hypotheses that we mentioned earlier exist in food grain production in Indian districts:

- 1) A significant gap exists between maximum⁵ and actual yields in many districts, with the magnitude of the gap increasing with increasing CWU;
- 2) A significant marginal gain in maximum yield can be achieved with additional CWU in low to moderate CWU districts. These are mainly the districts with large rain-fed areas; and
- 3) Little or no gain in maximum yield can be achieved by increasing CWU in moderate to high CWU districts.

So, WP of districts can be increased by:

- increasing the numerator (or yield)
- by reducing the gap between actual and maximum yield with or without increasing the CWU in districts with moderate CWU, and
- by increasing CWU in low CWU regions

Decreasing the denominator (or CWU) without losing any yield or overall production benefits to a unit of water consumed at all in mainly irrigated districts with high CWU.

Diversifying agriculture to high-value crops or livestock in rain-fed or irrigated regions with moderate to high CWU, where further increase in yields of food grains is not possible by increasing CWU.

Reducing Yield Gap

With large gaps between actual and maximum yield, first strategy in improving WP should be increasing yield without additional CWU, and hence without additional irrigation. To better understand the dynamics of WP variations, we divided the district into two groups. First group has districts with an irrigated grain area of less than 25 % of the total area under food grains, where rain-fed food grain production dominates. There are 158 districts in this group and the total CWU in rain-fed area is 79 % of the total CWU (see Annex Table 1). The other group has an irrigated grain area of more than 25 % of the total grain area. There are 251 districts in this group and the total CWU of irrigated area is 72 % of the total CWU, and more than half of CWU in the irrigated area is from irrigation water supplies.

⁵ The maximum yield attained at present could however, vary from one agro-climatic zone to other. So, the gap between the actual yield and the maximum attained at present as indicated in Figure 3 for some districts could be slightly lower.

There are 32 districts (25 from the first group, 7 from the second group) with yield gaps more than 75 % of maximum yield ,162 (86 and 76 from the two groups) districts with yield gaps between 50 % to 75 % of maximum yield, 151 (31 and 120 from the two groups) districts with yield gaps between 25 %-50 % of maximum yield and 58 districts has yield gaps less than 25 % of maximum yield (10 and 48 from the two groups)—(see maps on the left in Figures 4 and 5 for the locations). Maps on the right in Figures 5 and 6 show the absolute gap between actual and maximum yield.

Figure 5. Yield gap in food grains in districts with irrigated area under food grains less than 25% of the total area.

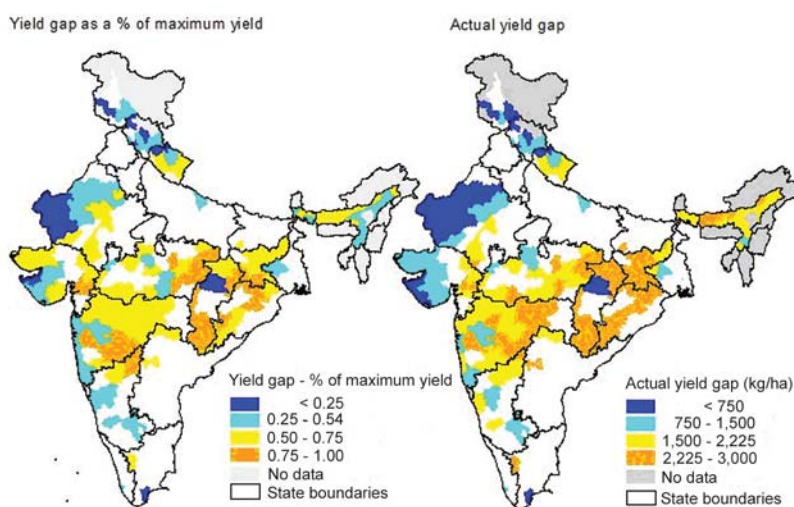
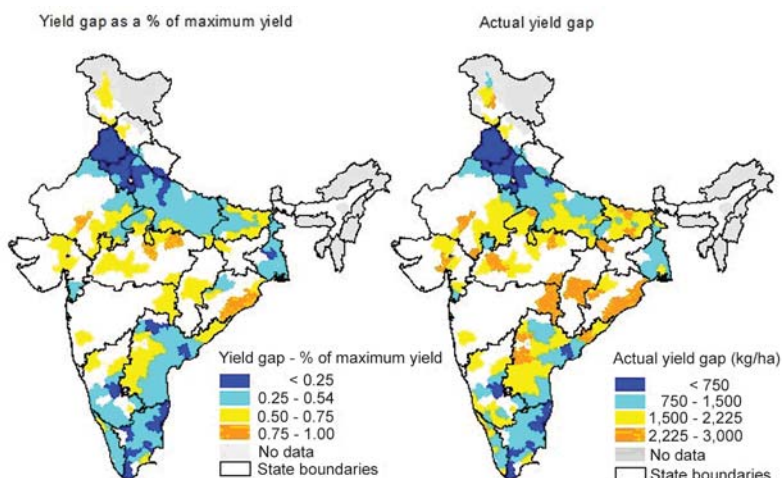


Figure 6. Yield gap of food grains in districts with irrigated area under food grains more than 25% of the total area.

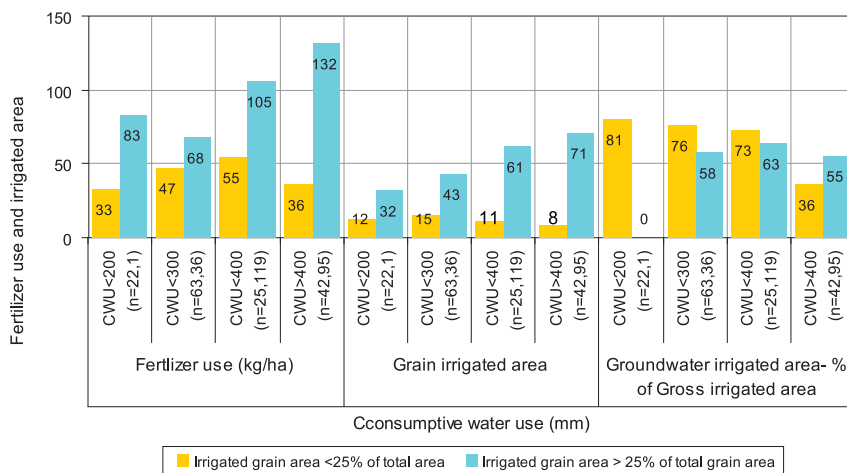


If the gap between actual and maximum grain yield of each district can be reduced by 25 %, total production could be increased from 203 to 252 million tonnes. If increase in yield is possible without increasing CWU, WP would increase from 0.48 to 0.60 kg/m³. A reduction in yield gap by 50, 75 and 100 % without increasing CWU could increase production to 300, 349 and 397 million tonnes, respectively, and WP to 0.72, 0.83 and 0.97 kg/m³, respectively. The latter requires only little over 1% yield increase annually, and the resultant total production is adequate for meeting the grain demand in 2050 (Amarasinghe et al. 2007a).

Indeed, reducing the yield gap without increasing consumptive water use or simply without additional irrigation offer significant opportunities for increasing production and WP. This shall be possible through better adoption of improved/ hybrid varieties in both rain-fed and irrigated areas, better targeting of nutrient requirements/deficiencies, timely completion of farming operations, control of plant diseases and pests and a better synchronization between crop water requirements and irrigation supplies in irrigated areas.

Many districts with a large proportion of the area under irrigated grain production (irrigated area under food grains >25 % total grain area) have yield gaps exceeding 25 % of maximum yield (Figure 6). The actual yield gap in most of these districts is more than the average yield at present (1,660 kg/ha), and majority of the CWU in irrigated areas of these districts are from irrigation water supply. These districts have high potential for reducing the yield gap without increasing CWU, through better in situ management of rains, and irrigation water management. We also observe that districts with a large irrigated area under food grains with large CWU have relatively high level of fertilizer use (Figure 7, see Annex Table 1). Thus better management of non-water inputs with existing irrigation supply could reduce most of the gap in the yield in these districts. This group, with 261 districts (Figure 6), contributes 53 % of total area under food grains, 80 % of total irrigated grain production, and share 79 % of total CWU through irrigation. Reducing the yield gap by 25, 50, 75 and 100 % in these districts could increase production by 17, 34, 51 and 68 %, respectively, from the level of production in 2000.

Figure 7. Fertilizer use at different levels of CWU.



Source: Authors' estimates

Note: Figures within parenthesis in the X-axis are numbers of districts with irrigated area <25% and >25%, respectively

The districts which are mainly rain-fed, i.e., districts with less than 25 % of its food grain area under irrigation, also have large yield gaps. The CWU of 55 % of these districts is less than 300 mm, and fertilizer application in those is very low compared to irrigated grain area. The quantity and reliability of the water supply, especially from rainfall are the biggest constraints for increasing input application and hence yield in this group. If yield is to increase in these districts, they require additional irrigation combined with better management of non-water inputs. This is the focus of in the next section.

Providing Additional Irrigation

Second strategy for improving WP is providing additional irrigation. The districts with low CWU have the highest potential for increasing yield by increasing CWU (Figure 4). Marginal yield curves ($d[\text{max yield}]/d[\text{CWU}]$) show that increasing CWU could significantly increase the maximum yield in many districts with low CWU. With 100 mm of additional CWU, the maximum yield can be doubled in districts with less than 150 mm of CWU (see $d(\text{yield})/d(\text{CWU})-100$ mm curve). With 200 mm of additional CWU, the yield can be doubled in districts with less than 225 mm of CWU. Many of these districts can increase the yield by providing small to moderate irrigation or by increasing the amounts of effective rainfall through in-situ conservation and storage.

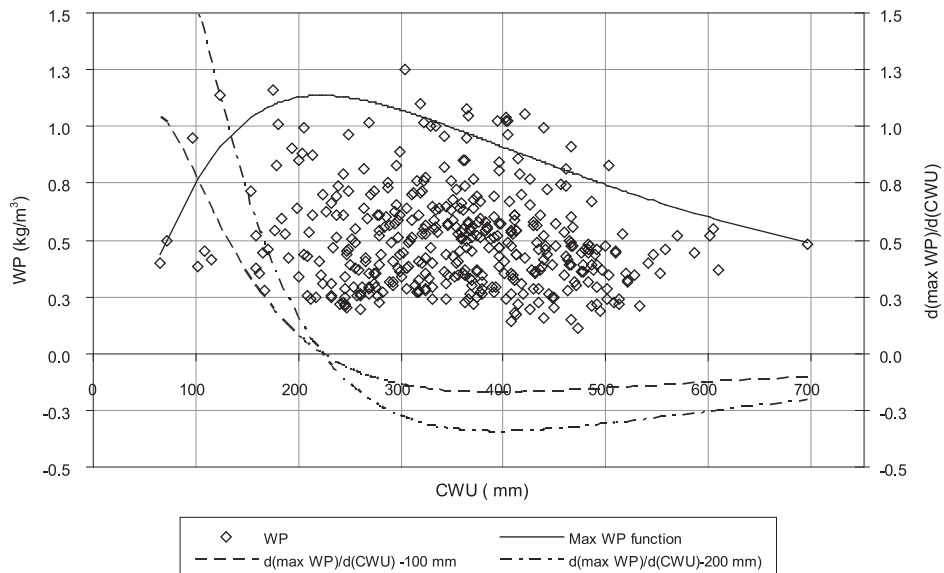
However, growth in the food grain yield with supplemental irrigation decreases in districts with high CWU. Both scenarios of supplemental irrigation (100 or 200 mm), marginal growth in yield decreases and become negative after 475 mm of CWU (Figure 4). This is also due to the fact that most food grain crops grown under rain-fed conditions (sorghum, pearl millet, local maize and small millets) have very low values of harvest index with only a fraction of biomass converted into grain yields. If increasing yield is the sole objective then providing additional irrigation (with existing crops and their varieties) would only benefit districts with CWU of less than 475 mm.

However, growth in WP becomes negative in many districts with CWU being well below 475 mm (Figure 8). Figure 8 depicts district level variation in WP with respect to CWU. Marginal WP curves ($d[\text{max WP}]/d[\text{CWU}]$) show that additional irrigation can more than double maximum WP in districts with only low CWU (below 150 mm). The WP growth becomes negative with additional irrigation after 225 mm of CWU. For assessing the potential benefits with additional irrigation, we consider three subgroups of districts: subgroup 1 with a total CWU of below 225 mm, subgroup 2 with total CWU of between 225 and 475 mm and subgroup 3 with a total CWU of above 475 mm.

Subgroup 1: There are 39 districts in this category (first group of map A and B in Figure 9).⁶ And 38 of them belong to districts with an irrigated area of food grains below 25 % of the area under food grains. These districts share 12 % of the total area under food grains but contribute to only 4 % of the food grain production at present. More than 80 % of the area in these districts is rain-fed. In fact, the CWU of rain-fed areas (map E, Figure 8) contributes the most

⁶Figure 8 shows two sets of maps indicating the variation of CWU in districts with irrigated area under food grains less and more than 25% of total area, respectively. Maps A and B show the variation of average CWU in the two groups. Maps C and D show the variation of CWU of irrigated areas, and maps E and F show the variation of CWU in rain-fed areas.

Figure 8. Relationships in water productivity (WP) and consumptive water use (CWU) of food grains.



Source: Based on authors' estimates

to the average CWU of these districts. With the present level of yield and WP frontiers, additional irrigation in rain-fed areas could increase both the maximum yield and WP in these districts. To illustrate the benefits of additional irrigation on production and WP gains, we use a marginal increase in maximum yield with respect to small increases in CWU. We estimate that with 100 mm (or 200 mm) of additional CWU, these 39 districts can increase their total food grain production and WP by 83 % (or 167 %), and 15 % (or 22 %), respectively.

In fact, average grain yield of many districts in subgroup 1 are significantly lower than the maximum yield at any given level of CWU. Sharma et al. (2006) found that water stress in critical periods of crop growth is a key determinant of low yields in these rain-fed areas. So, with proper application of a small quantity of supplemental irrigation in water stress periods by itself could reduce the yield gap, and additional irrigation with better application of non-water inputs could push up the average yield in parallel to the increasing path of maximum yield. Thus, cumulative benefit of additional irrigation in these districts could be much higher than what is illustrated above.

Subgroup 2: There are 316 districts in this category (second and third groups of map A and B). At present, they contribute to 79 % of total area under food grains and 84 % of total production. Figure 9 and Figure 8 show that increasing CWU would increase the yield but decrease WP in districts with a CWU total of between 225 mm and 475 mm. For example, with 100 mm of additional irrigation, this group as a whole can increase the total food grain production along the path of maximum yield only by 11 %, reducing WP by 10 %.

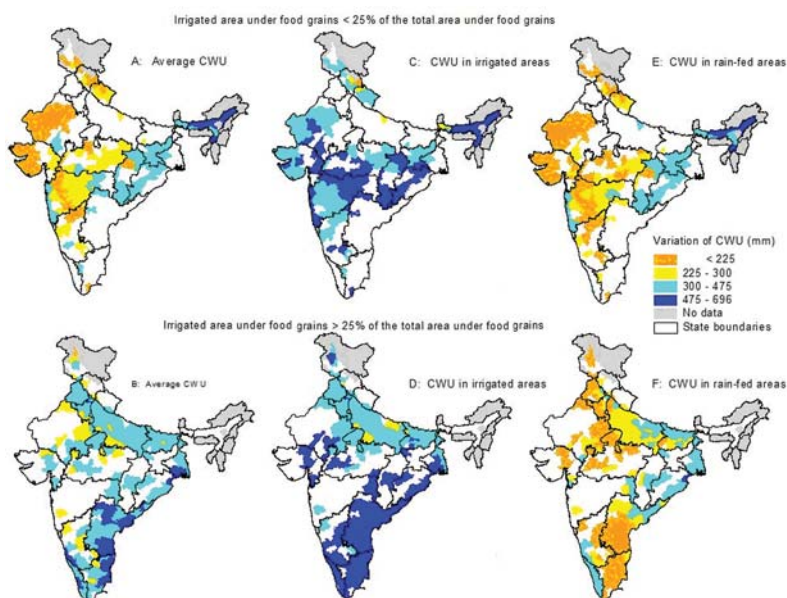
However, this does not mean that increasing CWU would decrease WP in all areas of these districts. Rain-fed area under food grains of subgroup 2, which is 57 % of the total rain-fed area under food grains, can further be divided into smaller classes. This consists of 57 % of the total rain-fed area under food grains.

- 119 districts in subgroup 2 have rain-fed areas under food grains with CWU (=effective rainfall) below 225 mm (map F in Figure 9). As in subgroup 1, supplemental irrigation in the rain-fed areas of these districts can also significantly increase both food grain yield and WP.
- Also, rain-fed areas under food grains of 110 districts have a CWU of between 225 and 300 mm (map F in Figure 9). These areas can also increase food grain yield with supplemental irrigation. But the extent of increase in WP depends on the gap between actual and the maximum yield.

So essentially, rain-fed areas under food grains of 268 districts (39 in subgroup 1, and 229 in subgroup 2) can increase yield, WP or both by increasing CWU through supplemental irrigation, provided that non-water inputs are closely integrated with additional irrigation applications.

Irrigation covers 46 % of the total area under food grains of districts in group 2. Among them, irrigated area under food grains of 15 districts has a CWU below 300 mm (map D in Figure 9). These districts can also significantly benefit from a small supplemental irrigation combined with better non-water input management. Among the remaining districts in group 2, irrigated area has rather a high total of CWU, and irrigation contributes to more than half of the total of CWU (CWU above 300 mm in map D in Figure 8). Increasing CWU through additional irrigation would not contribute much to increase yield or WP. However, unreliable irrigation water supply, combined with inadequate or improper application of other inputs, is the key factor responsible for substantial yield gaps. Therefore, better management of existing water and non-water inputs can still increase production and WP in irrigated areas of all these districts.

Figure 9. Spatial distribution of CWU in irrigated and rain-fed food grains areas across districts.



Source: Based on authors' estimates

Subgroup 3: This consists of districts with a total CWU of above 475 mm. Increasing CWU above 475 would have negative incremental benefits on both yield and WP. There are 48 districts in this group and they account for 14 and 15 % of total area under food grains and production (CWU above 475 mm in map A and B). Some of the districts in this group are major rain-fed areas with a high percentage of rice cultivation. They can improve both land water productivity by adopting hybrid rice with higher yield, or increase value of water productivity with integrated farming systems with crop-aquaculture. In irrigated areas, WP can be increased by reducing the CWU through deficit irrigation. We will discuss the implication of CWU reduction through deficit irrigation next.

Reducing CWU through Deficit Irrigation

Third strategy for increasing WP is to decrease consumptive water use through deficit irrigation. Main objective of deficit irrigation is to increase the water use efficiency by eliminating non-beneficial evaporation or non-recoverable deep percolation that do not contribute to transpiration and hence have little impact on crop yields. The resulting yield reduction may be small in comparison to benefits gained through diverting the saved water to irrigate other crops for which water would be insufficient under traditional irrigation practices (Kirda and Kanber 1999). In irrigated areas with more than 475 mm of CWU, this strategy could increase both yield and WP. In regions with a CWU of between 225 and 475 mm, it can only increase WP. However, even with some loss of yield this strategy can save water and then use that saved water for increasing crop production or in another productive use. To illustrate the positive impacts on crop production, we develop a few scenarios of reducing CWU and the resulting water savings and production increases (Table 3).

The data shows two deficit CWU scenarios of 25 and 50 mm (column 1, Table3) in districts with more than 25, 50 and 75 % irrigated area under food grains (column 2). In each category, we consider only districts with less than 10 % and 5 % and no yield reduction due to deficit CWU (column 3). Columns 4-7 show the total area under food grains, CWU in the irrigated area, NET part of the irrigated CWU and total food grain production, respectively. Columns 8 and 9 show the saved CWU as a percentage of NET in the irrigated area under food grains, and the net gain in production if the saved water is again used for additional grain production.

About 251 districts (Figure 10) with more than 25 % of irrigated food grain area will have 10 % less food grain yield with 25 mm of deficit CWU (column 3, Table 2).

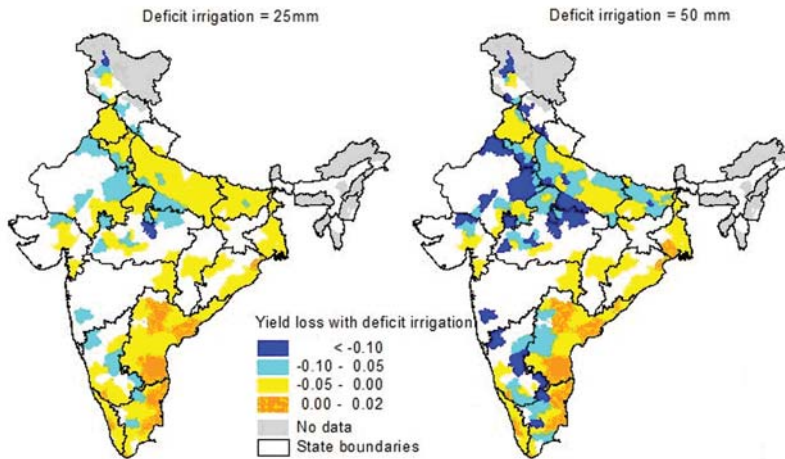
This group of districts account for 63 % of the total food grain area in the country, contributing to 79 % of the total food grain production. Deficit CWU of 25 mm on existing irrigated area can save 14 % of the NET requirement. If all that saved NET are again used for expanding food grain production, it can contribute to 8 % additional production. Deficit CWU of 50 mm can save 27 % of NET and can increase 17 % of production.

Reduction in CWU can increase grain production in all districts having a significant irrigated area (Table 2). However, such strategy can help the most in increasing production in districts that are poorly-endowed in water, but not of land. Almost all districts with 25 mm deficit CWU would, in fact, gain in yield or have yield loss less than 5 % (Figure 9). Number of districts with yield loss greater than 10 % would increase from 5 % with a 25 mm deficit of CWU to 43 % with a 50 mm of deficit CWU. Good strategy here is to increase deficit CWU to the extent that gains in benefits, whether in crop production or through other uses of the saved water are greater than value of the production loss due to yield decrease. The above example illustrates that many

Table 3. CWU saved and net gain in food grain production through deficit irrigation.

Deficit in CWU	Irrigated food grain area -% of total	Yield loss -% of max yield	Number of districts	Grain area	Irrigated CWU	NET	Grain production	Saved CWU- % of NET	Net gain in food grain production - % of total
(mm)	%	%	#	Million Ha	Km ³	Km ³	Million Mt	%	%
25	>25	<10	251	77	211	136	161	14	8
		<5	213	64	191	119	142	14	8
		<0	26	8	33	19	18	10	9
	>50	<10	165	50	166	110	123	11	7
		<5	153	46	158	103	117	11	7
		<0	25	7	33	19	18	9	8
	>75	<10	78	24	90	61	70	10	6
		<5	77	23	89	60	69	10	6
		<0	13	2	11	7	6	7	7
50	>25	<10	213	64	191	119	142	27	17
		<5	144	45	148	87	104	26	18
		<0	26	8	33	19	18	20	18
	>50	<10	153	46	158	103	117	22	15
		<5	110	34	127	79	89	22	16
		<0	25	7	33	19	18	19	17
	>75	<10	77	23	89	60	69	19	14
		<5	59	18	72	48	54	19	14
		<0	13	2	11	7	6	14	15

districts with substantial irrigated area can gain in food grain production by practicing 25 mm deficit irrigation. However, the main question here, as raised by Kumar and van Dam (2008), is whether there is adequate land for using the saved water for additional crop production. Most of the districts which can benefit from deficit irrigation lie in Indus, Ganga, Mahanadi, Godavari, Krishna and Cauvery basins (Figure 10). It is well-known that parts of north-west in the Indus and Ganga basin, practice deficit irrigation in canal command areas. Rice-wheat is the dominant cropping pattern in these basins. Among the other four basins, Krishna and Cauvery are water- stressed basins. Even with some loss of crop production, the Krishna and Cauvery basins can gain the most through the deficit irrigation concept. However, to what extent the existing cropping pattern allow deficit irrigation in these districts is another question. Rice dominates the irrigation cropping patterns in these basins, and they often use substantially more water in excess of Eta— the crop water requirement. However, studies show that different irrigation techniques such as wet and dry irrigation (Sakthivadivel et al. 2001), system of rice Intensification can increase both yield and water use efficiency in irrigated rice, which results in increased production and WP. Where and to what extent these techniques can be adopted and their benefits on major rice irrigated areas need further assessment.

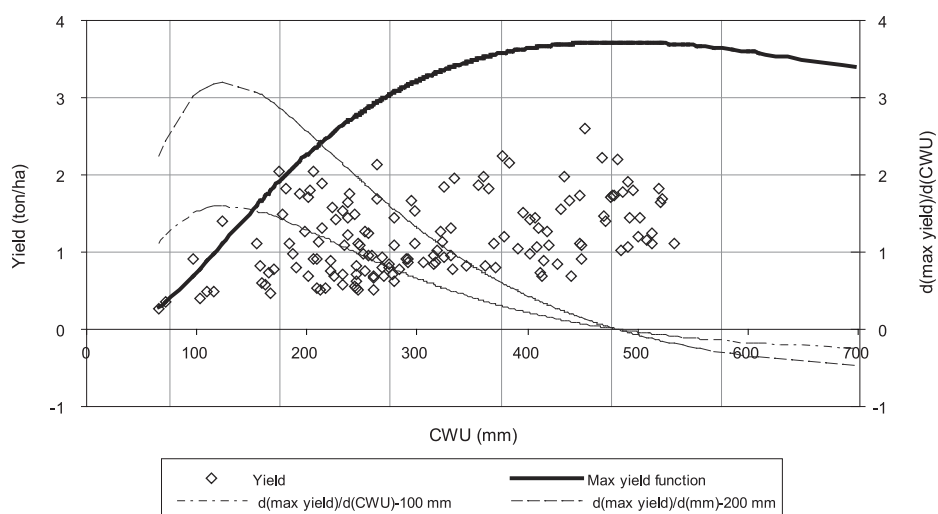
Figure 10. Yield loss with different deficit irrigation strategies.

Source: Based on authors' estimates

Increasing Water Productivity in Rain-fed Districts

Figure 11 shows the variation of grain yield in the 155 districts with mainly rain-fed agriculture, i.e., districts with less than 25 % of the total cropped area under irrigation. These districts have two-thirds of the total food grain area of India, contributing to only one-third of the food grain production. About 14 % of districts in this category have extreme dry conditions with a CWU of below 200 mm, and another 58 % of districts have moderate to low dry conditions (where CWU is between 200 and 400 mm). The cropping pattern explains a major part of low WP in this group. Due to low rainfall, less water-intensive crops such as coarse cereals and pulses dominate the grain cropping patterns in these districts. More than 70 % of the area under food grains consists of coarse cereals and pulses. Average yields of these crops (0.87 tonnes/ha of coarse cereals, and 0.55 tonnes/ha of pulses) compared with rice, wheat and maize (1.97, 2.82, and 1.82 tonnes/ha respectively) are very low. As discussed previously, a small supplemental irrigation could significantly increase existing grain yields and WP in many districts, particularly in those with CWU below 225 mm.

About a quarter of the districts in this category also have CWU between 400 and 535 mm, with rice as the major food grain crop. Effective rainfall contributes to almost all the total CWU of these districts. Although total rainfall is adequate for rice cultivation in these districts, rice yields are very low due to many factors including a mismatch between crop water demands and rain water availability periods. Such conditions discourage the farmers from making investments in farm inputs. As such, these districts have one of the lowest fertilizer application in India (36 kg of NPK /ha), which is only one-fourth of the fertilizer application in all other districts with similar CWU (135 kg of NPK/ha). Thus, an unreliable water supply from rainfall alone seemed to be a major impediment for proper input application and low rice yield in these districts. As availability of water is not a significant constraint, small supplemental irrigation during periods of input application and in critical periods of water stress could increase the yield in these districts. Another option is to change cropping patterns to best utilize the

Figure 11. Yield versus CWU of districts with grain irrigated area less than 25 % of total.

Source: Based on authors' estimates

water supply from rainfall. The demand for feed crops such as maize and vegetable oils are increasing rapidly and substantial part of this demand is projected to be imported from other countries (Amarasinghe et al. 2007b). Thus, changing cropping patterns from low-yielding rice to high-yielding maize or oil crops, especially in the rabi season could generate significant benefits for these regions. In fact, soil moisture through rainfall could be more than adequate for raising productive maize or oil crops in these regions.

Discussion and Conclusion

Our assessment using district-level data show that significant potential exists for increasing WP of food grains with substantial increase in production. Almost all districts can employ different types of water management interventions that can contribute to increasing water productivity and production, thus ensuring food and livelihood security and employment generation. These interventions vary from small to moderate supplemental irrigation to deficit irrigation. Small to moderate supplementary irrigation inputs can increase yield, WP or both in areas where CWU is below 300 mm. In fact, CWU (or the effective rainfall) of rain-fed areas in 158 districts falls below the threshold of 225 mm (districts indicated by 'A' in columns 19 and 21 in Annex Table 1). Irrigated areas of 15 districts and rain-fed areas of 110 more districts have CWU between 225 to 300 mm (districts indicated by 'B' in columns 18 and 20). The data of 1995/96 shows that India has more than 111 million agricultural landholdings covering 141 million ha of net sown area (GOI 2007). Of this, about 66 % of landholdings and 74 % cropped area are either partly irrigated or completely rain-fed. In this category, 28 % of the landholdings consist of 67 % of semi-medium (2-4 ha) to medium (4- 10 ha) and large (>10 ha) holding sizes. A significant part of this area is covered by food grain crops. These are the areas that can benefit through small to moderate supplementary irrigation and can have a significant impact on WP as well as on crop production. Increased production contributes to food and livelihood security of farmers of these areas.

What are the options for improving crop water productivity in marginal (<1ha) to small (1-2 ha) holdings in partially irrigated to rain-fed lands? Nearly 72 % of India's marginal and small landholdings are in partially irrigated or rain-fed land category, but they only have 33 % of the cropped area. Although it was not analyzed in this paper, the cost of providing supplemental irrigation to marginal and small landholdings could be higher than the benefits through production increase in food grains. As argued by Kumar and Dam (2008), it is in these holdings where the objective should be increasing value of agricultural productivity but not increasing water productivity of crops, and importantly that of low-value food grain crops. These areas could benefit with crop diversification to high-value crops or livestock production with additional supplemental irrigation.

Supplemental irrigation increases crop yield but decreases WP when CWU is between 300 and 475 mm. The CWU in irrigated areas of 219 districts and in rain-fed areas of 227 districts falls in to this category (districts indicated by 'C' in columns 19 and 21 of Annex Table 1). If availability of water is not a constraint, these areas can benefit from a small supplemental irrigation. If water availability is a constraining factor, increasing productivity of land should be the major focus. In fact, we observed that there is a substantial difference between the actual and maximum yield in these districts. Most of the variation in food grain yield is explained by variation in water and non-water inputs. Better water management improves non-water input application, which leads to higher productivity and production.

In irrigated areas, this means providing a reliable irrigation supply. One way of achieving this is through introducing intermediate water storage structures as in the Indira Gandhi Nehar Project in Rajasthan (IGNP)—(Amarasinghe et al. 2008). The intermediate water storage structures, called '*diggies*', in the IGNP store the water delivered from the watercourses to farms. Next it pumps water out of the *diggi* and distributes it to the field through field channels or sprinklers. It helps to supply irrigation when crop requires it the most. Thus, *diggies* simply improve the reliability of water application to crops, and hence improves application of non-water inputs too. Most importantly, *diggies* help introduce micro-irrigation in the canal command areas. All these interventions contribute to higher yield, production and WP. However, *diggies* are shown to be cost-effective for landholdings above 4 ha. Thus, *diggies* can directly help medium to large fully irrigated landholdings. In India, 8 % of the irrigated landholdings are in this category, and they account for 24 % of the irrigated land. Does this mean that small to semi-medium landholdings cannot benefit from intermediate water storage structures? Perhaps not! But it requires new types of institutions of water users. Like water user associations (WUAs) at the level of watercourses, small number of small landholdings ranging from 4 to 6 can form user groups, which share a common *diggi*. Such user group can reduce the cost of construction of *diggies* and improve performance of irrigation deliveries to farms. Understanding of the institutional mechanisms that requires for successful implementation of such water user groups is beyond the scope of this paper. However, a good lesson for a similar intervention can be seen in the areas under 'system tanks' in Tamil Nadu. Benefits from such interventions can be further enhanced by exploring the possibility of integrating aquaculture into the *diggies*/ system tanks/ intermediate storage structures.

Rain-fed areas with moderate CWU, i.e., between 300 and 475 mm, require different strategies for reducing the yield gap. One option for improving water productivity in these areas is to promote agricultural diversification to high-value crops and livestock. This should be done in areas where soil moisture is adequate for raising high-value non-grain crops or

fodder that is required for livestock. This is mainly in areas in the upper end of CWU region, i.e., those close to 475 mm. In other areas, increasing water productivity may not be the proper goal. These areas, as in low CWU rain-fed zones, could greatly benefit from some small supplemental irrigation in critical water-stressed periods. Although this does not result in increases in WP, the benefits from production increase may outweigh the cost of supplemental irrigation. To know to what extent the benefits outweigh the cost requires further research.

Irrigated areas with high CWU can benefit by reducing CWU. This increases both yield and WP. The water saved from deficit irrigation can again be used to increase crop production, if land is not a limiting factor. If the latter is true, the water saved can be used for productive purposes in other sectors. In India, 48 districts which account for 13 % of the total irrigated food grain area have CWU more than 475 mm (districts indicated by 'D' in columns 19 in Annex Table 1). The data presently available with us, however, do not show, whether all this area belongs to semi-medium to large landholdings.

Reducing crop consumptive use in irrigated areas, where CWU is below 475 mm, can also increase grain water productivity. Although the crop yield will marginally decrease in this case, water saved through reduction of CWU can again be used for expanding the cropped area. This can be practiced in places where increase in production through area expansion offsets the loss of production due to yield loss. Our results show irrigated areas in many districts with CWU below 475 mm can increase grain production (we have indicated only the districts with CWU in irrigated area above 425 mm, and they are denoted by 'CD' in column 19 of Annex Table 1). Once again, to what extent this actually can be done depends on the size of the landholding.

Finally, we focused our attention on rain-fed areas with large CWU (districts indicated by 'E' in column 20 of Annex Table 1). At present, paddy crop dominates cropping patterns of these areas and have a very low yield. This may be mainly due to cultivation of low-yielding local varieties and a mismatch between crop water demands and periods of rain water availability. Efforts should be made on both these fronts. Alternatively, these areas should diversify their cropping patterns. One option is to diversify to feed grains such as maize or non-grain crops such as oil crops. Both require less CWU than rice and also could be more productive than rice crop. With increasing demand for feed grains and vegetable oils, this could be a good option for these rain-fed regions.

In this paper, we have only discussed the potential for increasing WP and production through water management practices. We assumed that better water management would lead to better non-water input application and, which in turn will increase the crop yield and WP. However, many other factors affect the mode of water management or crop or agricultural diversification in different regions. They include reliability of power supply, availability of roads, access to markets, extension services etc. To know how these would influence the success in implementing different water management interventions require more data and research. Moreover, advances in biotechnology could help develop seed varieties that withstand droughts and conditions of water-stress or increases the yield frontiers with the existing levels of water consumption by the crop. All these would increase WP and crop production.

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Annex Table 1. Water productivity variations across districts in India.

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation								Other data			
		State	Area	Prod uction	Yield	CWU	WP	CWU NET				Area	Prod				CWU
								- %	- %	of	- %		- %	- %	of	- %	
								total	irri	total	of		total	of	of	of	
								CWU	CWU				GCA	GCA	GIA	GIA	
			M ha	M Mt	tonne/ha	m m	kg/m ³	%	%	%	%	%	%	%	%	%	m m
1	The Dangs	GU	0.05	0.05	1.0	250	0.4	0	33	0.0	0.0	82	2	1	1	100	329 C
2	Darjiling	WB	0.07	0.12	1.8	364	0.5	1	93	1.2	1.6	37	7	23	7	45	238 B
3	Puruliya	WB	0.32	0.63	2.0	434	0.5	1	71	1.6	2.2	81	12	32	10	16	376 C
4	Dhanbad	JH	0.09	0.10	1.1	419	0.3	1	88	1.6	2.6	98	30	5	5	66	336 C
5	Bidar	KA	0.39	0.21	0.5	245	0.2	4	89	1.7	4.2	84	15	13	9	100	554 D
6	Thane	MA	0.18	0.34	1.9	356	0.5	3	37	2.0	3.3	71	28	6	5	100	555 D
7	Mandla	MP	0.35	0.21	0.6	245	0.3	4	80	2.1	3.6	71	48	4	3	18	467 CD
8	Ratnagiri	MA	0.11	0.22	2.0	361	0.5	4	30	2.4	3.8	45	25	1	4	28	526 D
9	Amravati	MA	0.36	0.34	0.9	292	0.3	5	98	2.4	3.8	36	12	8	7	100	546 D
10	Jalpaiguri	WB	0.29	0.45	1.5	431	0.4	2	95	2.8	3.8	59	21	31	8	94	254 B
11	Gumla	JH	0.22	0.18	0.8	427	0.2	3	31	3.0	4.7	92	34	4	8	32	473 CD
12	Barmer	RA	1.11	0.29	0.3	66	0.4	21	94	3.0	10.6	66	20	6	10	99	465 CD
13	Sindhudurg	MA	0.09	0.19	2.2	384	0.6	4	29	3.0	4.8	57	15	24	12	1	525 D
14	Bastar (Jagdalpur)	CH	0.75	0.61	0.8	362	0.2	5	34	3.2	5.4	89	90	3	3	13	511 D
15	Churu	RA	0.70	0.35	0.5	109	0.5	12	91	3.2	11.4	62	25	12	8	63	399 C
16	Akola	MA	0.54	0.50	0.9	290	0.3	7	100	3.5	5.4	49	30	3	6	59	560 D
17	Bharuch	GU	0.32	0.18	0.6	232	0.2	8	75	3.5	7.3	75	14	22	19	83	517 D
18	Buldana	MA	0.47	0.46	1.0	255	0.4	8	100	3.7	5.8	57	36	5	6	96	562 D
19	Ranchi	JH	0.22	0.28	1.3	418	0.3	4	39	3.9	6.1	93	47	8	8	85	424 C
20	Dhule	MA	0.51	0.45	0.9	221	0.4	10	97	3.9	6.1	64	24	12	11	100	559 D
21	Dumka (Santal Pargana)	JH	0.18	0.26	1.4	408	0.4	4	56	4.1	6.4	98	60	6	7	57	375 C
22	Jhabua	MP	0.17	0.11	0.7	200	0.3	9	75	4.2	7.2	49	28	6	8	64	438 CD
23	Kolhapur	MA	0.20	0.40	2.0	333	0.6	7	91	4.3	6.8	28	6	26	21	34	554 D
24	Pashchimi Singhbhum (Ch.)	JH	0.22	0.15	0.7	439	0.2	5	18	4.4	6.9	99	84	4	5	2	523 D
25	Jamnagar	GU	0.06	0.05	0.9	97	0.9	22	98	4.4	9.0	8	2	14	16	98	494 D
26	Hamirpur	HP	0.07	0.12	1.7	200	0.9	9	52	4.4	5.1	96	88	5	5	3	433 CD
27	Purbi Singhbhum	JH	0.17	0.16	0.9	449	0.2	5	16	4.4	6.9	100	99	2	4	3	520 D

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation				Other data							
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	%	%	%	%	%	%	%	in
																	rain-fed
																	grain
																	area
																	mm
28	Yavatmal	MA	0.41	0.39	0.9	314	0.3	8	99	4.6	7.2	43	24	6	8	66	564 D
29	Gulbarga	KA	1.70	0.91	0.5	217	0.2	9	62	4.7	11.4	90	45	13	9	24	429 CD
30	Sahibganj	JH	0.11	0.16	1.5	396	0.4	4	61	4.9	7.7	96	51	7	9	9	347 C
31	Raigarh (Alibag)	MA	0.15	0.35	2.2	377	0.6	7	32	5.3	8.2	73	68	6	6	38	528 D
32	Udhampur	JK	0.11	0.16	1.4	227	0.6	9	49	5.5	6.1	98	105	8	5	0	390 C
33	Kullu	HP	0.05	0.10	2.0	175	1.2	10	42	5.7	6.7	80	88	7	5	0	298 B
34	Lohardaga	JH	0.05	0.05	1.0	402	0.2	6	55	6.1	9.4	88	54	9	10	44	378 C
35	Surguja (Ambikapur)	CH	0.57	0.49	0.9	315	0.3	9	37	6.1	10.1	88	93	6	6	18	479 D
36	Mariagan	AS	0.13	0.22	1.7	476	0.4	7	7	6.4	11.1	83	97	6	5	0	515 D
37	Koch Bihar	WB	0.32	0.53	1.7	437	0.4	6	40	6.4	8.6	63	83	7	5	100	376 C
38	Nanded	MA	0.46	0.40	0.9	292	0.3	11	81	6.5	10.0	57	29	8	13	100	512 D
39	Karimganj	AS	0.08	0.14	1.8	487	0.4	7	5	6.5	11.4	81	97	6	5	0	491 D
40	Cachar	AS	0.11	0.25	2.2	482	0.5	7	5	6.8	11.8	78	97	6	5	0	491 D
41	Giridih	JH	0.07	0.09	1.3	410	0.3	6	78	6.8	10.6	85	35	10	17	72	341 C
42	Nagaon	AS	0.27	0.48	1.7	477	0.4	7	10	6.8	11.9	78	97	6	5	0	516 D
43	Raigarh	CH	0.57	0.47	0.8	344	0.2	10	35	6.9	11.4	94	90	8	7	30	490 D
44	Nalbari	AS	0.16	0.18	1.1	512	0.2	7	8	6.9	12.0	77	97	6	5	0	534 D
45	Hajlakandi	AS	0.05	0.08	1.7	478	0.4	7	6	6.9	12.0	77	97	6	5	0	487 D
46	Kamrup	AS	0.20	0.29	1.4	492	0.3	7	6	6.9	12.0	77	97	6	5	0	514 D
47	Goalpara	AS	0.08	0.12	1.4	470	0.3	8	6	7.0	12.1	76	97	6	5	0	512 D
48	Bongaigaon	AS	0.11	0.12	1.1	491	0.2	7	7	7.0	12.1	76	97	6	5	0	525 D
49	Kokrajhar	AS	0.11	0.12	1.2	508	0.2	7	7	7.0	12.2	76	97	6	5	0	521 D
50	Deogarh	JH	0.07	0.10	1.4	402	0.4	6	74	7.1	11.0	83	60	8	10	34	344 C
51	Barpeta	AS	0.23	0.23	1.0	485	0.2	8	7	7.3	12.6	72	96	6	5	0	527 D
52	Shahdol	MP	0.45	0.35	0.8	283	0.3	10	93	7.3	12.2	86	93	7	7	36	476 D
53	Hazaribag	JH	0.17	0.20	1.2	379	0.3	6	78	7.3	11.3	88	42	15	15	66	328 C
54	Jodhpur	RA	0.89	0.42	0.5	115	0.4	30	95	7.3	23.1	70	32	11	16	92	479 D

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation				Other data							
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	Mt	tonne/ha	mm	kg/m ³	%	%	- % of total CWU	- % of total	- % of area	- % of NSA	- % of GCA	- % of GIA	in rain-fed grain area	in mm
55	Karbi Anglong	AS	0.13	0.20	1.5	469	0.3	8	5	7.4	12.8	72	97	6	5	0	488 D
56	Dhubri	AS	0.17	0.19	1.1	450	0.2	9	8	7.5	13.0	71	97	6	5	0	514 D
57	Lakhimpur	AS	0.11	0.12	1.1	533	0.2	8	5	7.8	13.4	68	97	6	5	0	545 D
58	Bilaspur	HP	0.06	0.11	1.9	214	0.9	16	48	7.9	9.2	97	88	11	9	3	434 CD
59	Nashik	MA	0.64	0.48	0.8	222	0.3	17	84	7.9	12.1	68	30	21	18	100	474 CD
60	Uttar Kannad	KA	0.58	0.97	1.7	294	0.6	11	30	7.9	18.3	80	86	4	7	10	389 C
61	Garhwal	UT	0.16	0.17	1.1	279	0.4	12	38	8.0	15.6	99	76	9	10	0	402 C
62	Darrang (Mangaldai)	AS	0.18	0.22	1.2	501	0.2	9	8	8.1	13.9	66	97	6	5	0	532 D
63	Parbhani	MA	0.79	0.67	0.9	274	0.3	17	96	8.1	12.4	60	35	10	14	97	565 D
64	Sonitpur (Tezpur)	AS	0.16	0.23	1.4	502	0.3	9	9	8.2	14.0	65	97	6	5	0	533 D
65	Jalgaon	MA	0.45	0.49	1.1	234	0.5	18	91	8.3	12.7	35	22	17	13	100	514 D
66	Bangalore Rural	KA	0.14	0.24	1.8	239	0.7	15	53	8.3	19.1	54	20	21	22	87	429 CD
67	Rajauri	JK	0.10	0.18	1.8	203	0.9	17	56	8.4	9.3	98	105	14	8	1	410 C
68	Sibsagar	AS	0.10	0.18	1.8	520	0.4	9	6	8.6	14.8	62	97	6	5	0	535 D
69	Almora	UT	0.14	0.15	1.1	248	0.4	13	32	8.7	16.8	93	76	9	11	0	363 C
70	Golaghat	AS	0.09	0.18	1.9	490	0.4	9	9	8.8	15.1	60	97	6	5	0	522 D
71	Kalahandi	OR	0.59	0.47	0.8	370	0.2	13	27	8.9	18.1	79	56	21	12	31	522 D
72	Dhemaji	AS	0.06	0.07	1.2	513	0.2	10	6	9.0	15.4	59	97	6	5	0	551 D
73	Amreli	GU	0.08	0.06	0.8	170	0.5	25	87	9.2	17.9	14	8	16	16	100	463 CD
74	Jorhat	AS	0.10	0.17	1.8	496	0.4	10	7	9.4	15.9	57	97	6	5	0	531 D
75	Tinsukia	AS	0.07	0.12	1.6	521	0.3	10	8	9.5	16.1	56	97	6	5	0	556 D
76	Pithoragarh	UT	0.08	0.10	1.2	237	0.5	14	36	9.5	18.1	76	76	7	10	0	338 C
77	Dibrugarh	AS	0.10	0.16	1.7	522	0.3	10	6	9.6	16.3	56	97	6	5	0	545 D
78	Chamba	HP	0.06	0.12	2.0	205	1.0	15	45	9.6	11.1	89	85	16	10	0	312 C
79	Wardha	MA	0.14	0.15	1.0	318	0.3	17	100	9.8	14.8	38	41	7	9	100	557 D
80	Chamoli	UT	0.05	0.06	1.3	214	0.6	15	40	10.3	19.5	74	76	7	10	0	315 C
81	Nagaur	RA	0.99	0.59	0.6	159	0.4	30	94	10.6	31.3	75	40	19	20	100	454 CD
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Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																						
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Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation								Other data			
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	%	%	%	%	%	%	%	in
									of	of	of	of	of	of	of	of	in
									total	total	total	total	total	total	total	total	rain-fed
									CWU	CWU	GCA	GCA	GCA	GCA	GCA	GCA	grain
									%	%	%	%	%	%	%	%	area
																	mm
109	Jalna	MA	0.51	0.42	0.8	245	0.3	30	72	17.3	25.1	70	68	12	18	74	208 A
110	Solapur	MA	0.89	0.45	0.5	213	0.2	36	72	17.6	25.5	80	59	21	24	89	166 A
111	Mandi	HP	0.14	0.30	2.1	263	0.8	23	30	17.8	20.3	85	88	17	17	0	246 B
112	Seoni	MP	0.32	0.16	0.5	260	0.2	34	73	17.8	27.7	74	91	22	15	43	207 A
113	Junagadh	GU	0.07	0.11	1.5	178	0.8	47	92	18.0	32.1	9	11	25	15	100	463CD
114	Sabarkantha (Himatnagar)	GU	0.31	0.35	1.1	247	0.5	39	85	18.4	32.8	61	28	41	40	100	185 A
115	Beed	MA	0.66	0.34	0.5	246	0.2	33	73	18.6	26.8	71	65	26	20	21	440 CD
116	Ajmer	RA	0.35	0.24	0.7	224	0.3	39	91	18.6	46.7	77	59	8	24	87	471 CD
117	Sidhi	MP	0.42	0.26	0.6	279	0.2	26	91	19.3	29.8	90	96	15	18	39	373 C
118	Jabalpur	MP	0.53	0.42	0.8	268	0.3	32	91	19.3	29.8	90	92	33	19	87	445 CD
119	Ratlam	MP	0.12	0.17	1.5	244	0.6	42	99	19.5	30.0	27	38	11	14	100	522 D
120	Mayurbhanj	OR	0.39	0.44	1.1	447	0.2	22	16	19.5	35.4	83	83	20	20	23	503 D
121	Jhunjhun	RA	0.42	0.33	0.8	190	0.4	41	92	19.7	48.4	69	43	47	32	100	395 C
122	Rajgarh	MP	0.18	0.13	0.7	245	0.3	40	99	19.9	30.5	33	46	24	15	100	498 D
123	Betul	MP	0.19	0.21	1.1	298	0.4	35	100	19.9	30.6	41	64	23	13	100	525 D
124	Surendranagar	GU	0.09	0.12	1.3	199	0.6	55	97	20.1	35.2	17	15	18	23	100	543 D
125	West Nimar (Khargon)	MP	0.19	0.18	1.0	259	0.4	43	98	20.2	30.9	32	30	25	21	100	553 D
126	Udaipur	RA	0.35	0.45	1.3	321	0.4	32	94	20.4	49.5	75	66	24	23	54	501 D
127	Chhindwara	MP	0.27	0.39	1.4	279	0.5	37	99	20.5	31.4	51	65	16	16	100	501 D
128	Adilabad	AP	0.37	0.48	1.3	331	0.4	37	53	20.5	47.6	64	73	14	18	38	588 D
129	Dhenkanal	OR	0.40	0.30	0.7	412	0.2	27	22	20.7	37.0	68	72	23	19	38	538 D
130	Koraput	OR	0.73	0.78	1.1	408	0.3	26	18	20.8	37.2	68	65	25	22	34	504 D
131	Bijapur	KA	0.69	0.62	0.9	209	0.4	44	75	21.0	40.9	57	41	29	29	50	433 CD
132	Uttarkashi	UT	0.04	0.05	1.4	124	1.1	42	67	21.1	36.1	83	76	15	23	0	246 B
133	Kendujhar	OR	0.30	0.21	0.7	413	0.2	26	20	21.2	37.7	79	81	22	20	26	509 D
134	Shajapur	MP	0.16	0.20	1.3	252	0.5	43	98	21.6	32.8	25	53	23	10	100	496 D
135	Pune	MA	0.88	0.62	0.7	270	0.3	32	62	21.7	30.8	76	64	25	26	58	395 C

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																												
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			Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian area	NIA	GIA	GWIRA	CWU	CWU	in	rain-fed																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																									

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation				Other data							
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	%	%	%	%	%	%	%	in
									of	of	of	of	of	of	of	of	rain-fed
									total	total	total	total	total	total	total	total	grain
									CWU	CWU	GCA	GIA	GCA	GIA	GCA	GIA	area
									%	%	%	%	%	%	%	%	mm
																	mm
157	Mahbubnagar	AP	0.55	0.50	0.9	324	0.3	53	69	26	56	59	61	20	26	78	206 A
158	Dharmapuri	TN	0.29	0.49	1.7	285	0.6	51	61	27	53	60	50	33	32	60	190 A
159	Quaide Milleth	TN	0.13	0.27	2.1	288	0.7	46	55	27	53	50	33	39	40	80	213 A
160	Birbhum (Situri)	WB	0.41	1.10	2.7	436	0.6	28	41	27	34	82	54	119	41	10	449 CD
161	Palamu (Daltenganj)	JH	0.23	0.21	0.9	365	0.2	38	33	28	38	71	81	27	24	38	315 C
162	Tonk	RA	0.29	0.22	0.8	268	0.3	48	91	28	60	50	52	42	27	90	456 CD
163	Mandsaur	MP	0.22	0.31	1.4	255	0.5	51	96	28	41	29	50	26	16	100	457 CD
164	Kolar	KA	0.15	0.26	1.7	277	0.6	47	59	29	51	47	43	22	31	89	453 CD
165	Medak	AP	0.41	0.52	1.3	363	0.3	51	61	29	59	74	60	29	36	67	641 D
166	Satara	MA	0.46	0.45	1.0	275	0.4	41	48	29	40	67	60	29	32	72	383 C
167	Puli	RA	0.34	0.22	0.6	257	0.3	58	93	30	62	55	55	26	30	70	497 D
168	West Dinajpur	WB	0.56	1.15	2.1	441	0.5	29	41	30	37	75	80	6	28	55	432 CD
169	Bilaspur	CH	0.85	0.91	1.1	379	0.3	40	39	30	43	93	90	33	31	10	508 D
170	Kangra	HP	0.20	0.31	1.5	278	0.5	39	29	30	34	91	88	31	31	0	358 C
171	Dakshin Kannad	KA	0.13	0.25	1.9	478	0.4	35	40	30	53	56	46	45	37	48	557 D
172	Mahendragarh	HA	0.17	0.32	1.9	244	0.8	42	90	32	63	62	41	81	48	100	321 C
173	Kozhikode	KE	0.01	0.01	1.3	409	0.3	43	48	32	39	3	61	3	2	100	548 D
174	Banda	UP	0.60	0.72	1.2	293	0.4	46	70	32	52	95	97	31	32	29	417 C
175	Sirmaur (Nahan)	HP	0.07	0.12	1.9	271	0.7	42	38	32	36	83	79	37	34	17	355 C
176	Kupwara (Gilgit Wazarat)	JK	0.04	0.04	1.0	177	0.5	85	92	32	35	84	69	42	39	0	466 CD
177	Bhilwara	RA	0.37	0.49	1.3	323	0.4	49	94	33	65	77	60	41	42	65	488 D
178	Balangir	OR	0.46	0.56	1.2	429	0.3	42	29	33	52	82	84	24	32	25	550 D
179	Valsad	GU	0.16	0.36	2.3	396	0.6	48	46	33	51	51	34	41	49	60	578 D
180	Thiruvananthapuram (Triv)	KE	0.01	0.02	2.0	394	0.5	45	45	33	40	4	75	3	2	20	538 D
181	Hamirpur	UP	0.55	0.62	1.1	249	0.5	35	87	33	53	88	92	33	32	50	261 B
182	Sagar	MP	0.50	0.30	0.6	232	0.3	56	93	33	47	74	95	32	26	59	393 C
183	Sehore	MP	0.20	0.27	1.3	302	0.4	58	99	34	47	38	68	45	19	100	519 D

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation				Other data							
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	%	%	%	%	%	%	%	in
										of	- %	of	- %	of	- %	of	in
										total	total	area	of	area	of	grain	rain-fed
										CWU	CWU	GCA	NSA	GCA	GIA	area	area
										%	%	%	%	%	%	mm	mm
184	Gonda	UP	0.65	1.26	1.9	317	0.6	29	91	34	54	82	75	37	96	272 B	340 C
185	Kishanganj	BI	0.11	0.13	1.2	434	0.3	33	26	34	48	64	78	28	87	412 C	445 C
186	Chitradurga	KA	0.48	1.16	2.4	249	1.0	71	80	35	58	55	64	30	48	507 D	110 A
187	Hassan	KA	0.19	0.34	1.8	336	0.5	54	52	35	58	55	71	21	27	514 D	241 B
188	Belgaum	KA	0.43	0.53	1.2	281	0.4	54	70	35	59	47	37	45	43	430 CD	201 A
189	Durg	CH	0.65	0.60	0.9	374	0.2	49	44	35	49	89	93	35	34	21	295 B
190	Banswara	RA	0.27	0.28	1.0	378	0.3	47	87	35	67	95	87	29	38	10	307 C
191	Surat	GU	0.18	0.36	2.0	367	0.5	55	55	35	54	39	20	49	72	27	254 B
192	Dewas	MP	0.13	0.14	1.1	327	0.3	59	99	35	49	25	58	30	15	100	207 A
193	Ganjam	OR	0.60	0.35	0.6	407	0.1	47	24	36	56	79	83	34	17	533 D	337 C
194	Kurnool	AP	0.29	0.45	1.5	328	0.5	67	75	36	66	31	41	20	27	43	170 A
195	Baleshwar	OR	0.48	0.44	0.9	494	0.2	38	13	36	56	85	83	37	39	527 D	476 E
196	Sitamarhi	BI	0.21	0.24	1.2	346	0.3	32	71	36	49	79	89	34	32	74	370 C
197	Chittaurgarh	RA	0.30	0.49	1.7	370	0.4	49	93	37	69	57	56	37	79	496 D	297 B
198	Raichur	KA	0.61	0.91	1.5	307	0.5	69	78	37	61	60	62	24	36	20	567 D
199	Raipur	CH	1.06	1.21	1.1	393	0.3	49	40	37	51	95	89	46	40	11	512 D
200	Banas Kantha	GU	0.40	0.45	1.1	265	0.4	70	89	37	56	44	50	43	33	100	321 C
201	Madhubani	BI	0.25	0.30	1.2	367	0.3	35	61	39	52	85	92	37	36	37	127 A
202	Satna	MP	0.48	0.25	0.5	240	0.2	52	86	39	53	93	100	31	37	331 C	390 C
203	Ramanathapuram	TN	0.13	0.17	1.3	318	0.4	81	83	40	67	72	81	37	36	49	191 A
204	Kathua	JK	0.11	0.17	1.5	309	0.5	57	36	40	43	89	105	35	34	22	643 D
205	Panna	MP	0.30	0.15	0.5	247	0.2	49	81	40	54	97	99	24	39	1	436 CD
206	Mysore	KA	0.33	0.60	1.8	359	0.5	57	50	40	64	61	72	28	34	15	302 C
207	Bhopal	MP	0.14	0.16	1.2	308	0.4	66	99	40	55	59	89	40	27	25	510 D
208	Darbhanga	BI	0.22	0.27	1.2	356	0.3	38	65	41	54	98	100	37	40	94	499 D
209	Cuttack	OR	0.79	0.40	0.5	472	0.1	48	16	41	61	79	82	62	40	25	331 C
210	Puri	OR	0.61	0.42	0.7	466	0.1	49	18	42	62	85	91	57	39	19	546 D
																24	404 C

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains														
		Total					Irrigation					Other data				
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	- % of total	- % of total	- % of area	- % of area	- % of area	- % of area	in rain-fed grain area
																mm
211	Garhchiroli	MA	0.18	0.17	1.0	434	0.2	52	34	42	53	96	100	31	40	3
212	Muzaffarpur	BI	0.26	0.44	1.7	320	0.5	40	72	42	55	86	86	46	42	78
213	Siddharthnagar	UP	0.30	0.60	2.0	346	0.6	32	94	42	62	88	87	56	42	79
214	Jalaun	UP	0.36	0.71	2.0	274	0.7	45	91	42	63	91	95	43	40	27
215	Sambalpur	OR	0.66	1.22	1.8	467	0.4	50	26	42	62	77	86	32	38	18
216	Balaghat	MP	0.34	0.34	1.0	380	0.3	58	43	43	57	98	97	49	43	15
217	Sonbhadra	UP	0.24	0.34	1.4	355	0.4	56	48	43	63	87	96	27	39	2
218	Dehra Dun	UT	0.06	0.11	1.7	279	0.6	62	40	43	62	81	76	79	46	0
219	Salem	TN	0.17	0.38	2.3	320	0.7	73	65	43	70	43	42	45	44	100
220	South 24 Panganas	WB	0.45	0.95	2.1	476	0.4	45	26	44	52	78	93	28	37	5
221	North 24 Panganas	WB	0.34	0.82	2.5	460	0.5	45	29	45	52	63	79	14	35	100
222	Sawai Madhopur	RA	0.35	0.50	1.4	291	0.5	66	92	45	76	61	57	57	48	85
223	Bellary	KA	0.27	0.53	1.9	296	0.7	78	79	46	69	54	58	32	43	27
224	Kannur (Cannanore)	KE	0.01	0.02	1.8	440	0.4	58	49	46	53	5	61	9	3	100
225	Samastipur	BI	0.22	0.39	1.8	322	0.6	46	66	46	60	85	91	40	43	87
226	Vaishali	BI	0.15	0.27	1.8	311	0.6	47	70	46	60	74	81	51	42	96
227	Maharajganj	UP	0.32	0.73	2.3	361	0.6	36	84	47	67	88	86	73	48	76
228	Kasaragod	KE	0.01	0.02	2.1	452	0.5	58	47	47	54	5	27	34	9	100
229	Jhalawar	RA	0.15	0.20	1.3	362	0.4	61	92	47	77	35	44	53	38	94
230	Jaipur	RA	0.74	1.21	1.6	290	0.6	69	92	47	77	66	56	60	55	92
231	Khammam	AP	0.25	0.49	1.9	463	0.4	62	48	47	76	57	63	38	43	35
232	Wayanad (Wynad)	KE	0.01	0.03	2.5	411	0.6	58	46	48	55	7	50	4	6	0
233	Bhagalpur	BI	0.35	0.53	1.5	344	0.4	57	40	48	62	94	91	49	50	55
234	Araria	BI	0.19	0.27	1.4	375	0.4	44	50	49	62	76	86	35	43	43
235	Paschim Champaran	BI	0.33	0.64	1.9	387	0.5	49	42	49	62	86	90	43	47	78
236	Kamarajar	TN	0.07	0.15	2.2	348	0.6	80	72	49	75	45	53	41	42	61
237	Sirohi	RA	0.09	0.11	1.3	360	0.4	67	85	49	79	49	65	37	38	91

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
		Total				Irrigation				Other data							
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU	CWU
			M ha	Mt	tonne/ha	mm	kg/m ³	%	%	%	%	%	%	%	%	%	in
									of	total	of	of	of	of	of	in	rain-fed
									total	total	total	total	total	total	total	total	grain
									CWU	CWU	GCA	GIA	GIA	GIA	GIA	GIA	area
									%	%	%	%	%	%	%	%	mm
																	mm
238	Jhansi	UP	0.37	0.58	1.6	267	0.6	56	90	49	69	83	95	55	43	47	300 C
239	Basti	UP	0.44	0.96	2.2	338	0.6	42	88	50	70	89	83	67	54	89	284 B
240	Idukki	KE	0.01	0.01	2.4	429	0.6	57	32	50	58	2	23	6	4	4	488 D
241	North Arcot (Ambedkar)	TN	0.19	0.48	2.5	410	0.6	77	63	50	76	36	39	43	47	53	630 D
242	Siwan	BI	0.25	0.42	1.7	324	0.5	47	83	51	64	93	91	61	52	70	296 B
243	Saran	BI	0.23	0.42	1.8	332	0.5	47	81	51	64	97	99	45	50	64	302 C
244	Gopalganj	BI	0.22	0.42	1.9	335	0.6	45	82	52	65	91	93	59	50	43	294 B
245	Murshidabad	WB	0.52	1.23	2.4	391	0.6	53	53	52	60	64	81	40	41	100	403 C
246	Rewari	HA	0.11	0.30	2.7	268	1.0	61	94	52	80	57	42	78	70	100	313 C
247	Tiruchirappalli	TN	0.28	0.67	2.4	433	0.6	79	74	52	77	53	58	46	47	60	656 D
248	Ujjain	MP	0.09	0.10	1.0	344	0.3	75	98	52	66	13	61	17	11	86	497 D
249	Kottayam	KE	0.02	0.04	2.3	484	0.5	59	33	53	60	8	78	9	5	7	542 D
250	Jammu	JK	0.18	0.24	1.3	300	0.4	77	46	53	56	91	100	49	48	0	438 CD
251	Munger	BI	0.30	0.35	1.2	353	0.3	58	53	53	66	96	92	59	55	31	389 C
252	Agra	UP	0.27	0.59	2.2	287	0.8	54	91	53	72	62	58	81	56	89	293 B
253	Gandhinagar	GU	0.03	0.09	2.8	342	0.8	87	75	53	71	51	47	60	58	100	565 D
254	Vishakhapatnam	AP	0.14	0.18	1.3	462	0.3	66	48	53	80	36	45	30	42	8	571 D
255	Bhandara	MA	0.40	0.46	1.2	445	0.3	65	40	54	65	72	93	50	42	22	541 D
256	Baramula (Kashmir North)	JK	0.06	0.07	1.1	299	0.4	90	87	54	57	66	70	48	51	2	501 D
257	Bhivani	HA	0.39	0.70	1.8	249	0.7	72	87	54	81	57	53	59	58	42	331 C
258	Gorakhpur	UP	0.36	0.77	2.1	334	0.6	46	87	54	73	94	91	78	56	94	284 B
259	Prakasam	AP	0.32	0.65	2.0	441	0.5	80	73	55	81	55	75	38	40	36	644 D
260	Purnia	BI	0.20	0.34	1.7	364	0.5	50	55	55	68	69	73	57	52	68	330 C
261	Purbi Champaran	BI	0.33	0.54	1.6	358	0.5	56	53	55	68	80	87	55	50	17	361 C
262	Indore	MP	0.11	0.14	1.3	379	0.3	79	99	56	69	27	69	29	21	100	538 D
263	Lalitpur	UP	0.32	0.34	1.1	266	0.4	65	87	56	74	90	99	70	51	43	309 C
264	Alwar	RA	0.43	0.78	1.8	298	0.6	74	91	56	83	59	53	86	62	100	395 C

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																											
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Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																
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Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains													
		Total				Irrigation				Other data					
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	CWU
			M ha	Mt	tonne/ha	mm	kg/m ³	%	%	- % of total CWU	- % of total	- % of area	- % of NSA	- % of GCA	- % in rain-fed grain area
319	Gangangar	RA	0.84	1.54	1.8	294	0.6	94	97	73	91	44	54	58	59
320	Kheri	UP	0.43	1.08	2.5	378	0.7	80	51	74	86	59	63	72	69
321	Etawah	UP	0.40	0.96	2.4	371	0.6	81	68	74	87	86	87	82	72
322	South Arcot	TN	0.38	1.12	2.9	570	0.5	90	67	74	90	57	67	63	72
323	Jaunpur	UP	0.41	0.83	2.0	368	0.6	82	63	75	87	90	89	78	75
324	Thanjavur	TN	0.69	1.75	2.6	557	0.5	95	75	75	90	88	90	88	73
325	Karimnagar	AP	0.43	1.17	2.7	516	0.5	87	56	75	91	79	76	72	78
326	Etah	UP	0.44	1.00	2.3	320	0.7	79	71	75	87	85	84	88	76
327	Pulwama	JK	0.04	0.05	1.4	409	0.3	93	75	76	78	48	52	62	69
328	Hardoi	UP	0.57	1.17	2.1	350	0.6	82	69	76	88	85	90	79	71
329	Rohtas	BI	0.61	1.32	2.2	410	0.5	87	47	76	84	98	89	98	84
330	Gaya	BI	0.25	0.38	1.5	431	0.4	85	40	76	85	97	100	65	74
331	Barabanki	UP	0.35	0.76	2.2	407	0.5	83	54	77	88	77	76	84	78
332	Aligarh	UP	0.61	1.46	2.4	316	0.8	80	73	77	89	80	79	99	79
333	Gwalior	MP	0.20	0.38	1.9	369	0.5	87	80	77	86	84	98	72	66
334	Unnao	UP	0.39	0.76	1.9	359	0.5	85	70	77	89	88	89	88	76
335	Cuddapah	AP	0.11	0.21	1.9	553	0.4	93	78	77	92	25	48	40	40
336	Nainital	UT	0.28	0.76	2.7	391	0.7	86	40	77	88	79	76	83	81
337	Pasumpon	Muthuramalingam	TN	0.09	0.18	2.2	542	0.4	92	67	78	92	73	83	70
338	Partapgarh	UP	0.32	0.60	1.8	395	0.5	83	63	78	89	94	96	80	77
339	Nellore	AP	0.29	0.74	2.6	586	0.4	94	78	78	93	77	70	73	86
340	Tikamgarh	MP	0.22	0.32	1.4	356	0.4	85	93	78	86	53	93	75	45
341	Katihar	BI	0.19	0.32	1.7	395	0.4	87	28	79	86	68	89	63	60
342	Mathura	UP	0.32	0.80	2.5	323	0.8	83	83	79	89	73	77	98	75
343	Bundi	RA	0.23	0.41	1.8	464	0.4	87	86	79	94	57	67	74	68
344	Trissur (Trichur)	KE	0.04	0.09	2.3	510	0.5	84	40	79	84	20	59	51	27
345	Srinagar	JK	0.02	0.03	1.8	412	0.4	96	83	80	82	60	65	72	74

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

ID	Districts ¹	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains														
		Total					Irrigation					Other data				
		State	Area	Prod uction	Yield	CWU	WP	CWU	NET	Area	Prod uction	Grian	NIA	GIA	GWIRA	CWU
			M ha	M Mt	tonne/ha	mm	kg/m ³	%	%	- % of total CWU	- % of total	- % of area	- % of NSA	- % of GCA	- % of irrigated area	- % in rain-fed grain area
346	Chhatrapur	MP	0.34	0.34	1.0	301	0.3	88	88	80	88	85	99	45	69	53
347	Gazipur	UP	0.37	0.75	2.0	392	0.5	86	56	81	91	91	93	81	79	78
348	Varanasi	UP	0.46	0.99	2.2	408	0.5	87	57	81	91	89	92	83	79	47
349	Tirunelveli	TN	0.11	0.36	3.4	457	0.7	94	64	82	93	60	68	69	73	46
350	Aurangabad	BI	0.24	0.46	1.9	486	0.4	93	61	82	89	90	89	95	83	19
351	Hoshiarpur	PU	0.27	0.89	3.3	329	1.0	89	52	82	91	73	78	73	77	84
352	Lucknow	UP	0.17	0.32	1.9	377	0.5	87	64	82	91	74	74	87	82	79
353	Rae Bareli	UP	0.38	0.73	1.9	407	0.5	88	62	83	92	90	92	84	81	54
354	Nawada	BI	0.15	0.28	1.8	412	0.4	89	45	83	89	97	94	84	85	44
355	Gurdaspur	PU	0.44	1.69	3.8	367	1.0	93	55	83	92	86	86	72	84	91
356	Faridabad	HA	0.20	0.65	3.3	343	1.0	90	83	83	95	75	75	76	83	79
357	Nalanda	BI	0.24	0.48	2.0	404	0.5	90	51	84	90	95	98	85	82	68
358	Haora	WB	0.12	0.27	2.2	479	0.5	85	29	85	88	69	93	46	63	9
359	Ambala	HA	0.20	0.65	3.2	397	0.8	91	52	85	95	84	85	81	84	87
360	Mainpuri	UP	0.27	0.68	2.5	370	0.7	90	67	86	93	88	87	94	87	76
361	Moradabad	UP	0.52	1.35	2.6	375	0.7	90	65	86	94	64	66	82	84	98
362	Rohtak	HA	0.34	0.90	2.7	349	0.8	91	81	86	96	75	78	87	83	27
363	Rupnagar	PU	0.17	0.60	3.4	364	0.9	88	56	87	94	81	82	80	86	84
364	Pudukkottai	TN	0.10	0.31	3.1	601	0.5	96	69	87	95	62	86	63	63	22
365	Saharanpur	UP	0.20	0.50	2.6	354	0.7	95	62	87	94	45	46	91	85	82
366	Hisar	HA	0.55	1.94	3.5	320	1.1	95	92	87	96	57	54	87	93	19
367	Jehanabad	BI	0.15	0.28	1.9	443	0.4	92	46	87	92	90	89	100	89	51
368	Hoshangabad	MP	0.49	0.80	1.6	401	0.4	93	92	89	93	56	93	73	53	29
369	Kanniyakumari	TN	0.03	0.14	4.1	502	0.8	97	59	89	96	34	70	35	42	6
370	Faizabad	UP	0.48	1.07	2.2	412	0.5	92	53	89	95	87	89	91	87	88
371	Kodagu	KA	0.04	0.09	2.2	491	0.5	92	39	89	96	34	85	2	35	0
372	Chittoor	AP	0.10	0.23	2.2	609	0.4	97	76	89	97	21	44	42	43	66

(Continued)

Annex Table 1. Water productivity variations across districts in India (*Continued*).

Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains																																																																																																																																																																																																																																																																																																																																																																																																											
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			Area	Prod uction	Yield	CWU	WP	CWU		NET	Area	Prod uction	Grian area	NIA	GIA	GWIRA	CWU	CWU	in	rain-fed																																																																																																																																																																																																																																																																																																																																																																																							
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(Continued)

Annex Table 1. Water productivity variations across districts in India (Continued).

ID	Districts ¹	State	Total and Irrigated area (Million ha), production (Million mt), CWU (km ³), NET and WP (kg/m ³) of grains															
			Total				Irrigation				Other data							
			Area	Prod	Yield	CWU	WP	CWU	NET	Area	Prod	Grian	NIA	GIA	GWIRA	CWU	CWU	
				uction				- %	- %	- %	of	- %	- %	of	- %	- %	of	in
Total or average (% grain irrigated area >25%)																		
CWU < 225 mm																		
225 mm < CWU < 300 mm																		
225 mm < CWU < 475 mm																		
475 mm < CWU																		
Total or average																		

¹ Districts are sorted in terms of increasing percentage of irrigated grain area