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Global experience on irrigation management under different scenarios

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Abstract

This study aims to assess global experience on agricultural water management under different scenarios. The results showed that trend of permanent crops to cultivated area, human development index (*HDI*), irrigation water requirement, and percent of total cultivated area drained is increasing and trend of rural population to total population, total economically active population in agriculture to total economically active population, value added to gross domestic production (*GDP*) by agriculture, and the difference between national rainfall index (*NRI*) and irrigation water requirement is decreasing. The estimating of area equipped for irrigation in 2035 and 2060 were studied acc. to the three scenarios: I – the values of the main indices would be changed by the same slope of the past half of century, II and III – the slopes would be decreased by 30% and 50% respectively. The minimum and maximum values of pressure on renewable water resources by irrigation, are related to the third and first scenarios by 2035 (6.1%) and 2060 (9.2%), respectively.

Key words: *irrigation, sustainable agriculture, water, world agriculture*

INTRODUCTION

Due to limitation of water resources, role of macroeconomic policies in agricultural water management is vital and undeniable. According to the Figure 1a, b, value of renewable water resources per capita is decreasing (whether based on regions or based on incomes), while value of total people undernourished is still considerable (Fig. 1c).

Therefore, pressure on renewable water resources is influenced due to demand for the food and applying irrigation systems to increase agricultural production. In the other hand, according to the Figure 2, total water withdrawal per capita has been decreased.

In Figure 2, agricultural indicates agricultural water withdrawal as percent of total water withdrawal (%), industrial indicates industrial water withdrawal as percent of total water withdrawal (%), municipal indicates municipal water withdrawal as percent of total withdrawal (%), withdrawal indicates total water

withdrawal per capita ($100 \text{ m}^3 \cdot \text{inhab}^{-1} \cdot \text{y}^{-1}$). Managed indicates total agricultural water managed area to cultivated area (%), potential indicates percent of irrigation potential equipped for irrigation (%), value of these parameters are not available before 1977.

Although agricultural water withdrawal as percent of total water withdrawal has been decreased due to industries and population growth as well as applying pressurized irrigation and management strategies to increase of efficiency, but more than 40% of irrigation potential is not developed yet.

As a result, the most pressure on renewable water resources is related to the agricultural sector and irrigation has the maximum water withdrawal in agriculture. Hence, the increase of pressure on renewable water resources by irrigation is possible and important in the future.

Although actual crop yield as percentage of potential yield is more than 60% for North America, and Western and Central Europe, it is less than 50% for

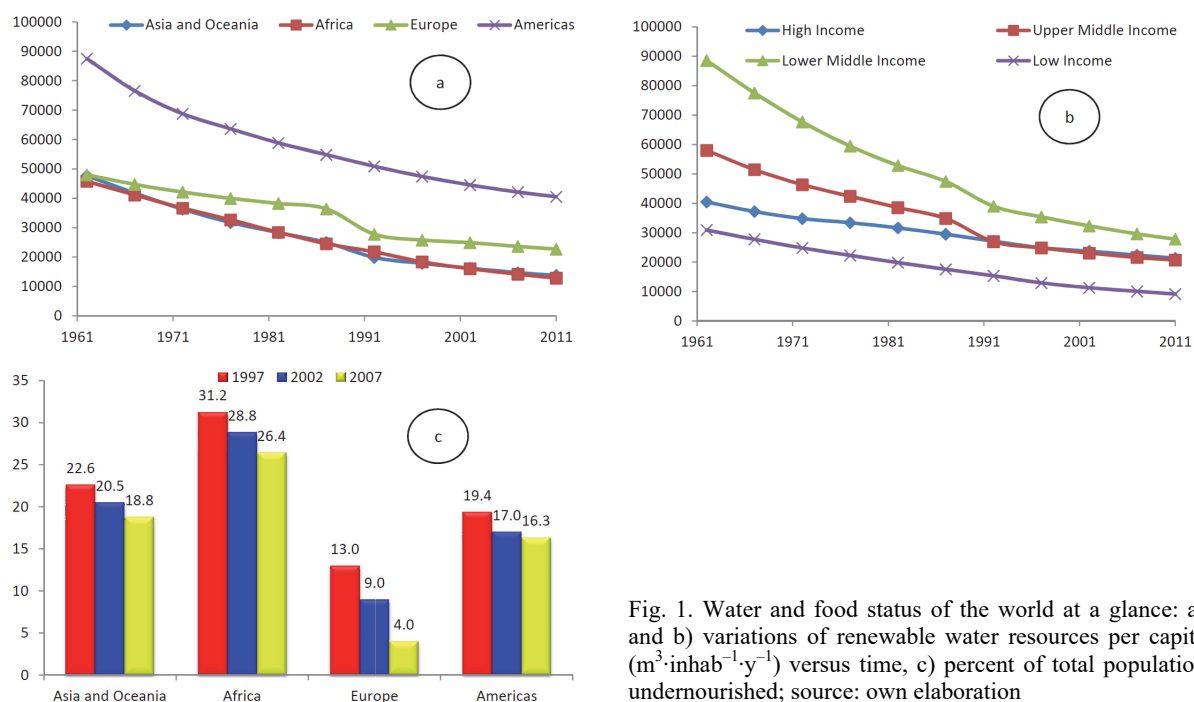


Fig. 1. Water and food status of the world at a glance: a) and b) variations of renewable water resources per capita ($\text{m}^3 \cdot \text{inhab}^{-1} \cdot \text{y}^{-1}$) versus time, c) percent of total population undernourished; source: own elaboration

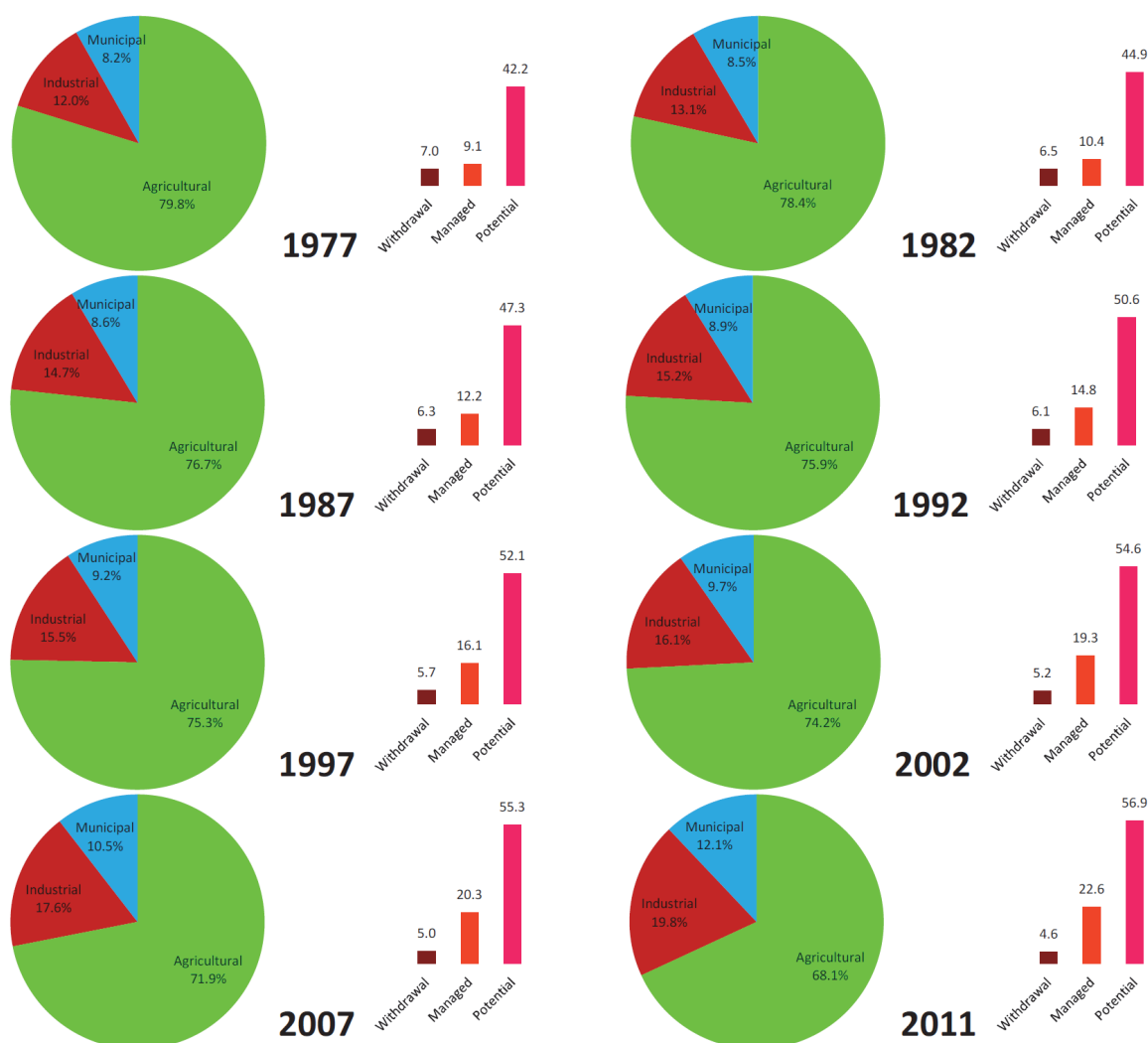


Fig. 2. Status of renewable water resources and agricultural water management in the previous half of century; source: own study

South America and North Africa and it is about 30% for Central America and the Caribbean, Eastern Europe, and Sub-Saharan Africa [FAO 2012].

Therefore, studying agricultural water management due to its role on renewable water resources is still reasonable in the world.

The different aspects of irrigation in agricultural water management, such as irrigation efficiency [VALIPOUR, MONTAZAR 2012], soil salinity [DU PLESSIS 1985], water-saving [MONTENEGRO *et al.* 2010; VALIPOUR 2016a, b, c], sustainable development [VALIPOUR 2014a, b; VALIPOUR 2017; VALIPOUR *et al.* 2012; YANNOPOULOS *et al.* 2015], soil water management [STEINER, KELLER 1992], evapotranspiration [MCCREADY, DUKES 2009; VALIPOUR 2014a, b; 2015a, b, c, d, e, f, g, h, i; VALIPOUR, ESLAMIAN 2014; VALIPOUR *et al.* 2017a, b; VALIPOUR, GHOLAMI SEFIDKOUHI 2017] and crop yield [WU *et al.* 2013] have been investigated in previous works. TURRAL *et al.* [2010] showed that investment is one of the most effective factors on area equipped for irrigation to 2050. NEUMAN *et al.* [2011] cited that area equipped for irrigation to be expanded by 40 million ha, by 2030. PLUSQUELLEC [2002] claimed that area equipped for irrigation would be increased by 15% to 22% for 2025. KNOX *et al.* [2012] claimed demonstrating efficient or 'best' use of water is not straightforward in England, but farmers and the water regulator needed a rational approach that reflects the needs of the farming community whilst providing a policy framework for protecting the environment. NAMARA *et al.* [2010] mentioned role the of agricultural water management to reduce poverty in the world as three pathways. Those are improvement of production, enhancement of employment opportunities and stabilization of income and consumption using access to reliable water, increasing high-value products, and finally its role to nutritional status, health, societal equity and environment. They preferred improving the management of existing systems as a selected strategy in Asia. VALIPOUR [2013a, b, c, d, e] mentioned the status of irrigated and rainfed agriculture in the world, summarized the advantages and disadvantages of irrigation systems, and attended to update of irrigation information to choose an optimum decision. His results showed that 46% of cultivated areas in the world are not suitable for rainfed agriculture because of climate changes and other meteorological conditions. FRANKS *et al.* [2008] studied developing capacity for agricultural water management in current practice and future directions. They suggested increased attention to monitoring and evaluation of capacity development, and closer links to emerging work on water governance. FERREYRA *et al.* [2008] concluded that, instead of forcing watershed-based governance structures, the exploration and examination of more creative and flexible ways of linking watershed imperatives to existing socially and politically meaningful scales in agricultural areas of Ontario and elsewhere was warranted. DE LOE *et al.* [2001] studied agricul-

tural water use in Ontario. They have claimed that future water allocation decisions must take account of the distribution of agricultural water withdrawals, especially those for irrigation, which are strongly seasonal. The previous researches are about a limited area and cannot apply them to other regions or did not consider role of all important indices for estimation of agricultural water management and the value of pressure on renewable water resources. Thus, the goal of this study is an estimation of pressure on renewable water resources by irrigation using to establish a link for more important parameters in agricultural water management based on available data in the world.

METHODS

Many variables are required to obtain the amount of area equipped for irrigation to cultivated area for cropping pattern design, macroeconomic decisions, and allocation of water resources. However, we cannot consider all parameters due to lack of adequate data. In this study, using AQUASTAT database [FAO 2013], 10 main indices were selected to assessment of agricultural water management in the world and values of them were checked using WBG database [WBG 2013]. Then, values of area equipped for irrigation and pressure on renewable water resources by irrigation were estimated in 2035 and 2060 using three different scenarios.

ESTIMATION OF EQUIPPED AREA AND ITS PRESSURE ON RENEWABLE WATER RESOURCES IN 2035 AND 2060

To estimate area equipped for irrigation in 2035 and 2060, in the first step, the author studied variations of the main indices during the past half of century using linear regression and R^2 value, then the amount of each index was estimated in 2035 and 2060 by obtained equations and three different scenarios. In the first scenario (scenario I), the author assumed that the values of the main indices would be changed by the same slope of the past half of century (Fig. 3a). However, changes of the indices show that rate of increase or decrease has been reduced in the current years. Hence, in the second (scenario II) and third (scenario III) scenarios, the author assumed that the slopes would be decreased by 30% and 50% respectively. Therefore new values of the indices (in 2035 and 2060) were computed using these new slopes. In the second step, variations of area equipped for irrigation versus the other main indices were surveyed and a linear equation with related R^2 was computed for each index. In the next step, values of area equipped for irrigation (for each index and each scenario) were determined using replacement of obtained values for each index in 2035 and 2060 (the first step) in linear equation of the second step. Finally, a relationship has been established between calculated data (for area equipped for irrigation) as:

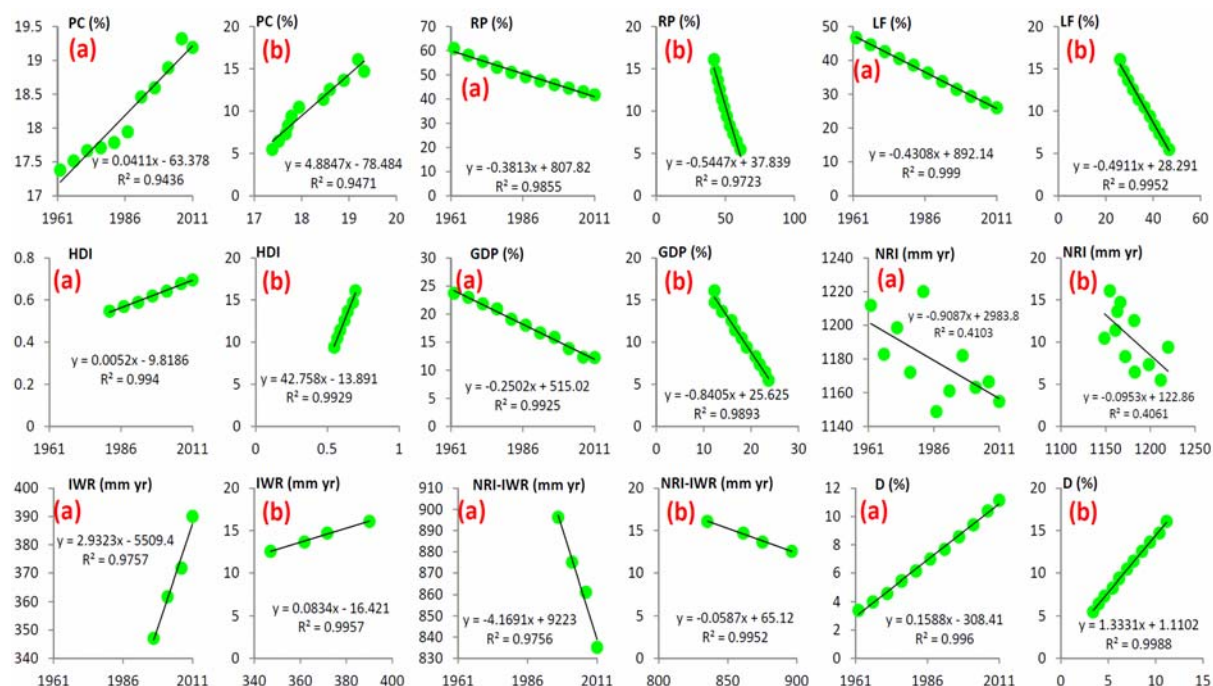


Fig. 3. Variations of the main indices versus time and area equipped for irrigation: (a) horizontal axes are time (year) and vertical axes are the indices and (b) horizontal axes are the indices and vertical axes are area equipped for irrigation (%), value of x in (b) is equal to value of y in (a); PC = permanent crops to cultivated area; RP = rural population to total population; LF = labour force = total economically active population in agriculture to total economically active population; HDI = human development index; GDP = value added to gross domestic product by agriculture; NRI = national rainfall index; IWR = irrigation water requirement; D = percent of total cultivated area drained; $NRI - IWR$ = the difference between NRI and IWR ; source: own study

$$I_{10} = \frac{\sum (y R^2)}{\sum R^2} \quad (1)$$

where, y is obtained value for area equipped for irrigation in the second step (Fig. 3b) and values of R^2 showed in the Figs 3b. Finally, pressure on renewable water resources by irrigation estimates using trend between renewable water resources and equipped area.

EVALUATION OF THE MAIN INDICES OF AGRICULTURAL WATER MANAGEMENT IN THE PAST HALF OF THE CENTURY

Figure 3 shows variations of the main indices versus time and area equipped for irrigation. According to the Figure 3a values of permanent crops to cultivated area, HDI , irrigation water requirement, and percent of total cultivated area drained have been increased and values of rural population to total population, economically active population in agriculture, value added to GDP by agriculture, and the difference between NRI and irrigation water requirement have been decreased in the previous half of the century. Thus, role of permanent crops to cultivated area, HDI , irrigation water requirement, and percent of total cultivated area drained is increasing for area equipped for irrigation and it is decreasing for the other indices (Fig. 3b). In addition, a significant change is observable in the middle of 1980s for permanent crops to

cultivated area. Although more values of this index can be helped to better scheduling for allocation of required water, it is dependent to climate conditions [DE SALVO *et al.* 2013; VALIPOUR 2012a, b, c, d], tendency of farmers [BOLLIGER *et al.* 2006], and government's policy [SUKHWAL 1991]. Previous researches show the advantages of rural development on agricultural water management and sustainable agriculture [EVANS *et al.* 2012]. Effect of proper labour force on water management and improvement of sustainable agriculture has been studied in a lot of researches [NAIKEN, SCHULTE 1976]. However, slope of reduction of rural population to total population and total economically active population in agriculture to total economically active population is more than increasing slope of HDI in the world. It is a big warning [HUSSAIN 2007] because although mechanization and use of new technologies have an important role in the enhancement of agricultural knowledge and increasing productivity [KIRPICH *et al.* 1999], labour force has a vital and irreplaceable role in agricultural scheduling and macroeconomic perspectives [HENDRICKSON *et al.* 2008]. The HDI index as a weighted measure of the Falkenmark indicator [FALKENMARK 1989] in order to account for the ability to adapt to water stress is termed the Social Water Stress Index.

According to the Fig. 3a, the value of NRI is variable during the past half of century due to many different factors such as greenhouse gases [LAL 2001], global warming [MICHAELS 1990], climate change

[MUZIK 2002] etc. and linear regression is not suitable for evaluation of its trend.

Thus, there is not a significant trend between variations of *NRI* and area equipped for irrigation (Fig. 3b). Due to the mentioned cases, the role of this index has not been considered in estimation of area equipped for irrigation in 2035 and 2060.

After GOMMES and PETRASSI [1994], this index was known as a considerable factor in drought studies [MISHRA, SINGH 2010]. Variation of irrigation water management can be effected on river basin management [SIMENSTAD *et al.* 1992], water allocation policy and agricultural expansion.

The difference between *NRI* and irrigation water requirement is known as water deficit and the regions with negative values of that have a critical status for water resources management [HUSSAIN *et al.* 2007].

Previous studies notify 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.* 2010].

ESTIMATION OF AREA EQUIPPED FOR IRRIGATION TO CULTIVATED AREA AND ITS PRESSURE ON RENEWABLE WATER RESOURCES USING THE OTHER MAIN INDICES OF AGRICULTURAL WATER MANAGEMENT

According to the Table 1, if the current decreasing trend continues, we will meet the world without value added to *GDP* by agriculture in the future. In addition, decreasing slope for rural population to total population and labour force is warning. In the Table 1, the minimum value for equipped area is related to *HDI* (16.1% in the scenario III by 2035) and the maximum value is related to irrigation water requirement and difference between *NRI* and irrigation water requirement (27.9% the scenario I by 2060). The similar values show that all selected indices are important and their selection is reasonable to study of agricultural water management and estimation of area equipped for irrigation in the future. In the Table 2, values of pressure on the renewable water resources by irrigation that estimated using Figure 4 have been presented.

Table 1. Estimated values for the main indices (*PC*, *RP*, *LF*, *HDI*, *GPD*, *IWR*, *D* and *NRI – IWR*)

Parameter	Scenario I				Scenario II				Scenario III			
	2035		2060		2035		2060		2035		2060	
	a	b	a	b	a	b	a	b	a	b	a	b
<i>PC</i> , %	20.3	20.5	21.3	25.5	20.0	19.0	20.7	22.6	19.8	18.1	20.3	20.6
<i>RP</i> , %	31.9	20.5	22.3	25.7	34.6	19.0	27.9	22.6	36.5	18.0	31.7	20.6
<i>LF</i> , %	15.5	20.7	4.7	26.0	18.6	19.2	11.0	22.9	20.6	18.2	15.2	20.8
<i>HDI</i>	0.763	18.8	0.893	24.3	0.726	17.1	0.817	21.0	0.701	16.1	0.766	18.9
<i>GDP</i> , %	5.9	20.7	0.0	25.6	7.7	19.2	3.3	22.9	8.9	18.2	5.7	20.8
<i>IWR</i> , mm·yr ⁻¹	457.8	21.8	531.1	27.9	436.7	20.0	488.0	24.3	422.6	18.8	459.3	21.9
<i>NRI – IWR</i> , mm·yr ⁻¹	738.9	21.7	634.7	27.9	768.9	20.0	695.9	24.3	788.9	18.8	736.8	21.9
<i>D</i> , %	14.7	20.8	18.7	26.1	13.6	19.2	16.4	23.0	12.8	18.2	14.8	20.9

Explanations: *PC*, *RP*, *LF*, *HDI*, *GPD*, *IWR*, *NRI – IWR*, *D* as at Fig. 3a; a estimated using the equations related to the Figs 3a, b estimated using the equations related to the Figs 3b.

Source: own study.

Table 2. Estimated values for area equipped for irrigation and pressure on renewable water resources by irrigation

State in year 2011	Scenario I		Scenario II		Scenario III	
	2035	2060	2035	2060	2035	2060
Area equipped for irrigation, %						
16	20.7	26.1	19.1	22.9	18.0	20.8
Pressure on renewable water resources, %						
5.5	7.1	9.2	6.5	8.0	6.1	7.2

Source: own study.

As seen in the Table 2, the minimum change related to the scenario III by 2035 (11.4%) and the maximum change related to the first scenario by 2060 (66.6%). Thus, pressure on renewable water resources will increase in the future and it can be considered in many different sections. As shown in the Figure 5, percent of area equipped for irrigation by surface water has been increased and instead percents of area equipped for irrigation by groundwater and mixed surface water and groundwater have been increased.

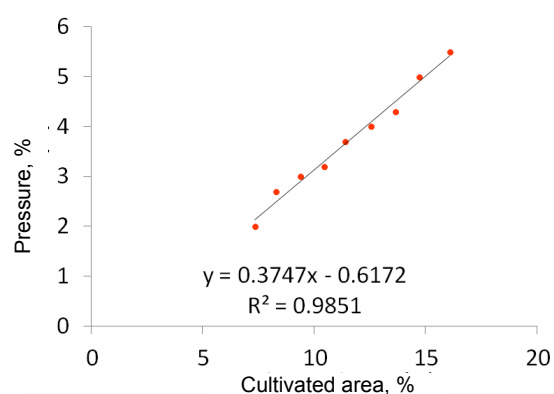


Fig. 4. Trend between pressures on renewable water resources by irrigation versus area equipped for irrigation to cultivated area in the previous half of century; source: own study

These lead to increase of pump stations to extraction of groundwater. In other hand, the tendency to pressurized irrigation systems due to their advantages

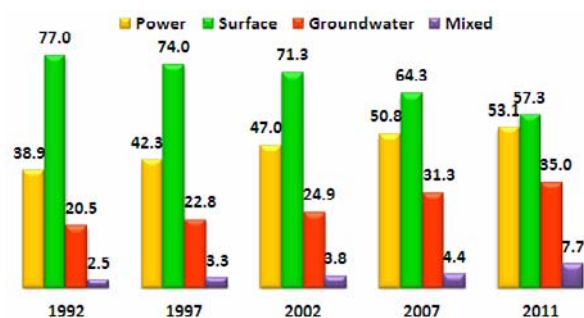


Fig. 5. Pressure on water resources in the previous two decades, surface indicates percent of area equipped for irrigation by surface water (%), groundwater indicates percent of area equipped for irrigation by groundwater (%), mixed indicates percent of area equipped for irrigation by mixed surface water and groundwater (%), power indicates percent of area equipped for irrigation power irrigated (%); source: own study

increases the need to electrical energy. Hence, percent of power irrigation has been increased (Fig. 5). So, estimation of area equipped for irrigation can be helped not only for estimation of its pressure on renewable water resources but also for the study of many different aspects of its impact on the science involved with irrigation and water resources. Although we can estimate area pressure on renewable water resources for after 2060, but it is advised that we update our information every year, every decade, or at least every half of the century.

CONCLUSION

Results showed that trend of permanent crops to cultivated area, human development index (*HDI*), irrigation water requirement, and percent of total cultivated area drained is increasing and trend of rural population to total population, total economically active population in agriculture to total economically active population, value added to *GDP* by agriculture, and the difference between *NRI* and irrigation water requirement is decreasing. The minimum and maximum values of pressure on renewable water resources by irrigation, are related to the third and first scenarios by 2035 (6.1%) and 2060 (9.2%), respectively.

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Globalne doświadczenie w zarządzaniu nawodnieniami z różnymi scenariuszami

STRESZCZENIE

Celem badań była ocena doświadczenia w zarządzaniu wodą w rolnictwie z różnymi scenariuszami. Zaobserwowano rosnący trend trwałych upraw na obszarach rolniczych, zwiększenie indeksu rozwoju społecznego (*HDI* – ang. human development index), zapotrzebowania na wodę do nawodnień i udziału drenowanych obszarów rolniczych oraz malejący trend udziału ludności wiejskiej, udziału ludności gospodarczo zaangażowanej w rolnictwie w stosunku do całkowitej liczby ludności aktywnej zawodowo, zwiększenie udziału w gospodarce wartości dodanej brutto w rolnictwie oraz zwiększenie różnicy między wskaźnikiem opadu (*NRI* – ang. national rainfall index) a zapotrzebowaniem na wodę do nawodnień. Powierzchnię do nawodnień planowaną na lata 2035 i 2060 r. oszacowano według trzech scenariuszy: I – wartości głównych wskaźników będą zmieniały się w taki sam sposób przez pół wieku, II i III – zmniejszenie wskaźników będzie następowało odpowiednio z nachyleniem 30 i 50%. Minimalne i maksymalne wartości presji nawodnień na zasoby wodne w odniesieniu do scenariusza trzeciego do 2035 r. i pierwszego do 2060 r. wynosiły odpowiednio 6,1% i 9,2%.

Słowa kluczowe: nawadnianie, światowe rolnictwo, woda, zrównoważone rolnictwo