СЕЛЬСКОХОЗЯЙСТВЕННЫЕ НАУКИ

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ASSESSING GREEN AND BLUE WATER UTILIZATION IN WHEAT PRODUCTION OF TAJIKISTAN: A SURVEY OF REGIONS, 1980-2015

ОЦЕНКА ПОТРЕБЛЕНИЕ ЗЕЛЕНОЙ И ГОЛУБОЙ ВОДЫ В ПРОИЗВОДСТВЕ ПШЕНИЦЫ В ТАДЖИКИСТАНЕ: ОБЗОР РЕГИОНОВ, 1980-2015

Abstract. The water footprint (WF) of national wheat production has been previously estimated for Tajikistan in regional (Central Asia) and global-scale studies. However, due to the large scale, these reports may provide a general view of the country's wheat production water usage, which cannot fully identify the regional demand on water resources. The aim of this study is to estimate the green and blue WF and the total water use of wheat irrigated crop in Tajikistan (1980-2015). The results were evaluated by comparison with previous documented results for the WF of wheat production in Tajikistan. We compared the water use for product (t/ha) among four regions and analyzed the water consumption by dehkan (peasant) farms, households and agriculture enterprises in 2015. The national average WF of wheat production for the period 1980-2015 were approximately 990.6 Mm3/yr (34.3% green and 65.7% blue). There is a notable difference in the WF among different regions: the WFP is low in the eastern region, while it is relatively high in the Khatlon region i.e. in southern Tajikistan. The major portion of WF (61.4%) comes from dehkan farms, while agriculture enterprises with households are share 39.6% of the country total water utilization. Blue water (BW) dominates in the four regions, whereas highest BW proportions are found in the districts located in central and eastern Tajikistan. Productivity plays an important role in food production by reducing the WF wheat production. Due to the low irrigation efficiency, more water is needed per-hectare in farmlands of Sughd region.

Аннотация. Водный след (ВС) национального производства пшеницы был предварительно оценен для Таджикистана в региональных (Центральная Азия) и глобальных исследованиях. Однако из-за большого масштаба эти отчеты могут дать общее представление об использовании воды для производства пшеницы в стране, которое не может полностью определить региональный спрос на водные ресурсы. Целью данного исследования является оценка зеленого и синего ВС и общего водопотребления орошаемых культур пшеницы в Таджикистане (1980-2015). Результаты были оценены путем сравнения с предыдущими документально подтвержденными результатами для ВС производства пшеницы в Таджикистане. Мы сравнили водопользование для продукта (т/га) между четырьмя регионами и проанализировали потребление воды дехканскими (крестьянскими) фермами, домашними хозяйствами и сельскохозяйственными предприятиями в 2015 году. Среднегодовой национальный показатель производства пшеницы за период 1980-2015 составил приблизительно 990,6. Мм3 / год (34,3% зеленого и 65,7% синего). Существует заметная разница в ВС между различными регионами: ВС низка в восточном регионе, в то время как она относительно высока в Хатлонской области, то есть на юге Таджикистана. Большая часть ВС (61,4%) поступает из дехканских хозяйств, в то время как сельскохозяйственные предприятия с домашними хозяйствами составляют 39,6% от общего водопотребления в стране. Голубая вода (ГВ) доминирует в четырех регионах, тогда как самые высокие пропорции ГВ обнаружены в районах, расположенных в центральном и восточном Таджикистане. Производительность играет важную роль в производстве продуктов питания за счет сокращения ВС производства пшеницы. Из-за низкой эффективности орошения требуется больше воды на гектар сельскохозяйственных угодий Согдийской области.

Keywords: Water Footprint, Households, Collective Farms, Agriculture Enterprises, Tajikistan.

Ключевые слова: Водный след, Хозяйства населения, Дехканские хозяйства, Сельхоз предприятия, Таджикистан.

Introduction

Wheat as a stable source of food is historically the most important crop, which is largely consumed by the country's population in Tajikistan [1]. According to national statistics, the consumption of bakery products is defined as 155 kg/person and the demand over the past 20 years has increased by 12% [2]. The problem of satisfying the population's need for food is one of the priorities in terms of ensuring food security, which is what the policy of the Government of the Republic of Tajikistan is oriented to after independence [3,4]. Over the past 25 years, the sown area throughout the country has increased by almost 1.2 times, and the crop occupies 84% of the total grain area. Along with the expansion of the area, there is also an increase in grain production, but the yield largely depends on the climatic characteristics of the year, and the national average varies from 1.4 to 2.1 t/ha [5,6].

Tajikistan by its surface character is typically a mountainous country with absolute elevations from 300 to 7495 meters, 93 percent of its territory is occupied by mountains belonging to the highest mountain systems of Central Asia, the Tien Shan and Pamir. The climate of Tajikistan is determined by its geographical position within the subtropical and temperate zones. Its characteristic features are high intensity of solar radiation, aridity, low cloud cover, long duration of sunshine, sharp fluctuations in daily and seasonal temperatures. Agriculture is the largest water user in Tajikistan, accounting for more than 80% of the total water withdrawal [7]. Meanwhile, irrigated agriculture is the most productive sector of agricultural production. The yield of irrigated wheat is greater than that of naturally moistened land for rainfed wheat [8]. The growth rate of irrigated agricultural land under wheat is significant in the arid zone of central and southern Tajikistan. The main consumers of water are agricultural enterprises and collective farmers. However, in the Khatlon region, where the majority of the rural population lives, household water consumption is higher than that of collective farmers. Currently, due to the backwardness in technology and poor management, agricultural irrigation water is used with low efficiency and is significantly wasted [9,10]. It is important to reduce the use of water in crop production to solve the problems of fresh water that Tajikistan may face in the future [11,12].

Water footprint (WF) is an approach/method for assessing water use in agricultural production [13]. The WF of a crop product is defined as the volume of water consumed in the crop process. WF consists of three components: green, blue and gray water. Green and blue water (GW and BW) refers to the efficient consumption of rainfall and irrigation, and gray water can be defined as an indicator of water pollution by fertilizers and pesticides. The total WF is the volume of direct and indirect use of water resources, and the GW and BW of one production reflect the regional efficiency of water apply [14].

Based on the growing season, wheat can be divided into spring and winter species. Winter wheat is planted in most regions of Tajikistan, and spring wheat mainly in the Badakhshan region. Several scholars quantified and analyzed the wheat WF in Tajikistan [13,15]. However, due to the large scale, these reports may provide a general view of the country's wheat production water usage, which cannot fully identify the regional demand on water resources.

In this study, we focused on the WF of spring and winter wheat (irrigated). The main objective was to assess the regional use of GW and BW in wheat production from the perspectives of WF. In addition, we aimed to estimate the volume of water consumption among land owners/types (i.e. households, collective farmers and agricultural enterprises) in four regions of the country.

2. Materials and Methods

2.1 Study area

The research area is focused on all four regions of the country, namely: Khatlon, Sughd, Districts of Republican Subordination (DRS) and Badakhshan (Fig. 1). The climate of the regions is classified as dry subtropics. Winters are mild and short, with the exception of the Badakhshan region, where winters are severe and long. The regions are advanced in agriculture, and wheat is one of the three (cotton and potato) most important crops.

2.2. Data collection

Statistical data on the annual crop yield, productivity and total seeded area (1980-2015), as well as on the distribution of agricultural land between households, collective farmers and agricultural enterprises in four regions, were referenced from the country statistical yearbooks (FIG. 2) [5,6]. Crop coefficients (Kc) [16], planting and harvesting dates for the different regions (Table 1) are obtained from FAO [17]. The meteorological data on temperature, precipitation (1980-2000), humidity, wind speed and sunshine (SD) duration (2000-2015) of four regions for 1980–2015 were provided by the National Hydrometeorology Agency (NHA) (http://meteo.tj). The average annual crop yield, productivity and total seeded area of four regions for 1980-2015 are illustrated in FIG. 2.

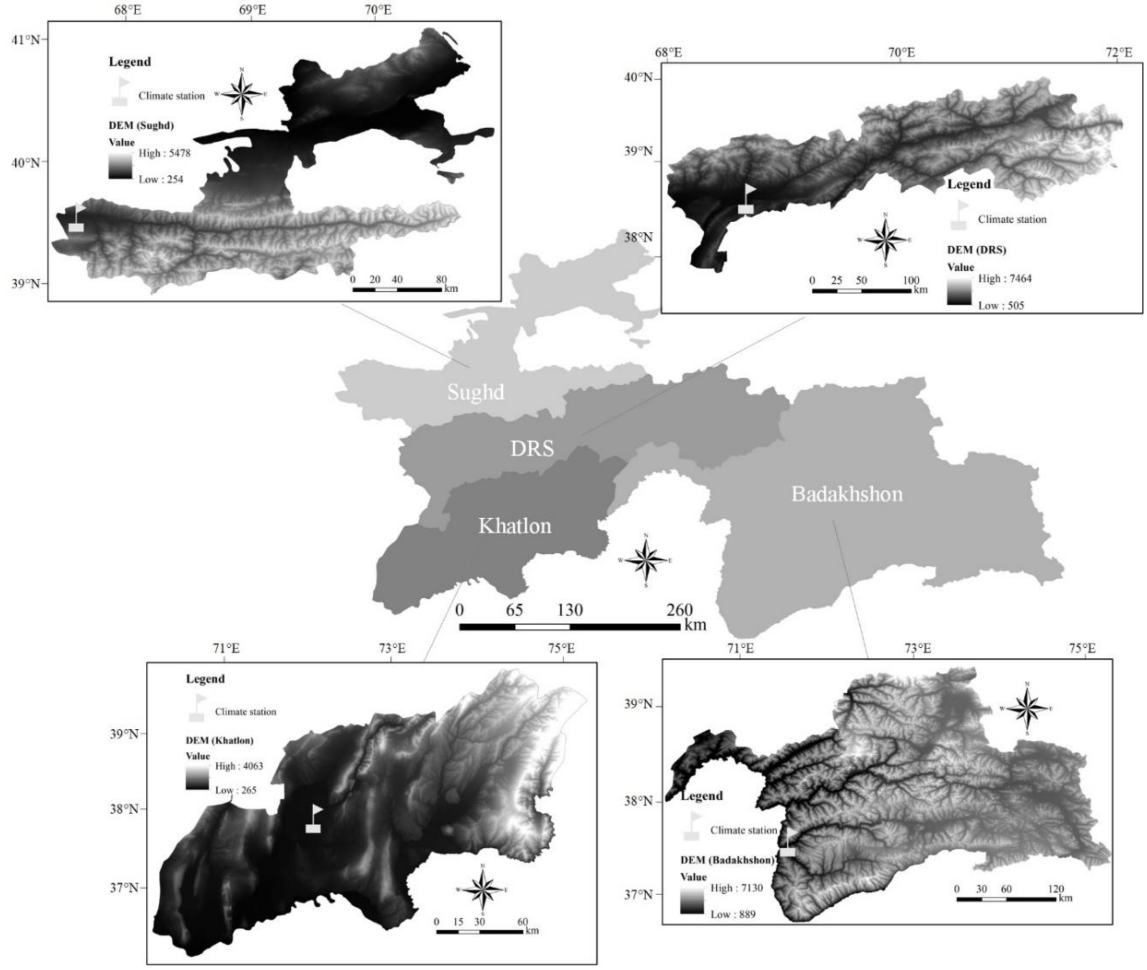

FIG. 1. Locations, terrain elevations and climate station locations of the four administrative divisions in Tajikistan.

2.3. Perfomance of the crop water requirements

The crop water requirements (CWRs) is the key component for calculating production WF. To simulate the CWR of winter and spring wheat, the CROPWAT model-decision support tool was used [18]. For the daily reference evapotranspiration (in CROPWAT), the Penman-Monteith equation was utilized [19]. The total CWR, effective rainfall (ER) and irrigation requirements (IR) in regions have been calculated using the CROPWAT model according to the crop phenology and Kc (from FAO)[20]. The calculations were performed (separately) using climatic data from four stations.

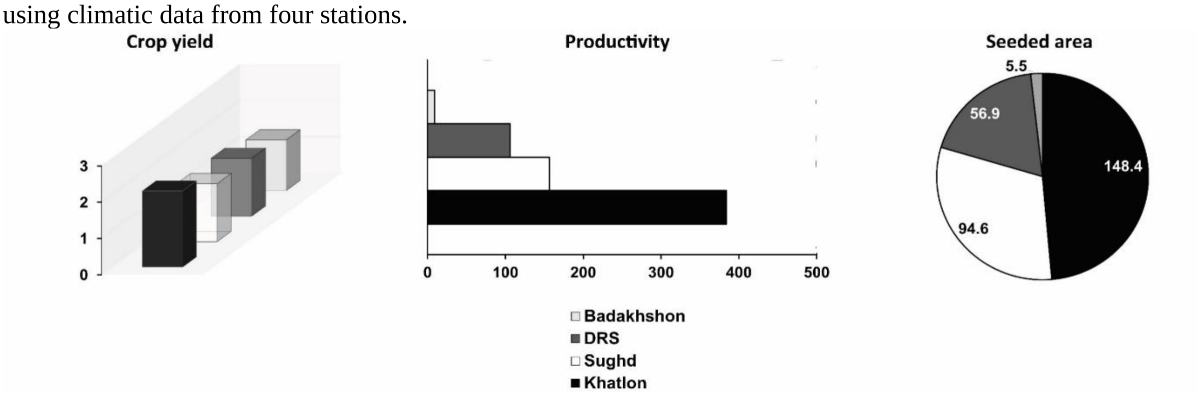

FIG. 2. The average annual crop yield (t/ha), productivity (1000/t) and total seeded area (1000/ha) of four regions for 1980-2015.

2.3.1 Water Footprint estimation

The GW and BW of winter and spring wheat production were calculated using the methodology described by Hoekstra et. al., 2011[14]. The GW of the crop (m^3/ton) has been calculated as the ratio of the GW use (GWU) (m3/ha) to the crop yield (Y) (ton/ha), where total GWU is obtained by summing up green water evapotranspiration (greenETo) over the growing period. GWU is calculated based on the CROPWAT model outputs, as the minimum of crop evapotranspiration (ETc) and ER with a time step of ten days.

$$WF_{Product} = \sum \begin{cases} WF_{green} = \frac{GWU}{Y} = 10 * \frac{ETo_{green = MIN\,(ETc\,\&\,ER)}}{Y} \\ WF_{blue} = \frac{IWR}{Y} = 10 * \frac{ETo_{blue} = \sum(IR)}{Y} \end{cases}$$

The blue water (BW) of the crop considered to be equal to the ratio of the volume of irrigation water consumed/requirement (IWR) to the Y. The IWR is taken equal to the IR as estimated with the CROPWAT model. When the ER is greater than the CWR the IR is equal to zero. The total evapotranspiration of irrigation water is obtained by summing up the blue water evapotranspiration (blueETo) over the growing period. CWRs are assumed to be always fully satisfied[21]. In addition, the total WF of product has been estimated by summing the green and blue components.

Table 1.

Regional WF of wheat production (1980-2015)

Region	CWR mm	Yield t/ha	GW m3/t	BW m3/t	WF m3/t
Khatlon	716	2.1	917	2693	3610
Sughd	463	1.6	1316	1582	2898
DRS	699	1.6	1800	2573	4373
Badakhshan	352	1.4	358	2161	2519
Average	557	1.7	1098	2252	3350

Results and Discussion

The WF of wheat were simulated with CROPWAT. For the all four stations, due to the lack of climatic data, for the period of 1980-2000, reference evapotranspiration was calculated from temperature (other data estimated) data. On the other hand, for the period 2000-2015, ETo Penman was calculated from climatic (including temperature, humidity, wind speed and sun duration) data. For the planting and harvesting dates, we opted to choose 15th October and 10th Jun respectively. However, due to the long and cold winters, majority in the eastern districts grow spring wheat. Therefore, the planting and harvesting dates in Badakhshan (only/alone) opted to be 25th March and 5th August, respectively.

The calculated national WF value in this study was compared to that reported in the literature. The WF, CWR, Y, proportion of GW and actual irrigation of wheat in previous studies, which was calculated at the country scale are listed in the Table 2. Chapagain and Hoekstra (2004)[13] obtained a WF of approximately 6629 m3/t, which is much higher than that in any other study. The WFP of wheat from 1997 to 2001 can be higher because of the low Y. The WF in this report was 3350 m3/t, which is approximately the same as the WF of the wheat product as estimated by Aldaya and Hoekstra (2010)[15]. The national wheat Y increased overtime in the last two decades and reached up to 2.9 t/ha in 2015. The national CWR of wheat ranged from 357 to 716 mm (with the average of 557 mm) which is agree with Aldaya and Hoekstra (2010).

Table 2.

Comparison of this study with documented results for the WF of wheat production in Tajikistan.

Reference	WF m3/t	Yield t/ha	CWR mm	Proportion of GW	Irrigation m3/ha
This study	3350	1.7	557	32.8%	-
Government of Tajikistan 2017	-	2.9	-	-	2200
Aldaya & Hoekstra 2010	3931	1.4	552	45.5%	-
FAO & EBRD 2006	-	1.8	-	-	3500
Chapagain & Hoekstra 2004	6629	1.1	779	-	-

Similar to our study, Aldaya and Hoekstra (2010) also applied the CROPWAT model but did not include Badakhshan inputs. Among the previous studies, only this study distinguished between the GW and BW. Thus, the proportions of GW at the country scale in that report was approximately 45.5%, which is 690 m3/t higher. Our CWR proportion was lower than (28.7%) the values from Chapagain and Hoekstra (2004). It is necessary to note that the reports of the government on actual irrigation in wheat production may be counted as BW[22]. However, only BW value cannot fully represent the amount of water utilization in wheat production. On the other hand, the results of FAO & EBRD (2006) can be counted as an overestimated[23].

3.1 Water Footprint of wheat production

In the period of 1980-2015, the average national WF of wheat production can be considered approximately 990.6 Mm^3/yr. The average annual water consumption for 4 regions is shown in FIG. 3. During the period of 45 years, the spatial difference of the WF was obvious among all of the regions of Tajikistan. A region with large WF values is concentrated in the Khatlon, while that with low WF values aggregated in east of the country. Approximately 65.1% of the wheat product and 50.8% of the WF are contributed by the southern region in contrast to 1.6 and 1.2% by the eastern. The average WFs of Khatlon, Sughd and DRS are estimated for 501.0, 262.6 and 213.7 Mm^3, respectively. These three regions together contribute to 98.1% of the national total sown area, 98.3% of the wheat production, and 98.7% of the wheat production-related WF. Consequently, Badakhshan constitutes only 1.9% of the national seeded area.

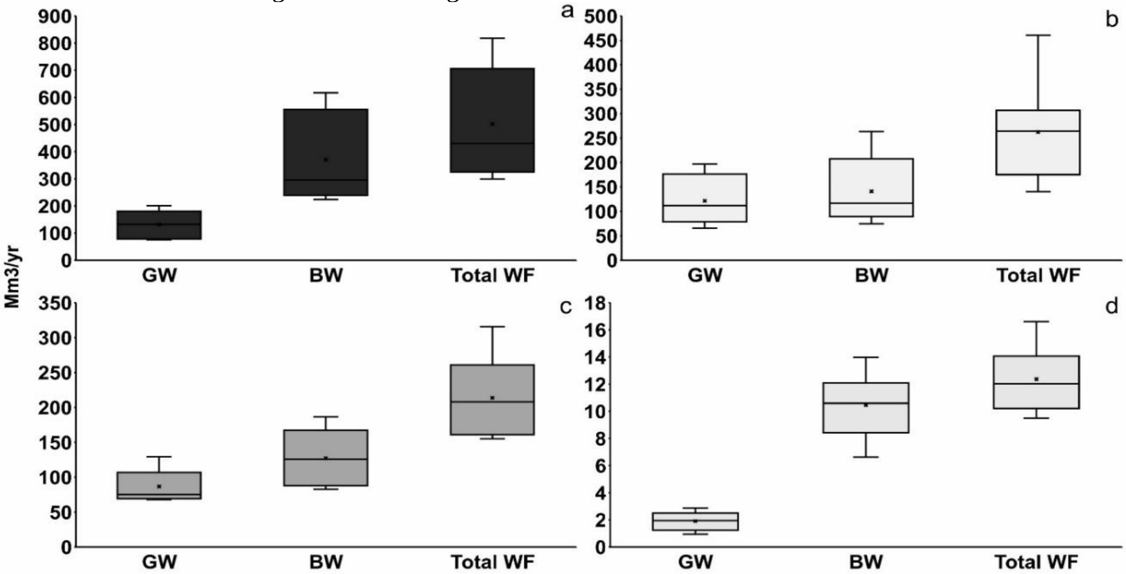

FIG. 3. The green, blue and total WF of wheat production in Khatlon (a), Sughd (b), DRS (c) and Badakhshan (d) for the period 1980-2015.

The average national GW in wheat cultivation during period 1980-2015 was calculated to be 340.1 Mm3/yr. The largest GW was observed for Khatlon (131.3 Mm3/yr) and Sughd (121.7 Mm3/yr). These two regions together account for 74.1% of the total BW related to wheat production. The GW in DRS estimated to be 86 Mm3/yr, and the smallest GW were in eastern Tajikistan (1.3 Mm3/yr). The average BW related to wheat production was 648.4 Mm3/yr in the studied years. The largest BW in wheat cultivation was also found in Khatlon (370.0 Mm3/yr). Sughd and DRS BW, calculated to be 141.1 and 127.1 Mm3/yr, respectively. These two regions alone account for approximately 41.3% and Khatlon for 57% of the national BW related to wheat production. The region with small GW and BW in wheat production is Badakhshan. The results of GW and BW also shown in FIG.3.

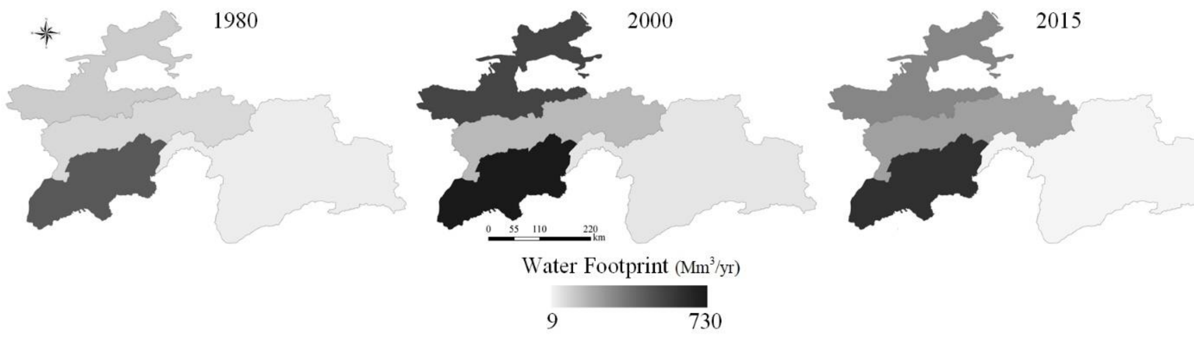

FIG. 4. Consumption of total WF in wheat production in the regions of Tajikistan by years.

The national average WFP in 1980, 2000 and 2015 was 638.3, 1267.6 and 847.9 Mm3 respectively. The results (in Fig.4.) demonstrate a great variation among regions. Badakhshan region is lower in WFP, while Sughd have a lower water-use efficiency (13.5%). These two regions together produced 73, 162 and 317 thousand ton of wheat, accumulatively contributing to 27.1, 30.5 and 22.8 percent of the total output of

Tajikistan in 1980, 2000 and 2015 respectively. Thus, increasing harvest from the regions with low WF improves the water productivity (WP) of the country. In contrast, Khatlon and DRS, averagely have a WF greater than 3350 m3/t. Khatlon is the largest wheat producer of Tajikistan and one of the most promising and pressing regions reducing the WF. In Khatlon the WF of wheat production was 3603, 4488 and 1792 m3/t in 1980, 2000 and 2015. The total WF of wheat production for the 1980, 2000 and 2015 are illustrated in FIG.4.

3.2 Water utilization among land owners/types

The importance of wheat for dehkan (peasant) farms is clearly seen from Table 3, which presents the wheat production structure for farms of each type separately. Thus, total production of wheat account for 17% in farm enterprises, 60% in dehkan farms, and fully 23% of sown area in household plots.

Table 3

Wheat production structure by different farm types (2007-2015).

Regions	Total	Farm types		
		Enterprises	Householders	Dehkan farms
	ha	%	%	%
Khatlon	190204	12.9	35.6	51.5
Sughd	53849	16.9	17.7	65.4
DRS	69322	20.9	24.9	54.2
Badakhshan	4685	19.2	12.6	68.2

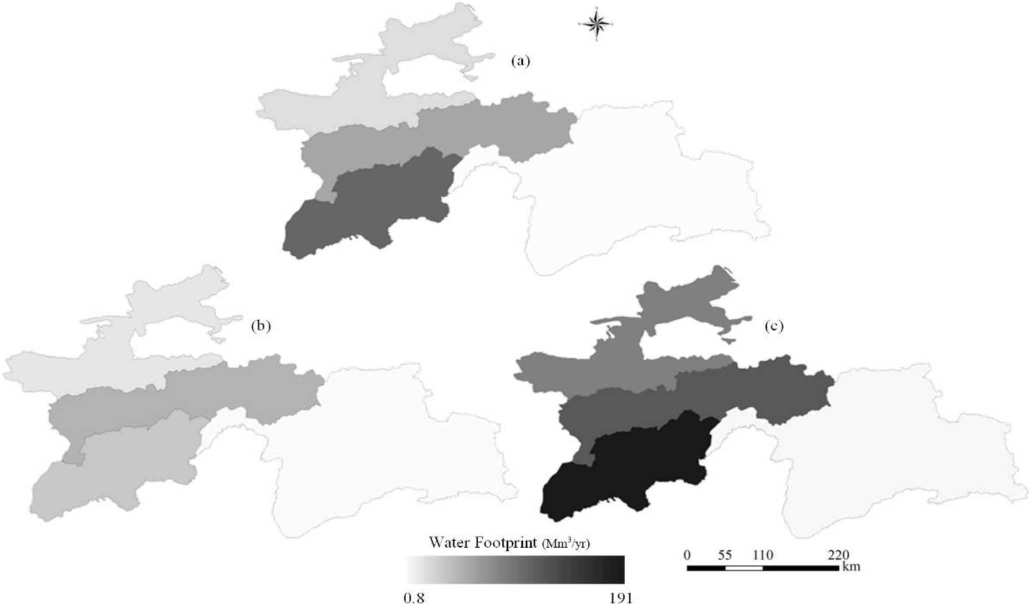

FIG. 5. Distribution of WF in wheat production for the households (a), agriculture enterprises (b) and dehkan farms (c) in the regions of Tajikistan for 2015.

Distribution of WF in wheat production among land owners/types in four regions of Tajikistan for 2015 is demonstrated in FIG. 5. The WF of wheat production, in 2015, was mainly consumed by dehkan farms (DF). For the four regions the WF of DF ranged from 4.1 to 190.7 Mm^3/yr. About 98.8% of the total DFs WF related to wheat production is related to Khatlon (54.4%), DRS (26.6%) and Sughd (17.8%) regions. Similar, for households, the lion's share of the WF was calculated to be in the Khatlon (62.3%) region. Agriculture enterprises (AE) with households share 39.6% of the country total water utilization. The largest WF among AE belongs to the DRS (37.5 Mm^3/yr). The remainder of regions along estimated to be 49.2 Mm^3/yr.

4. Conclusion

CROPWAT model was applied in this study to estimate the WF of regions, along the volume of water consumption among land owners/types. The results were evaluated by comparison with previous documented results for the WF of wheat production in Tajikistan. Results reviled that estimating the WFs crops at a global or national scale frequently suffer from limitations in terms of data availability and quality. Therefore, by accounting the winter and spring wheat at the microscale (regional), the WF of wheat production in Tajikistan was estimated. The results of BW in this study was comparable to those reported by government. However, some previous reports on WF of wheat production can lead to biased estimates of total volumes of this crop water usage. Also, this study agrees with some previous studies in terms of the CWR importance of water-use efficiency in Tajikistan's wheat production. In addition, estimated WF of wheat production was mainly related to dehkan farms. Whereas the Khatlon region consider to be a primary consumer. In contrast, Badakhshan accounts for the lowest consumption of the country's total WF related to wheat production. Although we admit that the accuracy of our results is subject to the quality of the input data, it is difficult to attribute the differences in assessments of various studies to specific factors and evaluate the quality of our new assessments relative to the quality of previous estimates.

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