GLOBAL CROPLANDS AND THEIR WATER USE—ADVANCED REMOTE SENSING METHODS AND APPROACHES

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ABSTRACT:

The paper provides a comprehensive review of global croplands and their water use. Global cropland (irrigated plus rainfed) areas increased from 265 Mha in year 1700 to about 1.5 Mha in year 2000. Major studies agree in their estimate of total croplands as about 1.5 billion hectares for nominal year 2000. However, these studies differ significantly in correct estimates of: (a) irrigated versus rainfed croplands, and (b) precise geographic location of these croplands.

Globally, only about 7 percent (3798 km^3\yr) of the available renewable water (54,695 km^3\yr) is currently withdrawn (but not necessarily used) by irrigated croplands. Typically, 1.6 to 2.5 times water actually required (equivalent to water used for optimal growing conditions) is actually withdrawn- so, only 40-60 percent irrigation efficiency. Results showed highly uneven spatial distribution in water availability and water withdrawal for irrigation around the world.

1. INTRODUCTION

Croplands are water guzzlers, taking anywhere between 60-90% of all human water use in the World. Throughout the World, agricultural water use is now competing with municipal, environmental, and ecosystem water requirements for priority. State and regional governments are buying out water rights of farmers to help sustain water production for other uses. Already, global change is putting unprecedented pressure on croplands and their water use for ensuring future food security for all. Cropland areas have nearly stagnated, yield per unit area have plateaued, population is increasing, steadily, every year, croplands are lost to biofuels, salinization, urbanization), and bio-fuels are taking croplands away from food production, and nutritional transition is raising the calorie intake swiftly in emerging markets due to economic change. With the world's food stocks fast dwindling (FAO, 2009), a need for systematic understanding of cropland distribution and their water use is critical than ever before. It is now becoming clear that continuous food crisis will be new global norm unless international agricultural research and investment efforts are directed to find long term solutions.

2. METHODS AND APPROACHES

In the past, irrigated and rainfed cropland areas were estimated, rather coarsely, in global land use classifications (Thenkabail et al., 2009a) derived from remote sensing, which usually focused on other objectives, such as LULC, forestry, rangelands and rain-fed croplands. Most remote sensing work at regional level produced LULC maps and not specific thematic maps like croplands.

More recently, irrigated **c**ropland mapping has become feasible by integrating agricultural statistics and census data from the National systems, and spatial mapping technologies involving geographic information systems (GIS). As a result, there are 3 main irrigated cropland maps and\or statistics of the United States for nominal year 2000. These are:

1. Thenkabail et al. (2009a, 2009b)- Figure 1;
2. Siebert and Döll, 2009; and
3. Ramankutty et al., 2008;

Global cropland mapping has become feasible by integrating agricultural statistics and census data from the National systems, and spatial mapping technologies involving geographic information systems (GIS) (Ramankutty et al., 2008). More recently, the availability of advanced remote sensing data along with secondary data and recent advances in data access, quality, processing, and delivery have made remote sensing based cropland estimates at global level possible (Thenkabail et al., 2009a, 2009b; Figure 1). The specific remote sensing advances enabling global cropland mapping and generation of their statistics include factors such as: (a) free access to well calibrated and guaranteed data such as Landsat and MODIS; (b) frequent temporal coverage of data such as MODIS backed by high resolution Landsat data; (c) free access to high quality secondary data such as long-term precipitation, evapotranspiration, surface temperature, soils, and GDEM; (d) global coverage of data; (e) web-access and broad band; (f) advances in computer technology and data processing.

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3. RESULTS AND DISCUSSIONS

Global cropland (irrigated + rainfed) areas increased from 265 Mha in year 1700 to about 1.5 Mha in year 2000. Major cropland area studies (Portmann et al., 2009; Ramankutty et al., 2008; Siebert and Döll, 2009; Thenkabail et al., 2009a; Thenkabail et al., 2009c) estimate total croplands (irrigated + rainfed) as about 1.5 billion hectares for nominal year 2000. So, by year 2000, agriculture covers about 10% of the world's terrestrial surface (148,940,000 Km^2).

3.1 Global Rainfed Croplands

About 70 percent of all incoming precipitation is stored as green water (unsaturated zone of soils). Rainfed croplands depend on this water for growth and food production. Rainfed croplands produce about 55 percent of the world's food from 75 percent (1.13 billion hectares; Thenkabail et al., 2009a) of the cropland areas. Rainfed croplands, even though far less productive than irrigated areas, are the main source of livelihood of subsistence farmers and are the focus areas of future crop and water productivity increases. They are also considered environmentally friendlier given the problems of salinization and soil degradation in irrigated cropland areas.

3.2 Global Irrigated Croplands

Irrigated areas consume about 80 percent of all blue water (water in rivers, reservoirs, lakes, and aquifer ground water) used by humans. It also produces nearly 45% of all food in the world from just about 25 percent (399 million hectares; Thenkabail et al., 2009b) of the cropland areas. So, the importance of irrigated cropland in water and food security is very high.

Rank based on Total IWMI GIAM cropland areas	Country	Croplands: irrigated	Croplands: irrigated	Croplands: irrigated	Croplands: irrigated	Croplands: irrigated	Croplands: rainfed	Croplands: irrigated	Croplands: rainfed	Croplands: rainfed + irrigated	Croplands: rainfed + irrigated
		Thenkabail et al. 2009a, 2009b	Thenkabail et al. 2009a, 2009b	Thenkabail et al. 2009a, 2009b	Thenkabail et al. 2009a, 2009b	Thenkabail et al. 2009a, 2009b	Thenkabail et al., 2009a, Biradar et al., 2008	Siebert and Döll, 2008, 2009	Portmann et al submitted; applied in Siebert and Döll, 2009.	Portmann et al submitted; applied in Siebert and Döll, 2009.	Ramnkutty and Foley, 1998
		Total area available for irrigation or Net irrigated areas	Season 1 irrigated areas	Season 2 irrigated areas	Continuous irrigated areas	Annualized irrigated areas or gross irrigated areas	Total rainfed cropland areas	Area equipped for irrigation	Maximum monthly growing area of rainfed crops	Harvested area of rainfed + irrigated crops	Harvested area of rainfed + irrigated crops
A1	A2	A3	A4	A5	A6	A7	A9	A16	A20	A21	A14
#	Name	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares	Hectares\yr	Hectares\yr
1	China	111988772	75880320	68233355	7688411	151802086	91635702	85655033	72835500	168346500	147070700
2	India	101234893	72612189	53685066	5956598	132253854	48824269	68724872	108352000	184443900	171696820
3	USA	28045478	18182104	4006141	2120942	24309188	133571602	20548479	111394000	131942500	183979540
5	Russia	13886856	8865013	2113783	224734	11203530	114788560	3772922	75288900	79061820	126892130
14	Brazil	4195118	2165151	869365	1051327	4085844	87408556	2820954	45258500	49965470	51341076
6	Argentina	9304258	3601505	1605815	3559092	8766412	34318900	1352379	29027100	30376780	34010544
11	Australia	11865244	2991344	0	2382064	5373409	36758302	2384292	15950000	23603900	30030778
9	Kazakhstan	7227718	4625716	1760606	83362	6469685	31722986	1804753	13517600	15889950	23507754
20	Canada	2658297	1727915	1124721	21616	2874252	34944402	707053	34146900	35060956	42773136
26	Ukraine	2995578	1631677	258515	491607	2381799	28290153	1005120	26733700	27738820	36282376
16	Indonesia	3172879	1221384	716038	1385021	3322443	17573608	7108333	21978300	31533630	54709968
21	France	2399518	1249368	829980	607806	2687153	17648821	1708020	16226300	17934320	19494778
4	Pakistan	14036151	7895566	7302243	761533	15959342	3642557	19344802	2998450	22816730	23634900
18	Spain	3421724	1516815	683698	825310	3025823	15392046	3423510	11499900	14923410	18712148
7	Thailand	6610586	3228550	2209523	1959295	7397368	9931747	6187300	11854100	17702000	17151778
164	Zambia	779	0	0	536	536	16677106	55387	1091760	1126457	5338720
107	Tanzania	47022	33678	7852	5467	46998	16410652	227000	4999840	5868460	5477548
15	Mexico	3854673	1818168	916083	874479	3608730	12497923	5958094	11157800	17204790	38267104
124	Congo, Dem. Rep.	21833	19326	191	857	20375	15815336	7771	6323630	6069421	
56	Poland	351514	268183	185150	779	454111	14424037	83292	12150000	12233292	14790640
	Total for 20 countries (ha)	327318891	209533972	146508125	30000836	386042938	782277265	232879366	632784280	893843106	1045162438
	Global total (ha)	398526952	251760119	173553844	41443717	466757677	1131552272	312384000	949425049	1304733596	1537977307

Table 1. Global Irrigated and Rainfed Cropland Areas for l year 2000 Based on 3 Different Studies

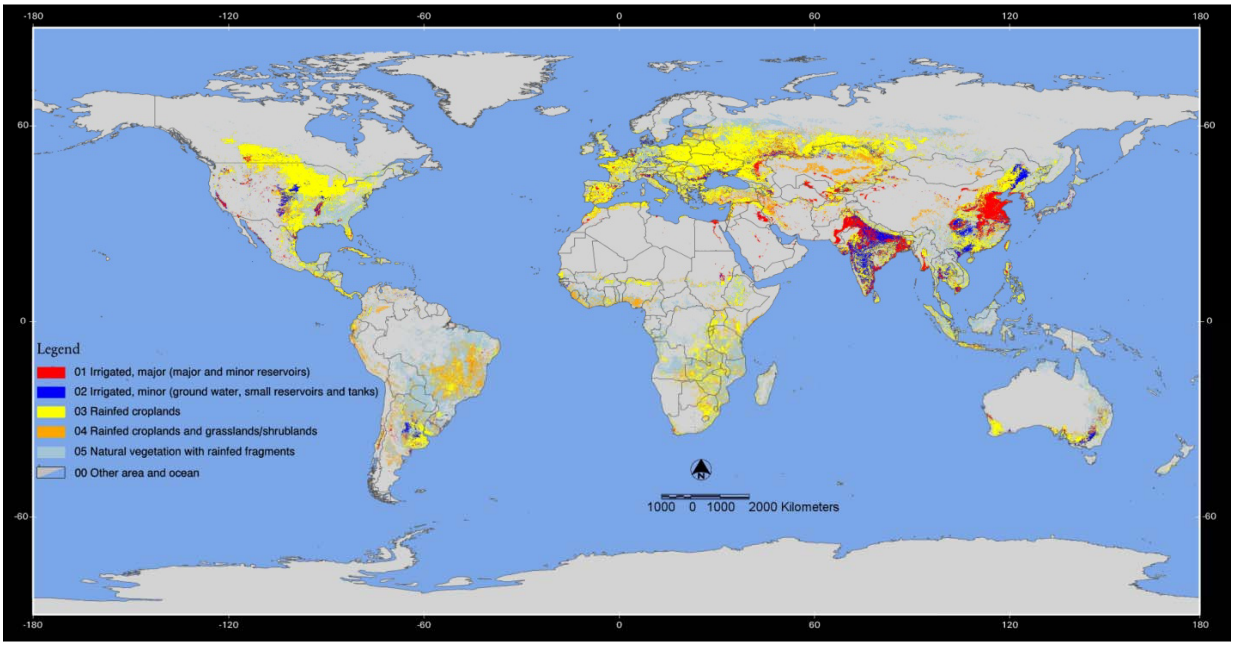

Figure 1. Global cropland map at nominal 1-km resolution using remote sensing for nominal year 2000 (Source: Thenkabail et al., 2009a; 2009c). Total cropland area was determined as 1.53 billion hectares of which 399 Mha was irrigated. Since irrigated areas often have more than 1 crop per year, the total annualized irrigated areas was 467 Mha

3.3 Water Use Assessments

Continued increase in demand for water and recent water shortages have intensified the need for better utilization of our water resources; it has also forced us to think more innovatively about different components of water available in the hydrological cycle, including white, green, and blue water (Falkenmark and Rockström, 2006).

Unfortunately, there is no systematic evaluation of water use by crops. Water withdrawals (Table 2) for irrigation are typically 1.6 to 2.5 times the water use (Table 2) making irrigation efficiency just around 40-60 % (Thenkabail et al., 2010). About 20% of all water used for crops comes from the blue water diversions (from water in lakes, reservoirs, rivers, and ground water in aquifers) irrigating 22-28 Mha annually. There is an additional 10% of water from direct rainfall (green water) over irrigated croplands. The rest, about 70%, of water used by crops is the green water (water in soil moisture in unsaturated zone) used by about 1.13 billion hectares of rainfed croplands. Spatial distribution of water required for irrigated croplands for USA is shown in Figure 2. Management strategies for blue and green water are not the same and the impacts on food security depend synergistically on how blue and green water is managed and for what crops and where.

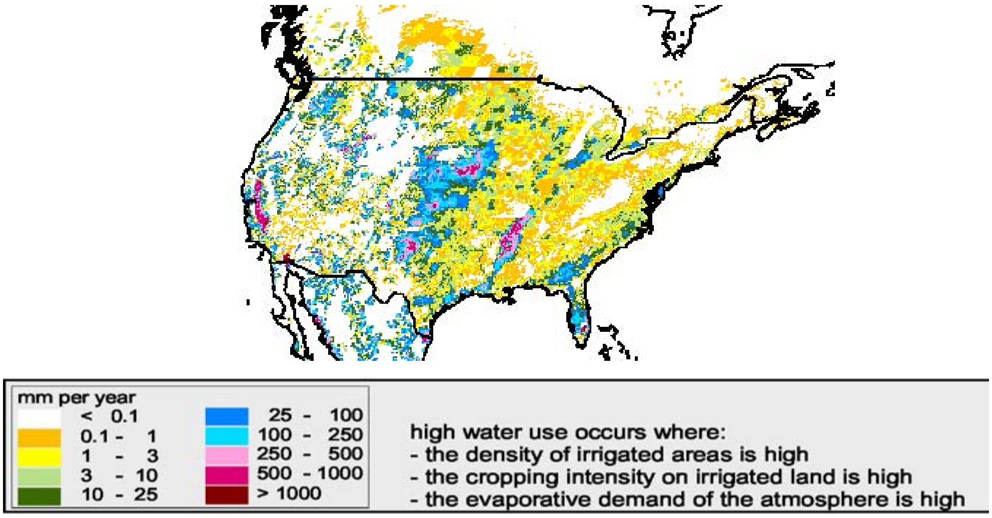

Figure 2. Water use by irrigated crops in the United States. This water use assessment includes blue water use (e.g., reservoirs, deep ground water, lakes, and rivers) plus green water use (water from precipitation falling directly on irrigated lands). [Source: Siebert and Döll, 2008; 2009]

Rank based on Total IWMI GIAM cropland areas	Country	Water: renewable	Water: withdrawl for irrigation	Water: withdrawl for irrigation	Water: requirement (ET) for irrigation	Water Green: requirement (ET) for irrigation	Water blue: requirement (ET) for irrigation	Area of Country
		Glieck et al. 2009	Wisser et al. (2008)	Wisser et al. (2008)	Siebert and Döll, 2009, 2008	Siebert and Döll, 2009, 2008	Siebert and Döll, 2009, 2008	Ramankutty and Foley, 1998
		annual renewable water resources	Total water withdrawl for irrigation based on IWMI GIAM irrigated areas	Total water withdrawl for irrigation based on FAO\UF V4.0 irrigated areas	Blue Water requirement for irrigation based on irrigated areas of FAO\UF V4.0	Green Water availability over irrigated areas based on FAO\UF V4.0	Total (blue + green) water requirement for irrigation based on FAO\UF V4.0	Area
A1	A2	A22	A26	A27	A28	A29	A30	A32
#	Name	km3 \yr	km3 \yr	km3 \yr	km3 \yr	km3 \yr	km3 \yr	Hectares
1	China	2830	755	606	147	257	404	959974780
2	India	1908	1694	844	287	175	462	309375230
3	USA	3069	122.3	141.2	139.1	79.1	218.3	944148610
5	Russia	4498	71.3	17.1	11.6	13.4	25.0	1689619300
14	Brazil	8233	28.1	14.2	8.3	18.0	26.4	852846140
6	Argentina	814.0	47.4	11.1	5.8	5.7	11.5	281208900
11	Australia	398.0	25.0	12.8	13.6	10.9	24.5	784884030
9	Kazakhstan	109.6	40.0	12.7	8.9	3.2	12.1	272919390
20	Canada	3300.0	5.1	2.2	2.7	2.3	5.1	992791680
26	Ukraine	139.5	8.5	11.4	3.5	3.6	7.1	62823012
16	Indonesia	2838.0	46.3	53.4	13.6	43.2	56.8	179527940
21	France	189.0	5.6	4.9	3.2	6.0	9.2	55032184
4	Pakistan	233.8	136.2	414.7	117.0	19.3	136.3	87530040
18	Spain	111.1	13.7	13.1	18.6	9.2	27.8	50116908
7	Thailand	409.9	123.9	124.3	19.1	30.8	49.9	51464260
164	Zambia	105.2	0.0	0.1	0.4	0.2	0.6	74768256
107	Tanzania	91.0	0.2	0.8	1.0	0.8	1.8	91471488
15	Mexico	457.2	36.9	32.0	26.8	24.2	51.0	201567600
124	Congo, Dem. Rep.	1283.0	0.0	0.0	0.0	0.1	0.1	0
56	Poland	63.1	0.7	0.3	0.1	0.3	0.4	31557156
	Total for 20 countries (km3 \yr)	31079.8	3160.7	2316.0	827.6	702.1	1529.7	7973626904.0
	Global total (km3 \yr)	54695.1	3797.8	3090.5	1180.3	918.9	2099.2	13317869385

Table 2: Water Withdrawal and Water Required\use for Irrigated Areas by Country

CONCLUSION

The global irrigated area estimates, withought considering intensity, varied between 312 Mha (Portmann et al., 2009) and 399 Mha (Thenkabail et al., 2009b) for year 2000. Thenkabail et al. (2009) also estimated the irrigated areas by considering intensity which amounted to 467 Mha for the same period. The results from the advanced remote sensing (Thenkabail et al. 2009a, 2009b, 2009c) and the non-remote sensing studies (Ramankutty et al., 2008, Portmann et al., 2009\Siebert and Döll, 2008; 2009) varied significantly in: (a) providing precise spatial location of cropland areas, and (b) seperating irrigated areas from rainfed areas. Further, none of the studies provide a proper crop type and\or dominance. A proper and precise estimates of these are crucial given 60-90 percent of all human water use is taken by croplands.

The global crop water use varied between 6,685 to 7500 km^3 yr^{-1}; of this about 70% by rainfed croplands (green water use) and the rest 30 percent by irrigated croplands (blue water use). However, irrigated croplands use blue water (water in rivers, reservoirs, lakes, and pumped ground water from the saturated zone). Nearly 80 percent of all blue water used currently by humans goes for irrigated areas; highlighting the need for focus on irrigated croplands and their water use.

The greatest difficulty and differences in cropland estimates is in differentiating between rainfed croplands versus irrigated croplands. This is also the most crucial difference because water use assessments and food production estimates depend heavily on whether an area is irrigated or rainfed. The other main causes of differences in areas reported in various studies can be attributed to (Thenkabail et al., 2009b,c, Dheeravath et al., 2009), but not limited to: (a) reporting of large volumes of census data with inadequate statistical analysis; (b) subjectivity involved in observation-based data collection process; (c) inadequate accounting of irrigated areas, especially minor irrigation from groundwater, in the national statistics; (d) definition issues involved in mapping using remote sensing as well as national statistics; (e) difficulties in arriving at precise estimates of area fractions (AFs) using remote sensing; (f) difficulties in separating irrigated from rainfed croplands; and (g) imagery resolution in remote sensing.

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