1 Introduction

The world population is growing each day and the need to provide food, at the same time guarantee sustainable development, require more precise decisions in agricultural management. Due to limitation of water resources, the role of macroeconomic policies in agricultural water management is vital and undeniable. Although actual crop yield as percentage of potential yield is more than 60% for North America, it is less than 50% and about 30% for South America and Central America and the Caribbean, respectively (FAO 2012). Therefore, the study of agricultural water management in the Americas is still necessary. Namara et al. (2010) mentioned the roles of agricultural water management in reducing poverty in the world: improvement in production, increase in employment opportunities, and stabilization of income and consumption by guaranteeing access to potable water and increasing high-value products (availability to people). Additionally, good agricultural water management is important for nutritional value of crops/food, which also contributes to population health, social equality, and healthy environment. Valipour (2013a,b,c,d) identified the situation of irrigated and rainfed agriculture in the world, listing the advantages and disadvantages of irrigation systems to provide an updated information on such systems to assist in decision making processes. His results showed that 46% of cultivated areas in the world are not suitable for rainfed agriculture because of climate change and other meteorological conditions. Franks et al. (2008) analysed the current practice of agricultural water management for future capacity development. They suggested an increased attention to monitoring and evaluation of capacity development, and closer links to emerging work on water governance. De Loe et al. (2001), who studied agricultural water use in Ontario, claimed that future water allocation decisions must take into account the distribution of agricultural water consents, especially those for irrigation, which are strongly seasonal. Khan et al. (2009) reviewed water management and crop production for food security and, according to their study, the links between water and other development-related...
sectors such as population, energy, food, and environment, and the interactions among them require reckoning, since future food security and poverty reduction are tightly connected to these factors. Previous researches (see also Calder et al. 1995; Tilman et al. 2002; Viala et al. 2008; Foley et al. 2005) are restricted to smaller areas and cannot be apply to other regions, and some studies did not consider the role of all important indexes for agricultural water management. Thus, the goals of this study were to establish a link among important parameters for agricultural water management field, and to investigate the conditions of irrigation and drainage systems and cultivated crops in the Americas during the last 50 years.

2 Methodology

Irrigation heavily controls global yield variability (Rezaei et al. 2016; Mueller et al. 2012; Valipour 2014a,b; Valipour 2012a,b,c,d; Valipour 2016a, b; Valipour and Montazar 2012; Valipour and Gholami Sefidkouhi 2017; Valipour and Eslamian 2014; Rahimi et al. 2015). Although irrigation efficiency is a proper index for agricultural water management status, it cannot be increased until the value of equipped area is obtained to encourage farmers to use irrigation systems instead of rainfed agriculture. Designing cropping patterns, microeconomic decisions and allocation of water resources required the assessment of several variables to calculate the amount of equipped area for irrigation per cultivated area. However, the lack of adequate data does not allow us to consider all parameters. In this study, ten main indexes were selected using AQUASTAT database (FAO 2013), for the assessment of agricultural water management in the Americas from 1962 to 2011, and their values were checked using WBG database (WBG 2013). The relative error for estimated equipped area were then calculated for the chosen countries based on agricultural water management status. In the next step, eight sub-main indexes (based on less information) were evaluated to generate the cropping intensity in the study area for the past 50 years.

2.1 Main indexes

2.1.1 Permanent crops/cultivated area (%)

Crops are divided into temporary and permanent crops. Permanent crops are sown or planted once, and cultivated in the same area for some years without the need of being replanted after every harvest. Examples of permanent crops are: cocoa, coffee and rubber. In this category are also included flowering shrubs, fruit and nut trees, and vines; however, trees grown for wood or timber, and permanent meadows and pastures are not part of this category. This index is calculated following the equation:

\[
I_1 = 100 \times \frac{\text{permanent crops (ha)}}{\text{cultivated area (ha)}}
\]

2.1.2 Rural population/total population (%)

Usually the rural population index is obtained by subtracting the number of the urban population from the total population. In practice, the criteria adopted for distinguishing between urban and rural areas vary among countries that can be roughly divided into three major groups depending on: localities of a specific size; certain minor civil divisions with administrative centres; and minor civil divisions based on a chosen criterion which may include the type of local government, the number of inhabitants or the proportion of the population that is engaged in agriculture. Thus, the rural population estimates in this domain are based on the varying national definitions of urban areas:

\[
I_2 = 100 \times \frac{\text{rural population (inhabitant)}}{\text{total population (inhabitant)}}
\]

2.1.3 Total economically active population in agriculture/total economically active population (%)

Part of the economically active population is engaged in or seeking work in agriculture, hunting, fishing or forestry (agricultural labour force). The economically active population refers to the number of all employed and unemployed persons (including those seeking work for the first time). It covers employers, self-employed workers, salaried employees, wage earners, unpaid workers assisting in a family or farm or business operation, members of producer cooperatives, and members of the armed forces. The economically active population is also called the labour force. This index is determined as:

\[
I_3 = 100 \times \frac{\text{rural population (inhabitant)}}{\text{total population (inhabitant)}}
\]
2.1.4 Human development index (HDI)

The HDI ($I_4$) is a composite statistic of life expectancy, education, and income indices used to rank countries into different tiers of human development.

2.1.5 National rainfall index (NRI) (mm/yr)

The NRI is defined as the national average of the total annual precipitation weighted by its long-term average. The NRI is calculated differently in the Northern and the Southern hemispheres. In the northern hemisphere, the indices are calculated based on the January-December rainfall level; the rainfall indices coincide with the calendar year. In the Southern Hemisphere, crops are planted at the end of a year to be harvested in the first half of the following calendar year. Consequently, the index of a year for a crop harvested in that specific year is calculated based on the amount of rainfall from July of the previous year to June of the year of interest. In fact, this index ($I_5$) is a type of effective rainfall.

2.1.6 Value added to gross domestic product (GDP) by agriculture (%)

Agriculture corresponds to International Standard Industrial Classification (ISIC) divisions 1-5 and includes forestry, hunting and fishing, as well as cultivation of crops and livestock production. The added value is obtained by calculating the net output of a sector after adding up all outputs and subtracting the intermediate inputs. This index ($I_6$) is calculated without making deductions for depreciation of manufactured assets or depletion and degradation of natural resources.

2.1.7 Irrigation water requirement (mm/yr)

Irrigation water requirement is the quantity of water exclusively from precipitation and from soil moisture (i.e. quantity of irrigation water) required for normal crop production. It consists of the water quantity that will ensure a crop’s full water requirement (i.e. irrigation consumptive water use, as well as extra water from paddy fields, for land preparation and protection of plants from salinization, therefore allowing plant growth). This index ($I_7$) corresponds to net irrigation water requirement.

2.1.8 Percent of total cultivated area drained (%)

This index is the percentage of cultivated area that was drained divided by the area of cultivated land, expressed in percentage.

$$I_8 = 100 \times \frac{\text{total drained area (ha)}}{\text{cultivated area (ha)}}$$

(4)

2.1.9 Difference between NRI and irrigation water requirement (mm/yr)

This index shows water deficit and is determined as:

$$I_9 = \text{NRI (mm/yr)} - \text{irrigation water requirement}$$

(5)

2.1.10 Area equipped for irrigation to cultivated area (%)

It is the area that is equipped to provide water (via irrigation) to crops. It includes areas equipped for full/partial controlled irrigation, equipped lowland areas, and areas equipped for spate irrigation. Although irrigated area and irrigation potential are better indexes than equipped area, there are more available data on equipped area than on the former. Since difference between irrigated area and equipped area is not significant in most countries; we have selected equipped area index to be used in this study. This index is determined as:

$$I_{10} = 100 \times \frac{\text{area equipped for irrigation (ha)}}{\text{cultivated area (ha)}}$$

(6)

2.1.11 Estimation of equipped area

We aimed at finding a link among the following indexes:

$$I_{10} = f (I_1, I_2, I_3, I_4, I_5, I_6, I_7, I_8, I_9)$$

(7)

Therefore, several scenarios were tested to study the effect of each index on the $10^{th}$ index. The final function was calculated by two methods using data from 2011:
Where, $f_c$ is the correction factor and can be updated at the end of any water year. It can be 1, 0.9, 0.8, 0.7, 0.6, 0.5, 0.4, 0.3, 0.2, or 0.1, if $I_{n10}$ is 90-100, 80-90, 70-80, 60-70, 50-60, 40-50, 30-40, 20-30, 10-20, or 0-10, respectively. The aforementioned formulae were calculated for different years and the standard errors were calculated:

\[
\text{Mean error} = \frac{1}{\text{Number of tested years}} \sum_{i=1}^{\text{Number of tested years}} \left[ 100 \times \frac{(I_{10})_{\text{actual}} - (I_{10})_{\text{estimated}}}{(I_{10})_{\text{actual}}} \right],
\]

\[
\text{Maximum error} = \max_{i=1}^{\text{Number of tested years}} \left[ 100 \times \frac{(I_{10})_{\text{actual}} - (I_{10})_{\text{estimated}}}{(I_{10})_{\text{actual}}} \right],
\]

\[
\text{Minimum error} = \min_{i=1}^{\text{Number of tested years}} \left[ 100 \times \frac{(I_{10})_{\text{actual}} - (I_{10})_{\text{estimated}}}{(I_{10})_{\text{actual}}} \right],
\]

### 2.1.12 Condition of the countries for agricultural water management

The status of all countries were identified using two methods:

Desirability = $I_{\text{avg1}} = \frac{\sum_{i=1}^{\text{Number of available indexes}} I_{n1} + I_{n2} + I_{n3} + I_{n4} + I_{n5} + I_{n6} + (100 - I_{n7}) + I_{n8} + I_{n9} + I_{n10}}{\text{Number of available indexes}}$

\[
\text{Desirability} = I_{\text{avg2}} = \frac{1}{1 + \sum_{i=1}^{\text{Number of available indexes}} \left[ \frac{1}{f_c I_{n10} - I_{n10}} + \frac{1}{f_c (100 - I_{n7}) - I_{n10}} \right]} \sum_{i=1}^{\text{Number of available indexes}} \left[ \frac{I_{ni}}{f_c I_{n10} - I_{n10}} + \frac{100 - I_{n7}}{f_c (100 - I_{n7}) - I_{n10}} + I_{n10} \right]
\]

Then, the agricultural water management condition of each country was classified as:

Suitable status: $\text{Desirability} \geq 50\%$

Moderate status: $30\% \leq \text{Desirability} < 50\%$

Difficult status: $\text{Desirability} < 30\%$
2.2 Sub main indexes

2.2.1 Surface irrigation (%)

Surface irrigation systems are based on the principle of moving water through the soil by gravity to moisten the soil. They can be subdivided into furrow, borderstrip and basin irrigation (including rice irrigation by submersion). Manual irrigation using buckets or watering cans is also included. Surface irrigation does not refer to the method of transporting the water from the source up to the field, which may be done by gravity or by pumping.

2.2.2 Sprinkler irrigation (%)

A sprinkler irrigation system consists of a method of water distribution through a pipe network that pumps the water by pressure until the sprinkler nozzles from where the water is then sprinkled over the crop, similar to natural rainfall. These systems are also known as overhead irrigation systems.

2.2.3 Localized irrigation (%)

Localized irrigation consists of a water distribution method which uses low pressure to pump water through a pre-determined pipe-network pattern, to be discharged, in regulated quantity, directly on to each plant adjacent to the pipe. There are three main categories of localized irrigation:
- drip irrigation: drip emitters are used to apply water slowly to the soil surface;
- spray or micro-sprinkler irrigation: the water is sprayed on to the soil near individual plants or trees; and
- bubbler irrigation: a basin is built around each plant or tree which is flooded with water during irrigation.

Micro-irrigation, trickle irrigation, daily flow irrigation, drop-irrigation, sip irrigation, diurnal irrigation are also other names for localized irrigation systems.

2.2.4 Spate irrigation (%)

Spate irrigation (sometimes referred to as floodwater harvesting) is an irrigation practice that uses the floodwaters of ephemeral streams (wadi) and channels it through short steep canals to bunded basins where cropping takes place. A dam is often built in the wadi to to divert the available water from its natural course. These systems are in general characterized by a very large catchment upstream (200-5000 ha) with a ratio of “catchment area: cultivated area” = between 100:1 – 10,000:1. There are two types of spate irrigation: 1) floodwater harvesting within streambeds which uses a turbulent channel flow to collect and distribute the water through the wadi to the crops; cross-wadi dams are constructed with stones, earth, or both, and often reinforced with gabions; 2) floodwater diversion, which diverts the floods or spates from the seasonal rivers to adjacent embanked fields for direct application. A stone or concrete structure raises the water level within the wadi to be diverted to the nearby cropping areas.

2.2.5 Agricultural water withdrawal (10 km$^3$/yr)

This is the annual quantity of self-supplied water withdrawn for irrigation, livestock and aquaculture purposes. It includes water from primary renewable and secondary freshwater resources, as well as over-abstraction of renewable groundwater or withdrawal of fossil groundwater, direct use of agricultural drainage water and (treated) wastewater, and desalinated water.

2.2.6 Conservation agriculture area as percentage of cultivated area (%)

Conservation Agriculture (CA) is an agricultural practice whereby the disturbed area is less than 15 cm wide or 25% of the cropped area (whichever is lowest). AQUASTAT distinguishes between 30%-60%, 61-90% and 91% of ground cover. Ground cover must be measured after planting time, and CA is disregarded when ground cover less than 30%. Rotation must involve at least three different crops, although it is a requirement for CA at this stage. However, AQUASTAT reports whether rotation is being carried out or not.

2.2.7 Percentage of salinized soil per area equipped for irrigation (%)

This is percent of area equipped for irrigation that has become salinized due to mineral buildup caused by inadequate drainage.
2.2.8 Waterlogged Area by irrigation (%)

This is a part of the land that is waterlogged because of irrigation. Waterlogging is when the water table rises and is located under or near the surface, resulting in crop yield decline. Irrigation can contribute to the raising of the level of the aquifers by over-saturating the soil profile due to poor soil aeration. Additional drainage is required when recharge to groundwater is greater than natural drainage to avoid waterlogging.

2.3 Cropping intensity in equipped area

This index shows cropping intensity for the temporary and permanent crops that are cultivated in the surface, sprinkler, localized, and spate irrigation areas.

3 Evaluation of the main indexes of agricultural water management for 36 countries in 2011

Fig. 1 shows values of permanent crops to cultivated area in 2011.

According to the Fig. 1, the value of permanent crops to cultivated area is low for North America (< 10%), < 30% for South America (except for Colombia and Ecuador, 48% and 54%, respectively), < 40% for Central America (except for Costa Rica: 57%), and < 50% for Greater Antilles. Although this index can help with allocating water resources to where and when it is required, this index also depends on climate conditions (De Salvo et al. 2013; Valipour and Singh 2016; Valipour et al. 2017a,b), on farmers’ preferences (Bolliger et al. 2006; Valipour 2015a,b,c,d,e,f,g,h,i), and on government policies (Sukhwal 1991; Yannopoulos et al. 2015).

Fig. 2 shows values of rural population to total population in 2011.

According to Fig. 2, the value of rural population to total population is less than 30% for North America and < 40% for South America (except for Guyana, 71%). This index is > 30% for Central America and > 40% for Lower Antilles (except for the Bahamas, 16%, and Dominican Republic, 32%). Previous researches show advantages of rural development on agricultural water management and sustainable agriculture in global scale (Evans et al. 2012).

Fig. 3 shows total economically active population in agriculture to total economically active population in 2011. According to the Fig. 3, the value of economically active population in agriculture is less than 20% for North America and Greater Antilles (except for Haiti, 58%) and < 30% for Central America (except for Guatemala, 38%), South America (except for Bolivia, 41%), and Lower Antilles. The effects of proper labour force on water management and improvement of sustainable agriculture have been studied by other researchers (Naiken and Schulte 1976).

Fig. 4 shows values of human development index (HDI) in 2011. HDI value is > 0.900 for North America (except for Mexico, 0.755) and > 0.700 for Greater Antilles (except for Haiti, 0.456) and Lower Antilles. The HDI index, as a weighted measure of the Falkenmark indicator (Falkenmark 1989) of the ability of a population to adapt to water stress, is termed the Social Water Stress Index.

Fig. 5 shows values of national rainfall index (NRI) in 2011. According to the Fig. 5, the value of the NRI is > 1000 mm/yr for the Americas (except for Canada, 694 mm/yr, the United States of America, 939 mm/yr, and Dominican Republic, 821 mm/yr). The NRI index was known as a significant factor in drought studies (Mishra and Singh 2010; Gommes and Petrassi 1994).

Fig. 6 shows value added to GDP by agriculture in 2011. As shown in the Fig. 6, the GDP index is < 30% for the Americas. Neumann et al. (2011) mentioned the effect of GDF on irrigation.

Fig. 7 shows values of irrigation water requirement in 2011. According to the Fig. 7, the value of irrigation water requirement is less than 700 mm/yr for the Americas (except for Belize, 793 mm/yr, Paraguay 704 mm/yr, and the USA, 789 mm/yr). Variation of this index can be effected by river basin management (Simenstad et al. 1992), by water allocation policy (Killgore 2009), and by agricultural expansion (McCready and Dukes 2009).

Fig. 8 shows value of percent of total cultivated area drained in 2011. According to the Fig. 8, drainage is very poor in the Americas (except for Mexico, 19%, and the USA, 29%). Previous studies have noted the influence of drainage on subirrigation (Valero et al. 2007), crop productivity (Ale et al. 2009), improving water management (Ayars et al. 2006), and water balance (Ale et al. 2012).

Fig. 9 shows the value of the difference between NRI and irrigation water requirement in 2011. According to the Fig. 9, the value of the difference between NRI and irrigation water requirement is > 500 mm/yr for the Americas (except for Canada, 201 mm/yr, and the USA, 150 mm/yr).
How do different factors impact agricultural water management?

The index is known as water deficit and low values of such index indicate a critical status for water resource management in those countries (Hussain et al. 2007, Qadir et al. 2007).

Fig. 10 shows the value of area equipped for irrigation to cultivated area in 2011 (see also FAO 2011a,b).

According to Fig. 10, the value of equipped areas is < 30% for the Americas (with the exception of Venezuela, 30%). The different aspects of irrigation in agricultural water management such as irrigation efficiency, soil salinity (du Plessis 1985), water-saving (Montenegro et al. 2010), sustainable development (Schultz and De Wrachien 2002), soil water management (Steiner and Keller 1992), and crop yield (Wu et al. 2013) have been investigated by previous works. Also, FAO (2011a,b) showed that pressure on water resources for irrigation will continue to increase until 2050. Fig. 11 is applied to summarize obtained results from Figs. 1-10.

The green arrows are favorable indices and the red arrows are unfavorable indices. If we accept the negative role of NRI (5th index) and the difference between NRI and irrigation water requirement (9th index), and the positive role of the other main indexes on equipped area (10th index) based on the Eqs 9 and 10 (with the assumption that reduction of 5th index and 9th index, increases 10th index and increase of the other main indexes, increases 10th index), then we have Fig. 11. For North America, the value of HDI and the difference between NRI and irrigation water requirement are suitable, but the value of equipped area is unsuitable (Fig. 11a). Therefore, the role of the other indexes can be effective on the 10th index for this region. The value of rural population to total population is suitable, but the value of equipped area is unsuitable in Central America (Fig. 11b); which leads to a significant role of the other indexes on the 10th index for this region. In the Greater Antilles, the value of HDI is suitable but the value of equipped area is unsuitable (Fig. 11c). Thus, the role of the other indexes can be expressive on the 10th index in this region. The values of rural population to total population and HDI are suitable, whereas the value of equipped area is not suitable in the Lower Antilles (Fig. 11d); therefore, role of the other indexes can be expressive on 10th index in this area. Finally, Fig. 11d shows the values of the all indexes (with the exception of HDI without trend) in South America that are unsuitable; hence, the role of the all indexes can be significant on 10th index for this part of the world. There is a wide range of changes in the effective main indexes on agricultural water management in the Americas, as seen in Figs. 1 to 10. Therefore, if we want to establish a relationship among the indexes, each country should be considered separately.

Figure 1: Values of permanent crops to cultivated area (%) in 2011

Figure 2: Values of rural population to total population (%) in 2011
### Figure 3: Total economically active population in agriculture to total economically active population (%) in 2011

| Country                      | Percentage |
|------------------------------|------------|
| Antigua and Barbuda          | 21         |
| Argentina                    | 7          |
| Bahamas                      | 2          |
| Barbados                     | 3          |
| Belize                       | 23         |
| Bolivia (Plurinational State of) | 41    |
| Brazil                       | 11         |
| Canada                       | 2          |
| Chile                        | 13         |
| Colombia                     | 14         |
| Costa Rica                   | 15         |
| Cuba                         | 11         |
| Dominican Republic           | 17         |
| Dominican Republic (Dominica)| 10         |
| Ecuador                      | 18         |
| El Salvador                  | 22         |
| Grenada                      | 20         |
| Guatemala                    | 14         |
| Haiti                        | 14         |
| Honduras                     | 17         |
| Jamaica                      | 16         |
| Mexico                       | 16         |
| Nicaragua                    | 14         |
| Panama                       | 15         |
| Paraguay                     | 24         |
| Peru                         | 24         |
| Puerto Rico                  | 1          |
| Saint Kitts and Nevis        | 22         |
| Saint Lucia                  | 20         |
| Saint Vincent and the Grenadines | 20  |
| Suriname                     | 16         |
| Trinidad and Tobago          | 6          |
| United States of America     | 2          |
| Uruguay                      | 11         |
| Venezuela (Bolivarian Republic of) | 5      |

### Figure 4: Human development index (HDI) in 2011, this index is not available for Puerto Rico

| Country                      | HDI |
|------------------------------|-----|
| Antigua and Barbuda          | 0.760       |
| Argentina                    | 0.761       |
| Bahamas                      | 0.796       |
| Barbados                     | 0.825       |
| Belize                       | 0.702       |
| Bolivia (Plurinational State of) | 0.679  |
| Brazil                       | 0.730       |
| Canada                       | 0.680       |
| Chile                        | 0.829       |
| Colombia                     | 0.719       |
| Costa Rica                   | 0.773       |
| Cuba                         | 0.780       |
| Dominican Republic           | 0.745       |
| Dominican Republic (Dominica)| 0.702       |
| Ecuador                      | 0.724       |
| El Salvador                  | 0.680       |
| Grenada                      | 0.770       |
| Guatemala                    | 0.581       |
| Guyana                       | 0.636       |
| Haiti                        | 0.666       |
| Honduras                     | 0.692       |
| Jamaica                      | 0.730       |
| Mexico                       | 0.779       |
| Nicaragua                    | 0.399       |
| Panama                       | 0.780       |
| Paraguay                     | 0.660       |
| Peru                         | 0.741       |
| Puerto Rico                  | 0.741       |
| Saint Kitts and Nevis        | 0.745       |
| Saint Lucia                  | 0.735       |
| Saint Vincent and the Grenadines | 0.735   |
| Suriname                     | 0.684       |
| Trinidad and Tobago          | 0.760       |
| United States of America     | 0.937       |
| Uruguay                      | 0.702       |
| Venezuela (Bolivarian Republic of) | 0.748   |

### Figure 5: NRI (mm/yr) in 2011, this index is not available for Antigua and Barbuda, Barbados, Dominica, Grenada, Saint Kitts and Nevis, Saint Lucia, and Saint Vincent and the Grenadines (in few cases due to lack of data, value of the index in the previous years has been reported)

| Country                      | Value |
|------------------------------|-------|
| Antigua and Barbuda          | 0.943 |
| Argentina                    | 1.330 |
| Bahamas                      | 1.593 |
| Barbados                     | 2.013 |
| Belize                       | 1.936 |
| Bolivia (Plurinational State of) | 3.604      |
| Brazil                       | 3.483 |
| Canada                       | 2.086 |
| Chile                        | 2.085 |
| Colombia                     | 1,019  |
| Costa Rica                   | 2,075  |
| Cuba                         | 1,404  |
| Dominican Republic           | 1,317  |
| Ecuador                      | 1,226  |
| Guatemala                    | 1,838  |
| Haiti                        | 3,114  |
| Honduras                     | 1,952  |
| Jamaica                      | 2,013  |
| Mexico                       | 2,461  |
| Nicaragua                    | 1,226  |
| Panama                       | 2,223  |
| Paraguay                     | 1,895  |
| Peru                         | 1,848  |
| Puerto Rico                  | 1,889  |
| Saint Kitts and Nevis        | 1,939  |
| Saint Lucia                  | 1,566  |
| Saint Vincent and the Grenadines | 1,813  |
| Trinidad and Tobago          | 1,830  |
| United States of America     | 1,813  |
| Uruguay                      | 1,813  |

### Figure 6: Value added to GDP by agriculture (%) in 2011 (in few cases due to lack of data, value of the index in the previous years has been reported)

| Country                      | Value |
|------------------------------|-------|
| Antigua and Barbuda          | 0.760 |
| Argentina                    | 0.796 |
| Barbados                     | 0.825 |
| Belize                       | 0.702 |
| Bolivia (Plurinational State of) | 0.679 |
| Brazil                       | 0.730 |
| Canada                       | 0.680 |
| Chile                        | 0.829 |
| Colombia                     | 0.719 |
| Costa Rica                   | 0.773 |
| Cuba                         | 0.780 |
| Dominican Republic           | 0.745 |
| Dominican Republic (Dominica)| 0.702 |
| Ecuador                      | 0.724 |
| El Salvador                  | 0.680 |
| Grenada                      | 0.770 |
| Guatemala                    | 0.581 |
| Guyana                       | 0.636 |
| Haiti                        | 0.666 |
| Honduras                     | 0.692 |
| Jamaica                      | 0.730 |
| Mexico                       | 0.779 |
| Nicaragua                    | 0.399 |
| Panama                       | 0.780 |
| Paraguay                     | 0.660 |
| Peru                         | 0.741 |
| Puerto Rico                  | 0.741 |
| Saint Kitts and Nevis        | 0.745 |
| Saint Lucia                  | 0.735 |
| Saint Vincent and the Grenadines | 0.735 |
| Suriname                     | 0.684 |
| Trinidad and Tobago          | 0.760 |
| United States of America     | 0.937 |
| Uruguay                      | 0.702 |
| Venezuela (Bolivarian Republic of) | 0.748 |
How do different factors impact agricultural water management?

Figure 7: Irrigation water requirement (mm/yr) in 2011 this index is not available for Bahamas, Chile, Costa Rica, Cuba, Dominican Republic, El Salvador, Guyana, Jamaica, Nicaragua, Panama, Peru, Saint Vincent and the Grenadines, Suriname, and Uruguay (in few cases due to lack of data, value of the index in the previous years has been reported)

| Country                        | Index Value |
|--------------------------------|-------------|
| Antigua and Barbuda            | 545         |
| Argentina                      | 1,226       |
| Bahamas                        | 255         |
| Barbados                       | 252         |
| Bolivia                        | 1,401       |
| Burkina (Republic of)          | 965         |
| Brazil                         | 1,491       |
| Canada                         | 1,150       |
| Chile                          | 1,650       |
| Costa Rica                     | 220         |
| Cuba                           | 1,208       |
| Dominican Republic             | 2,075       |
| Ecuador                        | 397         |
| El Salvador                    | 1,279       |
| Grenada                        | 940         |
| Guatemala                      | 514         |
| Haiti                          | 876         |
| Honduras                       | 1,586       |
| Jamaica                        | 1,586       |
| Mexico                         | 150         |
| Nicaragua                      | 1,100       |

Figure 8: Percent of total cultivated area drained (%) in 2011 (in few cases due to lack of data, value of the index in the previous years has been reported)

| Country                        | Index Value |
|--------------------------------|-------------|
| Antigua and Barbuda            | 3           |
| Argentina                      | 6           |
| Bahamas                        | 0           |
| Barbados                       | 0           |
| Bolivia                        | 4           |
| Burkina (Republic of)          | 7           |
| Brazil                         | 2           |
| Canada                         | 10          |
| Chile                          | 5           |
| Colombia                       | 0           |
| Costa Rica                     | 0           |
| Cuba                           | 0           |
| Dominican Republic             | 0           |
| Ecuador                        | 25          |
| El Salvador                    | 24          |
| Grenada                        | 2           |
| Guatemala                      | 4           |
| Guyana                         | 29          |
| Haiti                          | 0           |
| Honduras                       | 0           |
| Jamaica                        | 0           |
| Mexico                         | 23          |
| Nicaragua                      | 0           |
| Panama                         | 0           |
| Paraguay                       | 0           |
| Peru                           | 0           |
| Saint Kitts and Nevis          | 0           |
| Saint Lucia                    | 0           |
| Saint Vincent and the Grenadines | 0          |
| Suriname                       | 0           |
| Trinidad and Tobago            | 5           |
| United States of America       | 16          |
| Uruguay                        | 0           |

Figure 9: Difference between NRI and irrigation water requirement (mm/yr) in 2011, this index is not available for Antigua and Barbuda, Bahamas, Barbados, Chile, Costa Rica, Cuba, Dominica, Dominican Republic, El Salvador, Grenada, Guyana, Jamaica, Nicaragua, Panama, Peru, Saint Kitts and Nevis, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Uruguay (in few cases due to lack of data, value of the index in the previous years has been reported)

| Country                        | Index Value |
|--------------------------------|-------------|
| Antigua and Barbuda            | 0           |
| Argentina                      | 0.4         |
| Bahamas                        | 0           |
| Barbados                       | 0           |
| Bolivia                        | 0           |
| Burkina (Republic of)          | 0           |
| Brazil                         | 0           |
| Canada                         | 0           |
| Chile                          | 0           |
| Colombia                       | 3           |
| Costa Rica                     | 8           |
| Cuba                           | 0           |
| Dominican Republic             | 0           |
| Dominican Republic             | 0           |
| El Salvador                    | 0           |
| Grenada                        | 0           |
| Guatemala                      | 0.1         |
| Guyana                         | 0           |
| Haiti                          | 0           |
| Nicaragua                      | 3           |
| Panama                         | 0           |
| Paraguay                       | 0           |
| Peru                           | 0           |
| Puerto Rico                    | 0           |
| Saint Kitts and Nevis          | 0           |
| Saint Lucia                    | 0           |
| Saint Vincent and the Grenadines | 0          |
| Suriname                       | 0           |
| Trinidad and Tobago            | 0           |
| United States of America       | 0           |
| Uruguay                        | 0           |
4 Estimation of area equipped for irrigation to cultivated area using the other main indexes of agricultural water management

Tables 1 and 2 (using Eq. 8 and Eq. 9, respectively) show estimated functions for value of equipped area in the Americas.

A comparison between Table 1 and Table 2 shows that the obtained coefficients for the main indexes are similar in some cases, while different in others. These disparities (or similarities) are correspondent to the of Eqs. 8 and 9.

4.1 Prioritization of the main indexes of agricultural water management based on the obtained coefficients for each index

Fig. 12 (based on Eq. 8 and Eq. 9) shows the role of each index in estimating the value of equipped area (10th index) in the Americas.

The role of the indexes is similar or different depending on which equation (Eq. 8 or Eq. 9) is used. In addition, the comparison of the countries together shows a distinguishable role of each index for a specific country. According to Fig. 12, in North America, the most important parameter is rural population to total population (Canada and the USA), thus confirming the results in Fig. 11a and proving the reliability of Eqs. 8 and 9. According to the Fig. 12, the important parameters for Central America are NRI (for Belize, Honduras, and Panama) and permanent crops to cultivated area (for El Salvador and Nicaragua), and, therefore, support the results presented in Fig. 11b. The
### Table 1: Estimated functions using the first method (Eq. 9) for value of area equipped for irrigation to cultivated area in Americas (25 countries), this function is not calculable for Bahamas, Barbados, Chile, Costa Rica, Dominica, Guatemala, Peru, Puerto Rico, Saint Lucia, Saint Vincent and the Grenadines, and Suriname due to very poor irrigation or lack of adequate data

| Country                          | Suggested formula to estimate value of area equipped for irrigation to cultivated area (%) |
|----------------------------------|------------------------------------------------------------------------------------------|
| Antigua and Barbuda              | $I_{10} = 0.70I_{4} + 0.026I_{2} + 0.067I_{3} + 0.026I_{4} + 0.008I_{6} + 0.166I_{7}$     |
| Argentina                        | $I_{10} = 0.010I_{4} + 0.031I_{2} + 0.054I_{3} + 0.117I_{4} - 0.147I_{5} + 0.372I_{6} + 0.142I_{7} + 0.004I_{8} - 0.123I_{9} + 27.031$ |
| Belize                           | $I_{10} = 0.080I_{4} + 0.042I_{2} + 0.078I_{3} + 0.032I_{4} - 0.635I_{5} + 0.063I_{6} + 0.027I_{7} - 0.043I_{9} + 67.789$ |
| Bolivia (Plurinational State of) | $I_{10} = 0.049I_{4} + 0.172I_{2} + 0.117I_{3} + 0.116I_{4} - 0.144I_{5} + 0.150I_{6} + 0.119I_{7} + 0.010I_{8} - 0.122I_{9} + 26.586$ |
| Brazil                           | $I_{10} = 0.049I_{4} + 0.088I_{2} + 0.174I_{3} + 0.062I_{4} - 0.146I_{5} + 0.265I_{6} + 0.096I_{7} + 0.017I_{8} - 0.103I_{9} + 24.949$ |
| Canada                           | $I_{10} = 0.231I_{4} + 0.276I_{2} + 0.012I_{3} + 0.076I_{4} - 0.081I_{5} + 0.040I_{6} + 0.086I_{7} + 0.121I_{8} - 0.077I_{9} + 15.730$ |
| Colombia                         | $I_{10} = 0.005I_{4} + 0.020I_{2} + 0.710I_{3} + 0.004I_{4} - 0.00001I_{5} + 0.217I_{6} + 0.042I_{7} + 0.002I_{8} - 0.0000005I_{9} + 0.001$ |
| Cuba                             | $I_{10} = 0.059I_{4} + 0.195I_{2} + 0.203I_{3} + 0.058I_{4} - 0.066I_{5} + 0.157I_{6} + 0.262I_{7} + 6.645$ |
| Dominican Republic               | $I_{10} = 0.147I_{4} + 0.284I_{2} + 0.112I_{3} + 0.100I_{4} - 0.103I_{5} + 0.230I_{6} + 0.026I_{8} + 10.259$ |
| Ecuador                          | $I_{10} = 0.040I_{4} + 0.111I_{2} + 0.577I_{3} + 0.038I_{4} - 0.012I_{5} + 0.120I_{6} + 0.066I_{7} + 0.007I_{8} - 0.030I_{9} + 4.191$ |
| El Salvador                      | $I_{10} = 0.205I_{4} + 0.170I_{2} + 0.180I_{3} + 0.123I_{4} - 0.147I_{5} + 0.156I_{6} + 0.019I_{8} + 14.654$ |
| Grenada                          | $I_{10} = 0.042I_{4} + 0.047I_{2} + 0.081I_{3} + 0.044I_{4} + 0.708I_{6} + 0.079I_{7}$ |
| Guyana                           | $I_{10} = 0.024I_{4} + 0.092I_{2} + 0.365I_{3} + 0.104I_{4} - 0.320I_{5} + 0.096I_{6} + 32.020$ |
| Haiti                            | $I_{10} = 0.378I_{4} + 0.095I_{2} + 0.068I_{3} + 0.105I_{4} - 0.091I_{5} + 0.068I_{6} + 0.115I_{7} - 0.081I_{9} + 17.168$ |
| Honduras                         | $I_{10} = 0.133I_{4} + 0.102I_{2} + 0.133I_{3} + 0.092I_{4} - 0.123I_{5} + 0.107I_{6} + 0.125I_{7} + 0.078I_{8} - 0.107I_{9} + 22.954$ |
| Jamaica                          | $I_{10} = 0.040I_{4} + 0.042I_{2} + 0.132I_{3} + 0.035I_{4} - 0.444I_{5} + 0.708I_{6} + 4.370$ |
| Mexico                           | $I_{10} = 0.022I_{4} + 0.217I_{2} + 0.489I_{3} + 0.042I_{4} - 0.050I_{5} + 0.025I_{6} + 0.062I_{7} + 0.049I_{8} - 0.044I_{9} + 9.469$ |
| Nicaragua                        | $I_{10} = 0.252I_{4} + 0.109I_{2} + 0.273I_{3} + 0.096I_{4} - 0.178I_{5} + 0.092I_{6} + 17.828$ |
| Panama                           | $I_{10} = 0.142I_{4} + 0.195I_{2} + 0.243I_{3} + 0.081I_{4} - 0.165I_{5} + 0.175I_{6} + 16.499$ |
| Paraguay                         | $I_{10} = 0.021I_{4} + 0.162I_{2} + 0.167I_{3} + 0.130I_{4} - 0.141I_{5} + 0.124I_{6} + 0.123I_{7} + 0.006I_{8} - 0.126I_{9} + 26.706$ |
| Saint Kitts and Nevis            | $I_{10} = 0.912I_{4} + 0.015I_{2} + 0.016I_{3} + 0.015I_{4} + 0.025I_{6} + 0.016I_{7}$ |
| Trinidad and Tobago              | $I_{10} = 0.109I_{4} + 0.089I_{2} + 0.060I_{3} + 0.096I_{4} - 0.198I_{5} + 0.008I_{6} + 0.259I_{7} + 0.019I_{8} - 0.164I_{9} + 36.157$ |
| United States of America         | $I_{10} = 0.008I_{4} + 0.285I_{2} + 0.010I_{3} + 0.130I_{4} - 0.158I_{5} + 0.018I_{6} + 0.130I_{7} + 0.130I_{8} - 0.132I_{9} + 29.045$ |
| Uruguay                          | $I_{10} = 0.008I_{4} + 0.034I_{2} + 0.178I_{3} + 0.107I_{4} - 0.176I_{5} + 0.287I_{6} + 0.210I_{8} + 17.597$ |
| Venezuela (Bolivarian Republic of) | $I_{10} = 0.020I_{4} + 0.001I_{2} + 0.001I_{3} + 0.004I_{4} - 0.014I_{5} + 0.006I_{6} + 0.004I_{7} + 0.945I_{8} - 0.006I_{9} + 1.987$ |
Table 2: Estimated functions using the second method (Eq. 10) for value of area equipped for irrigation to cultivated area in Americas (25 countries), this function is not calculable for Bahamas, Barbados, Chile, Costa Rica, Dominica, Guatemala, Peru, Puerto Rico, Saint Lucia, Saint Vincent and the Grenadines, and Suriname due to very poor irrigation or lack of adequate data

| Country                        | Suggested formula to estimate value of area equipped for irrigation to cultivated area (%) |
|--------------------------------|------------------------------------------------------------------------------------------|
| Antigua and Barbuda            | $f_{10} = 0.742f_{n1} + 0.009f_{n2} + 0.053f_{n3} + 0.009f_{n4} + 0.028f_{n6} + 0.160f_{n7}$ |
| Argentina                      | $f_{10} = 0.093f_{n1} + 0.116f_{n2} + 0.142f_{n3} + 0.044f_{n4} - 0.076f_{n5} + 0.320f_{n6} + 0.071f_{n7} + 0.087f_{n8} - 0.051f_{n9} + 12.701$ |
| Belize                         | $f_{10} = 0.069f_{n1} + 0.026f_{n2} + 0.067f_{n3} + 0.015f_{n4} - 0.736f_{n5} + 0.050f_{n6} + 0.009f_{n7} - 0.027f_{n9} + 76.335$ |
| Bolivia (Plurinational State of) | $f_{10} = 0.232f_{n1} + 0.152f_{n2} + 0.105f_{n3} + 0.055f_{n4} - 0.102f_{n5} + 0.113f_{n6} + 0.060f_{n7} + 0.164f_{n8} - 0.065f_{n9} + 16.748$ |
| Brazil                         | $f_{10} = 0.089f_{n1} + 0.126f_{n2} + 0.209f_{n3} + 0.017f_{n4} - 0.998f_{n5} + 0.296f_{n6} + 0.050f_{n7} + 0.058f_{n8} - 0.057f_{n9} + 15.507$ |
| Canada                         | $f_{10} = 0.313f_{n1} + 0.228f_{n2} + 0.079f_{n3} + 0.014f_{n4} - 0.202f_{n5} + 0.109f_{n6} + 0.026f_{n7} + 0.195f_{n8} - 0.015f_{n9} + 3.513$ |
| Colombia                       | $f_{10} = 0.002f_{n1} + 0.017f_{n2} + 0.713f_{n3} + 0.001f_{n4} - 0.003f_{n5} + 0.216f_{n6} + 0.040f_{n7} + 0.004f_{n8} - 0.003f_{n9} + 0.563$ |
| Cuba                           | $f_{10} = 0.105f_{n1} + 0.160f_{n2} + 0.256f_{n3} + 0.016f_{n4} - 0.026f_{n5} + 0.207f_{n6} + 0.229f_{n8} + 2.556$ |
| Dominican Republic             | $f_{10} = 0.089f_{n1} + 0.235f_{n2} + 0.187f_{n3} + 0.039f_{n4} - 0.042f_{n5} + 0.313f_{n6} + 0.095f_{n8} + 4.183$ |
| Ecuador                        | $f_{10} = 0.017f_{n1} + 0.090f_{n2} + 0.567f_{n3} + 0.015f_{n4} - 0.368f_{n5} + 0.147f_{n6} + 0.043f_{n7} + 0.031f_{n8} - 0.054f_{n9} + 9.060$ |
| El Salvador                    | $f_{10} = 0.209f_{n1} + 0.145f_{n2} + 0.164f_{n3} + 0.059f_{n4} - 0.103f_{n5} + 0.120f_{n6} + 0.200f_{n7} + 10.255$ |
| Grenada                        | $f_{10} = 0.010f_{n1} + 0.015f_{n2} + 0.055f_{n3} + 0.012f_{n4} + 0.855f_{n6} + 0.052f_{n7}$ |
| Guyana                         | $f_{10} = 0.084f_{n1} + 0.032f_{n2} + 0.425f_{n3} + 0.044f_{n4} - 0.380f_{n5} + 0.036f_{n6} + 38.033$ |
| Haiti                          | $f_{10} = 0.550f_{n1} + 0.075f_{n2} + 0.029f_{n3} + 0.092f_{n4} - 0.067f_{n5} + 0.029f_{n6} + 0.108f_{n7} - 0.051f_{n9} + 11.838$ |
| Honduras                       | $f_{10} = 0.125f_{n1} + 0.069f_{n2} + 0.126f_{n3} + 0.052f_{n4} - 0.106f_{n5} + 0.077f_{n6} + 0.110f_{n7} + 0.257f_{n8} - 0.078f_{n9} + 18.423$ |
| Jamaica                        | $f_{10} = 0.018f_{n1} + 0.020f_{n2} + 0.119f_{n3} + 0.012f_{n4} - 0.022f_{n5} + 0.809f_{n6} + 2.184$ |
| Mexico                         | $f_{10} = 0.051f_{n1} + 0.251f_{n2} + 0.532f_{n3} + 0.015f_{n4} - 0.023f_{n5} + 0.054f_{n6} + 0.035f_{n7} + 0.022f_{n8} - 0.017f_{n9} + 4.069$ |
| Nicaragua                      | $f_{10} = 0.441f_{n1} + 0.056f_{n2} + 0.282f_{n3} + 0.038f_{n4} - 0.151f_{n5} + 0.033f_{n6} + 15.123$ |
| Panama                         | $f_{10} = 0.091f_{n1} + 0.151f_{n2} + 0.206f_{n3} + 0.022f_{n4} - 0.259f_{n5} + 0.271f_{n6} + 25.926$ |
| Paraguay                       | $f_{10} = 0.238f_{n1} + 0.124f_{n2} + 0.134f_{n3} + 0.062f_{n4} - 0.084f_{n5} + 0.050f_{n6} + 0.047f_{n7} + 0.209f_{n8} - 0.053f_{n9} + 13.660$ |
| Saint Kitts and Nevis          | $f_{10} = 0.985f_{n1} + 0.001f_{n2} + 0.001f_{n3} + 0.001f_{n4} + 0.011f_{n6} + 0.001f_{n7}$ |
| Trinidad and Tobago            | $f_{10} = 0.052f_{n1} + 0.026f_{n2} + 0.160f_{n3} + 0.035f_{n4} - 0.163f_{n5} + 0.095f_{n6} + 0.240f_{n7} + 0.108f_{n8} - 0.120f_{n9} + 28.361$ |
| United States of America       | $f_{10} = 0.113f_{n1} + 0.419f_{n2} + 0.116f_{n3} + 0.039f_{n4} - 0.070f_{n5} + 0.124f_{n6} + 0.039f_{n7} + 0.039f_{n8} - 0.042f_{n9} + 11.192$ |
| Uruguay                        | $f_{10} = 0.076f_{n1} + 0.099f_{n2} + 0.234f_{n3} + 0.032f_{n4} - 0.096f_{n5} + 0.200f_{n6} + 0.263f_{n8} + 9.642$ |
| Venezuela (Bolivarian Republic of) | $f_{10} = 0.022f_{n1} + 0.003f_{n2} + 0.004f_{n3} + 0.002f_{n4} - 0.012f_{n5} + 0.008f_{n5} + 0.002f_{n7} + 0.944f_{n8} - 0.003f_{n9} + 1.480$ |
most important parameter detected for the Greater Antilles is the value added to GDP by agriculture (for Dominican Republic and Jamaica), which supports the results presented in Fig. 11c. In the Lower Antilles, the most important parameter is the permanent crops to cultivated area index (for Antigua, Barbuda, Saint Kitts and Nevis), thus confirming the results in Fig. 11d. Lastly, the parameters that are more important in South America include total economically active population in agriculture to total economically active population index (for Guyana, Colombia, Ecuador, and Paraguay) and the value added to GDP by agriculture index (for Argentina, Chile, and Uruguay). These results also confirm what is depicted in Fig. 11e and proves that the Eqs. 8 and 9 are reliable.

Fig. 13 is useful to assess the effect of the main indexes on equipped area (10th index) in the Americas based on Eq. 8 and Eq. 9.

Total economically active population in agriculture to total economically active population, permanent crops to cultivated area, and the value added to GDP by agriculture indexes have a significant effect on the estimation of area equipped for irrigation to cultivated area index (or 10th index), as opposed to HDI, which has the least impact on the same index (Fig. 13). It is supported by Figs. 11 and 12 and proves that the Eqs. 8 and 9 are reliable.

The index values of total economically active population in agriculture to total economically active population (Figs. 3 and 11), permanent crops to cultivated area (Figs. 1 and 11), and the value added to GDP by agriculture (Figs. 6 and 11) are low; hence, these factors can lead to a reduced propensity of governments and/or farmers to use irrigation systems. Contrarily, the value of HDI is relatively high for the Americas (Fig. 4 and Fig. 11), indicating that this index has a small effect on low values of equipped area for irrigation in the Americas (Figs. 12 and 13). Although equations 8 and 9 have been shown to be reliable in the calculation of the status of agricultural water management, their accuracy was determined by equations 12 to 14.

**Figure 12:** Role of each index to estimate value of equipped area (10th index) based on Eq. 8 (a) and Eq. 9 (b) in the Americas (25 countries), the prioritization is not calculable for Bahamas, Barbados, Chile, Costa Rica, Dominica, Guatemala, Peru, Puerto Rico, Saint Lucia, Saint Vincent and the Grenadines, and Suriname due to very poor irrigation or lack of adequate data.
4.2 Calculation of the error for suggested functions to estimate the value of irrigation index

Table 3 shows calculated errors for suggested functions (Tables 1 and 2) using equations 12 to 14. According to the Table 3, the accuracy of equation 8 is higher than that of equation 9. The values of the mean relative error are < 20% (except for Grenada and Venezuela). Therefore, equations 8 and 9 should be applied for Grenada and Venezuela (Tables 1 and 2) with care due to their estimated errors. However, we can update the formulas in Tables 1 and 2 by using Eqs. 8 and 9, and base the new formula on new data (or only on fc) at the end of any water year. In the next step, total status of the countries for agricultural water management has been studied using the Eqs. 15 and 16.

5 Total status of the countries in terms of agricultural water management based on the main indexes for 2011

Table 4 presents the total status of the countries in terms of agricultural water management based on the equations 15 and 16.
Table 3: Calculated errors for suggested functions (Tables 1 and 2), the errors less than 10% show a suitable status, the errors between 10% and 20% show a fairly status, and the errors more than 20% show a difficult status to apply the Eqs. 8 and 9 (the first and the second formulas, respectively).

| Country                              | Relative error in the first formula (%) | Relative error in the second formula (%) |
|--------------------------------------|----------------------------------------|------------------------------------------|
|                                      | Minimum | Mean | Maximum | Minimum | Mean | Maximum |
| Antigua and Barbuda                  | 8.6     | 17.1 | 26.5     | 8.3     | 14.9 | 16.0     |
| Argentina                            | 7.4     | 15.0 | 23.8     | 6.7     | 15.0 | 22.8     |
| Belize                               | 2.0     | 5.6  | 10.9     | 1.6     | 6.0  | 8.5      |
| Bolivian Plurinational State of      | 4.1     | 8.1  | 13.8     | 2.8     | 6.0  | 13.2     |
| Brazil                               | 6.7     | 17.3 | 30.0     | 5.4     | 17.0 | 27.3     |
| Canada                               | 1.4     | 7.7  | 14.2     | 1.6     | 7.0  | 13.9     |
| Colombia                             | 2.3     | 16.3 | 21.8     | 2.3     | 14.6 | 20.7     |
| Cuba                                 | 0.9     | 7.4  | 17.5     | 2.0     | 8.3  | 15.0     |
| Dominican Republic                   | 1.0     | 16.9 | 29.0     | 1.1     | 14.9 | 27.1     |
| Ecuador                              | 6.6     | 15.5 | 23.5     | 2.7     | 16.0 | 26.5     |
| El Salvador                          | 1.6     | 12.2 | 17.9     | 1.0     | 13.7 | 18.6     |
| Grenada                              | 2.7     | 19.5 | 38.7     | 3.9     | 21.0 | 34.2     |
| Guyana                               | 2.5     | 11.6 | 18.2     | 3.8     | 10.1 | 16.8     |
| Haiti                                | 2.4     | 16.0 | 24.7     | 1.1     | 15.1 | 19.6     |
| Honduras                             | 4.5     | 8.9  | 14.6     | 2.1     | 5.6  | 9.3      |
| Jamaica                              | 4.4     | 15.1 | 21.8     | 6.6     | 14.6 | 18.2     |
| Mexico                               | 0.8     | 14.9 | 21.9     | 1.9     | 13.3 | 17.5     |
| Nicaragua                            | 6.3     | 12.2 | 18.9     | 4.2     | 13.8 | 17.7     |
| Panama                               | 3.1     | 16.8 | 27.5     | 3.8     | 15.7 | 27.0     |
| Paraguay                             | 5.3     | 13.3 | 18.8     | 4.7     | 12.2 | 17.6     |
| Saint Kitts and Nevis                | 3.8     | 7.4  | 13.8     | 1.7     | 5.5  | 9.0      |
| Trinidad and Tobago                  | 4.0     | 7.3  | 14.7     | 4.9     | 7.5  | 15.0     |
| United States of America             | 5.5     | 16.3 | 25.3     | 2.7     | 16.9 | 20.9     |
| Uruguay                              | 4.1     | 12.1 | 18.8     | 2.0     | 12.6 | 15.5     |
| Venezuela (Bolivarian Republic of)   | 12.7    | 26.5 | 47.9     | 6.3     | 24.8 | 47.1     |

The status of agricultural water management is suitable for Costa Rica, Dominican Republic, Ecuador, Guatemala, Guyana, Mexico, and Venezuela (Bolivarian Republic of Venezuela) and it is fairly for Barbados, Belize, Chile, Colombia, Dominica, Haiti, Peru, Saint Lucia, Saint Vincent and the Grenadines, Suriname, Trinidad and Tobago, United States of America, and Uruguay (Table 4). However, the situation is different in Central America (except for Belize, with a moderate status) and < 40% for the Greater Antilles (except for Dominican Republic, 55%). It is important to highlight that Guyana has the highest status for agricultural water management (72%) among all other American countries. These differences in the statuses of agricultural water management in the American countries are due to nature of equations 15 and 16. The functions used to estimate the equipped area for irrigation (or the 10th index) were applied to all years (when there were available data). However, due to the sparse data for 2011, other aspects were considered for this specific year. Therefore, a more thorough study is still necessary to assess the trend of agricultural water management in the Americas in the last 50 years.

6 Agricultural water management based on the main indexes for Americas in the past 50 years

Fig. 14 shows variations of the main indexes for Americas in the past 50 years.

Variations of permanent crops to cultivated area index were not significant and the value of NRI varied during the
past fifty years due to various factors such as greenhouse gases (Lal 2001), global warming (Michaels 1990), climate change (Muzik 2002), among others (Fig. 14). According to the Fig. 14, increasing slopes for permanent crops to Cultivated area, HDI, percent of total cultivated area drained, and equipped area are less than decreasing slopes for rural population to total population, total economically active population in agriculture to total economically active population, and value added to GDP by agriculture. It should be noted that, although mechanization and the use of new technologies have an important role in enhancing agricultural knowledge and increasing productivity (Kirpich et al. 1999), rural development and labor force have a vital and irreplaceable role in agricultural development and macroeconomic perspectives (Hendrickson et al. 2008). Other parameters such as possible disadvantages of irrigation systems (the sub-main indexes) have also an effect

| Country                                      | I_{a1} | I_{a2} | I_{a3} | I_{a5} | I_{a6} | 100-I_{a7} | I_{a8} | I_{a9} | I_{avg1} | I_{avg2} |
|----------------------------------------------|--------|--------|--------|--------|--------|------------|--------|--------|----------|----------|
| Antigua and Barbuda                          | 27     | 81     | 35     | 81     | NR     | 8          | 71     | 0      | NR       | 9        |
| Argentina                                    | 3      | 9      | 13     | 87     | 37     | 38         | 35     | 1      | 20       | 20       |
| Bahamas                                      | 41     | 18     | 4      | 85     | 46     | 8          | NR     | 0      | NR       | 0        |
| Barbados                                     | 10     | 64     | 5      | 88     | NR     | 11         | 68     | 0      | NR       | 0        |
| Belize                                       | 40     | 55     | 40     | 75     | 70     | 43         | 0      | 46     | 10       | 38       |
| Bolivia (Plurinational State of)             | 7      | 38     | 70     | 72     | 52     | 45         | 32     | 2      | 36       | 13       |
| Brazil                                       | 12     | 15     | 18     | 78     | 68     | 20         | 58     | 6      | 60       | 23       |
| Canada                                       | 14     | 22     | 3      | 97     | 24     | 7          | 38     | 11     | 8        | 23       |
| Chile                                        | 34     | 13     | 22     | 87     | 87     | 12         | NR     | 1      | NR       | NR       |
| Colombia                                     | 63     | 29     | 25     | 77     | 100    | 25         | 74     | 9      | 100      | 33       |
| Costa Rica                                   | 76     | 41     | 26     | 82     | 100    | 23         | NR     | 27     | NR       | 53       |
| Cuba                                         | 13     | 29     | 19     | 83     | 38     | 18         | NR     | 27     | NR       | 15.1     |
| Dominica                                     | 100    | 38     | 30     | 80     | NR     | 48         | NR     | 0      | NR       | 42       |
| Dominican Republic                           | 48     | 35     | 17     | 75     | 29     | 21         | NR     | 8      | NR       | 82       |
| Ecuador                                      | 73     | 38     | 31     | 77     | 90     | 25         | 54     | 7      | 83       | 79       |
| El Salvador                                  | 34     | 41     | 38     | 73     | 50     | 46         | NR     | 3      | NR       | 13       |
| Grenada                                      | 93     | 70     | 34     | 82     | NR     | 19         | 65     | 0      | NR       | 7        |
| Guatemala                                    | 52     | 58     | 65     | 62     | 77     | 41         | 82     | 0      | 78       | NR       |
| Guyana                                       | 8      | 83     | 24     | 68     | 76     | 76         | NR     | 0      | NR       | 95       |
| Haiti                                        | 29     | 54     | 100    | 49     | 43     | 100        | 55     | 0      | 33       | 25       |
| Honduras                                     | 40     | 56     | 40     | 67     | 56     | 52         | 57     | 12     | 48       | 13.9     |
| Jamaica                                      | 61     | 56     | 30     | 78     | 46     | 23         | NR     | 0      | NR       | 32       |
| Mexico                                       | 13     | 25     | 27     | 83     | 37     | 14         | 48     | 66     | 24       | 76.5     |
| Nicaragua                                    | 14     | 49     | 24     | 64     | 70     | 71         | NR     | 0      | NR       | 12       |
| Panama                                       | 35     | 28     | 26     | 83     | 86     | 14         | NR     | 0      | NR       | 12.9     |
| Paraguay                                     | 3      | 44     | 42     | 71     | 43     | 84.1       | 11     | 1      | 20       | 11       |
| Peru                                         | 25     | 26     | 41     | 79     | 78     | 23         | NR     | 7      | NR       | 40       |
| Puerto Rico                                  | 53     | 1      | 2      | NR     | 38     | 2          | 72     | 0      | 33       | 22       |
| Saint Kitts and Nevis                        | 3      | 79     | 37     | 80     | NR     | 6          | 65     | 0      | NR       | 1        |
| Saint Lucia                                  | 93     | 84     | 34     | 77     | NR     | 12         | 68     | 0      | NR       | 0        |
| Saint Vincent and the Grenadines             | 50     | 59     | 35     | 78     | NR     | 23         | NR     | 0      | NR       | 0        |
| Suriname                                     | 12     | 35     | 28     | 73     | 65     | 39         | NR     | 0      | NR       | 0        |
| Trinidad and Tobago                          | 62     | 100    | 11     | 81     | 64     | 2          | 68     | 5.0    | 60       | 16       |
| United States of America                     | 2      | 20     | 3      | 100    | 33     | 4          | 0      | 100    | 6        | 54       |
| Uruguay                                      | 3      | 9      | 19     | 85     | 54     | 36         | NR     | 20     | NR       | 45       |
| Venezuela (Bolivarian Republic of)           | 27     | 7      | 9      | 80     | 63     | 21         | 23     | 30     | 45       | 100      |

Table 4: Total conditions of the countries for agricultural water management based on the Eqs. 15 and 16, the desirability more than 50% shows a suitable status, the desirability between 30% and 50% shows a fairly status, and the desirability less than 30% shows a difficult status for agricultural water management (NR: Not Reported)
on agricultural water management. However, a more comprehensive study on these aspects would require further information on the Americans that are not available yet.

7 Evaluation of the sub main indexes of agricultural water management for Americas

Fig. 15 shows variations of the sub-main indexes of agricultural water management in the Americas.

According to the Fig. 15, the value of conservation agriculture area had a considerable increase whilst the value of waterlogged area decreased due to increases in pressurized irrigation as well as percentage drained area per total cultivated area (Fig. 14). From 1977 to 2002, the value of salinized area increased due to the expansion of agricultural water withdrawal and, consequently, irrigation. During that period, it is possible to see a reduction in agricultural water withdrawal (although this index may increase in case of proper use) and, thereby, in salinized area. From 2007 to 2011, drained areas are continued to increase and the positive effect of such phenomenon is the expansion of localized irrigation systems and their (Schaible and Aillery 2012) considerable impact on water conservation (Ward and Pulido-Velazquez 2008). However, the value of spate irrigation increased, which calls for specific attention to sedimentation risks that may derive from this irrigation system (Embaye et al. 2011).
Figure 15: Variations of the sub main indexes of agricultural water management in Americas (value of the sub main indexes is not available before 1977). Surface indicates value of surface irrigation to total irrigation, Sprinkler indicates value of sprinkler irrigation to total irrigation, Localized indicates value of localized irrigation to total irrigation, Spate indicates value of spate irrigation to total irrigation, Withdrawal indicates agricultural water withdrawal (10 km³/yr), Conservation indicates conservation agriculture area as percent of cultivated area (%), Salinized indicates percent of area equipped for irrigation salinized (%), Waterlogged indicates area waterlogged by irrigation (%).
Figure 16: Status of cropping intensity (equipped area) for Americas in the previous half of century
In the final step, cropping intensity (equipped area) has been studied for Americas in the previous half of century.

8 Cropping intensity (equipped area) for Americas in the previous half of century

Fig. 16 shows status of cropping intensity (equipped area) in the Americas in the past 50 years.

In the first three decades (1962-1992), a considerable change in cropping intensity could not be detected. During 1992-1997, maize, fodder, and cotton plantation areas increased while those of rice, citrus, grapes, and tea decreased. During this period, irrigation systems were used on growing wheat, barley and, other cereals, as well as vegetables, soybeans, groundnuts, sweet potatoes, leguminous crops, sugar beet, sugarcane, tobacco, flowers, plantains, and other fruits, plus coconut, and rubber (Fig. 15). The increased cropping area demanded an unprecedented increase in agricultural water withdrawal during this period (Bouwer 2002). Between 1997 and 2002, the plantation area for rice, barley, vegetables, soybeans, flowers, citrus, grapes, coconuts, tea, increased and, whereas cropping area for wheat, maize, other cereals, fodder, cotton, groundnuts, leguminous crops, sugar beet, sugarcane, tobacco, plantains, rubber, and other fruits decreased. During those years, irrigation systems were used for cassava, grass and fodder plantations for the first time. These changes led to an increase in irrigation water concessions (Fig. 14) and a significant increase in sprinkler irrigation (Fig. 15) (Winch 2006). From 2002 to 2007 (see also Schaible and Aillery 2012), the area for cultivating wheat, maize, other cereals, vegetables, groundnuts, sugar beet, sugarcane, fodder, cotton, flowers, plantains, grapes, other fruits, coconuts, and tea increased, and the opposite trend was detected for rice, soybeans, sweet potatoes, cassava, citrus, and grass and fodder. Irrigation systems were being used for sesame and bananas during those years, which also led to a decrease in irrigation water concessions (Fig. 14) and significant increase in pressurized irrigation (Fig. 15) during that period (Colalizzi 2008). From 2007 to 2011, cropping area for wheat, maize, vegetables, soybeans, groundnuts, sesame, sugarcane, cotton, flowers, tobacco, oil palm, and grass and fodder increased, while cultivated land for rice, other cereals, sugar beet, fodder, plantains, bananas, citrus, grapes, other fruits, coconuts and tea decreased. Then, irrigation systems were used for olive and coffee plantations, which led to an increase in the irrigation water requirement (Fig. 14) and to a significant increase in localized irrigation during this period (Fig. 15). Although part of cropping intensity depends on climate conditions (Lobell et al. 2008, Lobell et al. 2011) and on crop rotation (Tilman et al. 2002), trial-and-error policies (whether by governments or by farmers) lead to decreased water use efficiency (WUE) and waste of water resources. For example, during 1997 and 2002, irrigation systems were being used on cassava plantation; then, from 2002 to 2007, their use shifted to banana cultivation for the first time, only to be excluded from cropping intensity (equipped area) in the next periods (Fig. 16). Another example is when irrigation systems were being used for oil palm plantation for the first time from 1967 to 1972 (0.4%). Then, oil palm was excluded from cropping intensity (equipped area) from 1972 to 1982, and re-shifted back to oil palm planting between 1982 and 1987 (0.1%). Oil palm was later excluded from cropping intensity (equipped area) from 1987 to 2007, when a sudden 4% increase was detected in the subsequent year (Fig. 16). Note that values of water use, per kilogram output and energy value are 2 m³/kg and 0.73 m³/1000 kcal, respectively, for oil palm. While these values are 1.5 m³/kg and 0.47 m³/1000 kcal for cereals and 0.15 m³/kg and 0.49 m³/1000 kcal for sugar beet (FAO 2011b).

9 Conclusion

The goal of this study was to investigate the status of agricultural water management in the Americas during the last fifty years. A total of 18 indexes (as the main and sub main indexes) were selected to assess agricultural water management of each country based on their relevance and on other indexes that could not be included because of sparse data. The changes in the main indexes in 2011 showed that the values varied significantly across different regions due to the nature of the indexes and the conditions of each country. Subsequently, the value of area equipped for irrigation to cultivated area (or the 10th index) was estimated using the other main indexes. The obtained functions were used to estimate the mentioned index for any year (with a relative error < 20%), to assess the importance of each index for every country and to forecast changes in the 10th index based on variations in the contributing indexes in future years. Prioritization of the main indexes showed that total economically active population in agriculture to total economically active population, permanent crops to cultivated area, and value added to GDP by agriculture...
had significant effects on the estimation of area equipped for irrigation to cultivated area (10th index). The classification of the countries based on the main indexes showed that Guyana had more desirable conditions (willingness to provide better agricultural water management) for agricultural water management than the other countries. The trend of the main indexes shows that, although mechanization and use of new technologies have an important role in enhancing agricultural knowledge and increasing productivity, rural development and labor force have a vital and irreplaceable role in agricultural planning and macroeconomic perspectives. The analysis of the submain indexes showed that the values of pressurized irrigation and agricultural water withdrawal increased significantly over the period in question. Finally, the findings presented in this study warn against trial-and-error policies in regards of cropping intensity, and recommend the involvement of specialists to help plan appropriate irrigation systems according to crop/plantation type. The variations in the indice values occurred due to various parameters, such as human activities, climate change, climate variability, global warming, hydrological cycle, greenhouse gas emission, environmental issues, among others. The present study has also allowed us to create a list for the Americans regarding their strengths and weaknesses in terms of agricultural water management during the last 50 years. However, the only way to meet sustainable development in these countries is to use past experiences in future agricultural water management plans.

References

[1] Ale S., Bowling L.C., Brouder S.M., Frankenberger J.R., Youssif M.A. (2009). Simulated effect of drainage water management operational strategy on hydrology and crop yield for Drummer soil in the Midwestern United States. Agricultural Water Management. 96: 653-665
[2] Ale S., Bowling L.C., Owens P.R., Brouder S.M., Frankenberger J.R. (2010). Development and application of a distributed modeling approach to assess the watershed-scale impact of drainage water management. Agricultural Water Management. 107: 23-33
[3] Ayars J.E., Christen E.W., Hornbuckle J.W. (2006). Controlled drainage for improved water management in arid regions irrigated agriculture. Agricultural Water Management. 86: 128-139
[4] Bolliger A., Magid J., Amado J.C.T, Neto F.S., de Fatima dos Santos Ribeiro M., Calegari A., Ralisch R., de Neergaard A. (2006). Taking Stock of the Brazilian “Zero-Till Revolution”: A Review of Landmark Research and Farmers’ Practice. Advances in Agronomy. 91: 47-110
[5] Calder I.R., Hall R.L., Bastable H.G., Gunston H.M., Sheha O., Chirwa A., Kafundu R. (1995). The impact of land use change on water resources in sub-Saharan Africa: a modelling study of Lake Malawi. Journal of Hydrology. 170(1): 123-135
[6] De Salvo M, Raffaelli R & Moser R. (2013). The impact of climate change on permanent crops in an Alpine region: A Ricardian analysis. Agricultural Systems. 118: 23-32
[7] du Plessis H.M. (1985). Evapotranspiration of citrus as affected by soil water deficit and soil salinity. Irrigation Science. 6: 51-61
[8] Evans A.E.V., Giordano M., Clayton T. (Eds.). (2012). Investing in agricultural water management to benefit smallholder farmers in Ethiopia. AgWater Solutions Project country synthesis report Colombo, Sri Lanka: International Water Management Institute (IWMI). 35p. (IWMI Working Paper 152). http://dx.doi.org/10.5337/2012.215
[9] Falkenmark M. (1989). The massive water scarcity threatening Europe-why isn’t it being addressed. Ambio. 18: 112-118
[10] FAO. (2012). THE STATE OF FOOD AND AGRICULTURE. ISSN 0081-4539
[11] FAO. (2013). AQUASTAT database. http://fao.org
[12] Foley J. A., DeFries R., Asner G. P., Barford C., Bonan G., Carpenter S. R., Chapin S., Doney S. C., Field C., Galloway J., Godar T., Helkowski J.H., Holloway T., Howard E.A., Kucharik C.J., Monfreda C., Patz J.A., Prentice I.C., Ramankutty N., Snyder P. K. (2005). Global consequences of land use. Science, 309(5734): 570-574
[13] Franks T., Garces-Restrepo C., Putuhena F. (2008). Developing capacity for agricultural water management: current practice and future directions. Irrigation and Drainage. 57: 255-267
[14] Gommes R., Petra di F. (1994). Rainfall Variability and Drought in Sub-Saharan Europe Since 1960. Agro-meteorology Series Working Paper 9, Food and Agriculture Organization, Rome, Italy
[15] Hussain I. (2007). Pro-poor intervention strategies in irrigated agriculture in Asia: issues, lessons, options and guidelines. Irrigation and Drainage. 56: 119-126
[16] Hussain I., Turral H., Molden D., Ahmad M.D. (2007). Measuring and enhancing the value of agricultural water in irrigated river basins. Irrigation Science. 25: 263-282
[17] Killgore M. (2009). Recent Developments in Water Policy in the The world. World Environmental and Water Resources Congress 1-8
[18] Kirpich P., Haman D., Styles S. (1999). Problems of Irrigation in Developing Regions. Journal of Irrigation and Drainage Engineering. 125: 1-6
[19] Knox J.W., Kay M.G., Weatherhead E.K. (2012). Water regulation, crop production, and agricultural water management — Understanding farmer perspectives on irrigation efficiency. Agricultural Water Management. 108: 3-8
[20] Hendrickson M.K., James Jr H.S., Heffernan W.D. (2008). Does The world Need U.S. Farmers Even If The world Don’t? Journal of Agricultural & Environmental Ethics. 21: 311-328
[21] Lai R. (2001). Potential of Desertification Control to Sequester Carbon and Mitigate the Greenhouse Effect. Climate Changes. 51: 35-72
[22] McCready M., Dukes M. (2009). Evaluation of irrigation Scheduling Efficiency and Adequacy by Various Control Technologies Compared to Theoretical Irrigation Requirement. World Environmental and Water Resources Congress 1-19
[23] Michaels P.J. (1990). The greenhouse effect and global change: view and reappraisal. International Journal of Environmental Studies. 36: 55-71

[24] Mishra A.K., Singh V.P. (2010). A review of drought concepts. Journal of Hydrology. 391: 202-216

[25] Montenegro S.G., Montenegro A., Ragab R. (2010). Improving agricultural water management in the semi-arid region of Brazil: experimental and modelling study. Irrigation Science. 28: 301-316

[26] Muzik I. (2002). A first-order analysis of the climate change effect on flood frequencies in a subalpine watershed by means of a hydrological rainfall–runoff model. Journal of Hydrology. 267: 65-73

[27] Namara R., Munir E., Hanjra A., Castillo G.E., Ravnborg H.M., Smith L., Van Koppen B. (2010). Agricultural water management and poverty linkages. Agricultural Water Management. 97: 520-527

[28] Naiken L., Schulte W. (1976). Population and labour force projections for agricultural planning. Food Policy. 1: 192–202

[29] Neumann K., Stehfest E., Verburg P.H., Siebert S., Muller C., Veldkamp T. (2011). Exploring global irrigation patterns: A multilevel modelling approach. Agricultural Systems. 104: 703-713

[30] Plusquellec H. (2002). Is the daunting challenge of irrigation achievable? Irrigation and Drainage. 51: 185–198

[31] Rahimi S., Gholami Seifidkouhi M.A., Raeini-Sarjaz M., Valipour M. (2015). Estimation of actual evapotranspiration by using MODIS images (a case study: Tajan catchment). Archives of Agronomy and Soil Science. 61 (5): 695-709

[32] Rezaei M., Valipour M., Valipour M. (2016). Modelling evapotranspiration to increase the accuracy of the estimations based on the climatic parameters. Water Conservation Science and Engineering. 1 (3): 197-207

[33] Simenstad C.A., Jay D.A., Sherwood C.R. (1992). Impacts of Watershed Management on Land-Margin Ecosystems: The Columbia River Estuary. Watershed Management 266-306. ISBN 978-0-387-94232-2

[34] Steiner R., Keller A. (1992). Irrigation Land Management Model. Journal of Irrigation and Drainage Engineering. 118: 928–942

[35] Sukhwal B.L. (1991). Native The world water rights in the water scarce Western United States, its causes, consequences and probable solutions. Geojournal. 24: 347-354

[36] Tilman D., Cassman K.G., Matson P.A., Naylor R., Polasky S. (2002). Agricultural sustainability and intensive production practices. Nature. 418(6898): 671-677

[37] Turlal H., Svendsen M., Faures J.M. (2010). Investing in irrigation: Reviewing the past and looking to the future. Agricultural Water Management. 97: 551-560

[38] Valero C.S., Madramootoo C.A., Stampfli N. (2007). Water table management impacts on phosphorus loads in tile drainage. Agricultural Water Management. 89: 71–80

[39] Valipour M. (2016a). How Much Meteorological Information Is Necessary to Achieve Reliable Accuracy for Rainfall Estimations? Agriculture. 6(4): 53

[40] Valipour M. (2016b). Variations of land use and irrigation for next decades under different scenarios. Irriga. In Press

[41] Valipour M., Singh V.P. (2016). Global Experiences on Wastewater Irrigation: Challenges and Prospects. Balanced Urban Development: Options and Strategies for Liveable Cities. Basant Maheshwari, Vijay P. Singh, Bhadranie Thoradeniya, (Eds.). AG: Springer. Switzerland. 289-327

[42] Valipour M., Gholami Seifidkouhi M.A., Raeini-Sarjaz M., (2017a). Selecting the best model to estimate potential evapotranspiration with respect to climate change and magnitudes of extreme events. Agricultural Water Management. 180 (Part A): 50-60

[43] Valipour M., Gholami Seifidkouhi M.A., Khoshravesh M., (2017b). Estimation and trend evaluation of reference evapotranspiration in a humid region. Italian Journal of Agrometeorology. In Press

[44] Valipour M., Gholami Seifidkouhi M.A., (2017). Temporal analysis of reference evapotranspiration to detect variation factors. International Journal of Global Warming. In Press

[45] Valipour M. (2015a). Future of agricultural water management in Africa. Archives of Agronomy and Soil Science. 61 (7): 907-927

[46] Valipour M. (2015b). Calibration of mass transfer-based models to predict reference crop evapotranspiration. Applied Water Science. In Press. http://dx.doi.org/10.1007/s13201-015-0274-2

[47] Valipour M. (2014c). Analysis of potential evapotranspiration using limited weather data. Applied Water Science. In Press. http://dx.doi.org/10.1007/s13201-014-0234-2

[48] Valipour M. (2015d). Evaluation of radiation methods to study potential evapotranspiration of 31 provinces. Meteorology and Atmospheric Physics. 127 (3): 289-303

[49] Valipour M. (2015e). Temperature analysis of reference evapotranspiration models. Meteorological Applications. 22 (3): 385-394

[50] Valipour M. (2015f). Investigation of Valiantzas' evapotranspiration equation in Iran. Theoretical and Applied Climatology. 121 (1-2): 267-278

[51] Valipour M. (2015g). Long-term runoff study using SARIMA and ARIMA models in the United States. Meteorological Applications. 22 (3): 592-598

[52] Valipour M. (2015c). Land use policy and agricultural water management of the previous half of century in Africa. Applied Water Science, 5 (4): 367-395

[53] Valipour M., Montazar A.A., (2012). An Evaluation of SWDC and WinSRFR Models to Optimize of Infiltration Parameters in Furrow Irrigation. American Journal of Scientific Research 69: 128-142

[54] Valipour M. (2013a). INCREASING IRRIGATION EFFICIENCY BY MANAGEMENT STRATEGIES: CUTBACK AND SURGE IRRIGATION. ARPN Journal of Agricultural and Biological Science. 8 (1): 35-43

[55] Valipour M. (2013b). Necessity of Irrigated and Rainfed Agriculture in the World. Irrigation & Drainage Systems Engineering. S9, e001. http://omicsgroup.org/journals/necessity-of-irrigated-and-rainfed-agriculture-in-the-world-2168-9768.S9-e001.php?id=12800

[56] Valipour M. (2013c). Evolution of Irrigation-Equipped Areas as Share of Cultivated Areas. Irrigation & Drainage Systems Engineering. 2 (1): e114. http://dx.doi.org/10.4172/2168-9768.S9-e001.php?id=12800

[57] Valipour M. (2013d). USE OF SURFACE WATER SUPPLY INDEX TO ASSESSING OF WATER RESOURCES MANAGEMENT IN COLORADO AND OREGON, US. Advances in Agriculture, Sciences and Engineering Research. 3 (2): 631-640. http://vali-pour.webs.com/13.pdf
How do different factors impact agricultural water management?

[58] Valipour M. (2012a). HYDRO-MODULE DETERMINATION FOR VANAEI VILLAGE IN ESLAM ABAD GHARB, IRAN. ARPN Journal of Agricultural and Biological Science. 7 (12): 968-976

[59] Valipour M. (2012b). Ability of Box-Jenkins Models to Estimate of Reference Potential Evapotranspiration (A Case Study: Mehrabad Synoptic Station, Tehran, Iran). IOSR Journal of Agriculture and Veterinary Science (IOSR-JAVS). 1 (5), 1-11. http:/ /dx.doi.org/10.9790/2380-0150111

[60] Valipour M. (2012c). A Comparison between Horizontal and Vertical Drainage Systems (Include Pipe Drainage, Open Ditch Drainage, and Pumped Wells) in Anisotropic Soils. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 4 (1): 7-12. http:/ /dx.doi.org/10.9790/1684-0410712

[61] Valipour M. (2012d). Number of Required Observation Data for Rainfall Forecasting According to the Climate Conditions. American Journal of Scientific Research 74: 79-86

[62] Valipour M. (2014a). Application of new mass transfer formulae for computation of evapotranspiration. Journal of Applied Water Engineering and Research. 2 (1): 33-46

[63] Valipour M. (2014b). Use of average data of 181 synoptic stations for estimation of reference crop evapotranspiration by temperature-based methods. Water Resources Management. 28 (12): 4237-4255

[64] Viala E. (2008). Water for food, water for life a comprehensive assessment of water management in agriculture. Irrigation and Drainage Systems, 22(1): 127-129

[65] WBG. (2013). WBG database. http:/ /www.worldbank.org/

[66] Wu I.P., Barragan J., Bralts V. (2013). Irrigation Systems: Water Conservation. Encyclopedia of Environmental Management, Taylor & Francis.,http:/ /dx.doi.org/10.1081/E-EEM-120010068

[67] Valipour M. (2015h). Study of different climatic conditions to assess the role of solar radiation in reference crop evapotranspiration equations. Archives of Agronomy and Soil Science, 61 (5): 679-694

[68] Valipour M. (2015i). Importance of solar radiation, temperature, relative humidity, and wind speed for calculation of reference evapotranspiration. Archives of Agronomy and Soil Science, 61 (2): 239-255

[69] Yannopoulos S.I., Lyberatos G., Theodossiou N., Li W., Valipour M., Tamburrino A., Angelakis A.N., (2015). Evolution of Water Lifting Devices (Pumps) over the Centuries Worldwide. Water, 7 (9): 5031-5060