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Research Article

Adoption of High Efficiency Irrigation Systems to Overcome Scarcity of Irrigation Water in Pakistan

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Abstract: Water resources of Pakistan are dwindling but its water needs are continuously rising due to tremendous increase in population and urbanization. Fulfillment of increasing water demands is a challenge for the policy makers, planners, researchers as well as the end water users. Under the situation of looming water resources development in the country, efficient and economical use of existing water resources is inevitable. Unfortunately, efficiency of existing irrigation method which is predominately surface irrigation is less than 40 percent. Inadequate storage of surface water, sedimentation of existing reservoirs, falling groundwater levels, low land and water productivities are some of the major challenges of water resources in the country. The relevant literature tells that irrigation efficiency of pressurized irrigation systems, particularly of drip irrigation, is more than double the efficiency of traditional surface irrigation methods. Due to competitive water demands, it is very unlikely that in future more water will be made available to the agriculture sector. Thus agriculture is facing the challenge of 'producing more with less water'. Climate change is further intensifying this challenge due to more variability, increased frequency and intensity of extreme hydrologic events. Under these scenarios, accelerated and sustainable adaption of pressurized irrigation especially drip irrigation must be implemented judiciously (not just experimenting as has been done in the last 4-5 decades) to fulfill future water needs as illustrated for different countries in this article. For instance, in the United States, California State which contributes about 50 percent of its total production of vegetables, fruits and nuts in addition to cereal crops. Results of a study revealed that 30 percent of the irrigators' switched from surface irrigation (gravity) to drip irrigation from 1972 to 2001 in this state. Comparison of data for the last 3 decades in California further revealed consistent trend of decreasing use of surface irrigation and there is corresponding increase in high efficient drip irrigation. Due to water conservation and adaption of high efficiency irrigation systems (HEIS), proportion of irrigation water has reduced by 27 percent in China and 35 percent in Australia. Similarly, more examples cited in the paper also demonstrate rapid adaption of pressurized irrigation to fulfill increasing irrigation water demands. Therefore, to meet increasing irrigation demands, meticulous adaption of sustainable pressurized irrigation system is proposed along with other measures such as growing of short duration & drought resisting crop varieties, promoting water conservation and rain-water harvesting, deficit irrigation and other similar measures.

Keywords: Water resources, irrigation methods, surface, sprinkler and drip irrigations, water saving, water productivity

1. INTRODUCTION

Water is critically important for socio-economic uplift and development of any country. Increasing water scarcity and efficient use of existing water resources is becoming a global challenge. Irrigation is considered inevitable for survivable of mankind particularly in the arid and semi-arid regions of the world. About 40 percent of world's food requirements are currently met by only 17 percent of irrigated agriculture [1]. Agriculture based economy of Pakistan is highly dependent on irrigation which accounts for more than 90 percent

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of its crop production. The irrigation system of Pakistan comprises of three major reservoirs, 16 barrages, two head works, two syphons, 12 link canals, 44 canal commands, and more than 140,000 watercourses. Although Pakistan possesses one of the largest contiguous gravity flow irrigation network but it is confronted with many issues such as low irrigation efficiency and water productivity, under designed capacity, old infrastructure requiring extensive maintenance, water scarcity and its inequity and many more.

Irrigated agriculture is the largest water consumers and it contributes more than one-third of the food supply all over the world. Worldwide around 93 percent water is consumed by the agriculture, 4 percent by the industry and 3 percent by the municipality [2].The agriculture sector is often criticized for low efficiency and excessive water losses. Due to competitive water demands of the other sectors (industry and municipality); it is very unlikely that more water resources will be made available for agriculture sector in future. Furthermore, due to increase in population and prosperity, there is continuous increase in food, fiber and shelters requirements to fulfill the basic needs of the human beings. Thus to meet the increasing food requirements, the irrigated agriculture has to be more- efficient, cost effective, reliable and flexible which may be accomplished by rehabilitation and modernization of the irrigation systems.

Water may be applied to the crops mainly by surface (gravity driven), sprinkler and drip irrigation methods. In the first method, water moves over the soil surface to lower parts of the fields resulting in more water losses. This is the traditional and predominated irrigation method used by the farmers in Pakistan and many other countries. Basin, border and furrow are the main types of surface irrigation. Efficiency of the surface irrigation methods is very low ranging from 30 to 50 percent. In the pressurized irrigation systems (sprinkler and drip) also called High Efficiency Irrigation Systems (HEIS) pipes are used to convey water from the source to the points of use and therefore efficiency of these methods is much higher than the surface irrigation methods. Although the pressurized irrigation systems are costly but water saved and other benefits (increase in yield, saving in labor, etc.) often overshadow the cost.

In future, existing irrigation water supplies will be under more stress due to increasing urbanization and industrialization. More economic value of water for the non-agricultural water use puts increasing stress on the existing irrigation water supplies. Objective of this paper is to search the literature to explore how increasing irrigation water demands should be fulfilled in future, particularly in Pakistan as well as in other developing countries in general.

Water Supply

Pakistan has become one of the most water starving country in the world. In Pakistan, per capita water availability has reduced drastically from nearly 5,260 m^3in 1951 to about 1,040 m^3in 2010 [2] for population of approximately 190 million. This situation will further worsen with projected increase in population of about 230 million by 2025. It is projected that per capita water availability will decrease to about 800 m^3 by year 2025, making Pakistan a water scarce country. Currently, Pakistan is confronted with different water challenges including but not limiting to severe water shortage, inadequate storage, reduction in storages capacities of the existing reservoirs due to sedimentation (0.2 million acre-feet, MAF per year), low irrigation (system) efficiency (less than 40%), low land and water productivities, mining of groundwater, and many more [3].

Surface water and groundwater are the major source of water in the country. For the last four decades since commissioning of Tarbela dam, there has been no appreciable addition of surface water storage (except raising of Mangla dam) resulting in decreasing canal water diversion. The canal water diversion reached to 105 MAF during the last decade of the twentieth century but now it has reduced to 94 MAF in spite of increase in irrigation water demands. The canal water diversion is almost constant for the summer (‘kharif’) season whereas it has substantially decreased in the winter (‘rabi’) season when wheat crop is grown which is the main staple food crop of Pakistan.

The available surface water supplies are insufficient to fulfill crop water needs. The deficiency of surface water supply is partially fulfilled by groundwater which is mainly underlain in most of the areas in the country. Large scale groundwater pumping projects (commonly called Salinity Control and Reclamation Projects, SCARPs) were initiated in the public sector during 1960's to late 1980's to pump groundwater to supplement canal water supplies. But now the private sector has surpassed the public sector and nearly 40-50 percent of irrigation water requirements are met by pumping groundwater. However, high pumping cost, present energy crises and high salt contents of groundwater are major obstacles of using groundwater. Nevertheless, due to severe canal water shortage, groundwater is pumped desperately to make up shortage of canal water supplies. Due to more salts contained in groundwater as compared to canal water, continuous use of groundwater for longer time normally threatens sustainability of agriculture lands unless appropriate measures are adopted. Furthermore, declining water table and mining the aquifer are the other issues which have outcrop in some areas in the country.

Apart from high losses from the irrigation system, low crop yields per unit of both land and water are the other issues faced by the irrigated agriculture in Pakistan (Table 1). Average crop yields in Pakistan are much lower than the other countries but yields of the progressive farmers are comparable. Thus there is potential for increasing average yields provided better inputs are used by the common farmers. Astonishingly, water productivity in Pakistan is the lowest than all the other countries which is only one-third of India and much less of the other countries (last column of the table).

It is evident from the foregoing discussion that irrigation water supplies in Pakistan are constantly under severe stress and water use is very inefficient. Due to social, financial, environmental and geopolitical situation, chances of construction of new dams are very bleak and even if additional surface water is added to the system, it will hardly meets the storage capacity lost due to sedimentation of existing reservoirs. The groundwater which has supplemented the canal water supplies during the last many decades is also touching its safe potential yield. Thus under the stated circumstances efficient use of available water resources is inevitable which is possible by adopting high efficiency irrigation systems which has been done in many countries which is illustrated and discussed in the next section through literature search.

2. EXAMPLES OF ADOPTION OF HIGH EFFICIENCY IRRIGATION SYSTEMS IN DIFFERENT COUNTRIES

2.1 United States of America

Total irrigated land in USA is 24.75 million hectares (61.15 million acres) which is only 14.3 percent of its total arable land. Five states namely Arkansas, California, Idaho, Nebraska and Texas

Table 1. Land and water productivities in different countries, 2005 [4, 5].

Country\crop	Wheat (kg/ha)	Cotton (kg/ha)	Rice (Paddy) (kg/ha)	Maize (kg/ha)	Sugarcane (kg/ha)	Country	Water Productivity (kg/m^3)
World	2,906	1,949	4,019	4,752	65,597	Canada	8.72
China	4,227	3,379	6,266	5,153	66,063	America	1.56
India	2,717	850	3,007	1,939	61,952	China	0.85
Egypt	6,006	2,603	9,538	8,095	121,000	India	0.39
Mexcio	5,151	-	-	2,563	70,070	Pakistan	0.13
France	6,983	-	-	8,245	-	-	-
Pakistan							
Average	2,586	2,280	1,995	2,848	48,906	-	-
Progressive farmers	4,500	2,890	4,580	7,455	106,700		

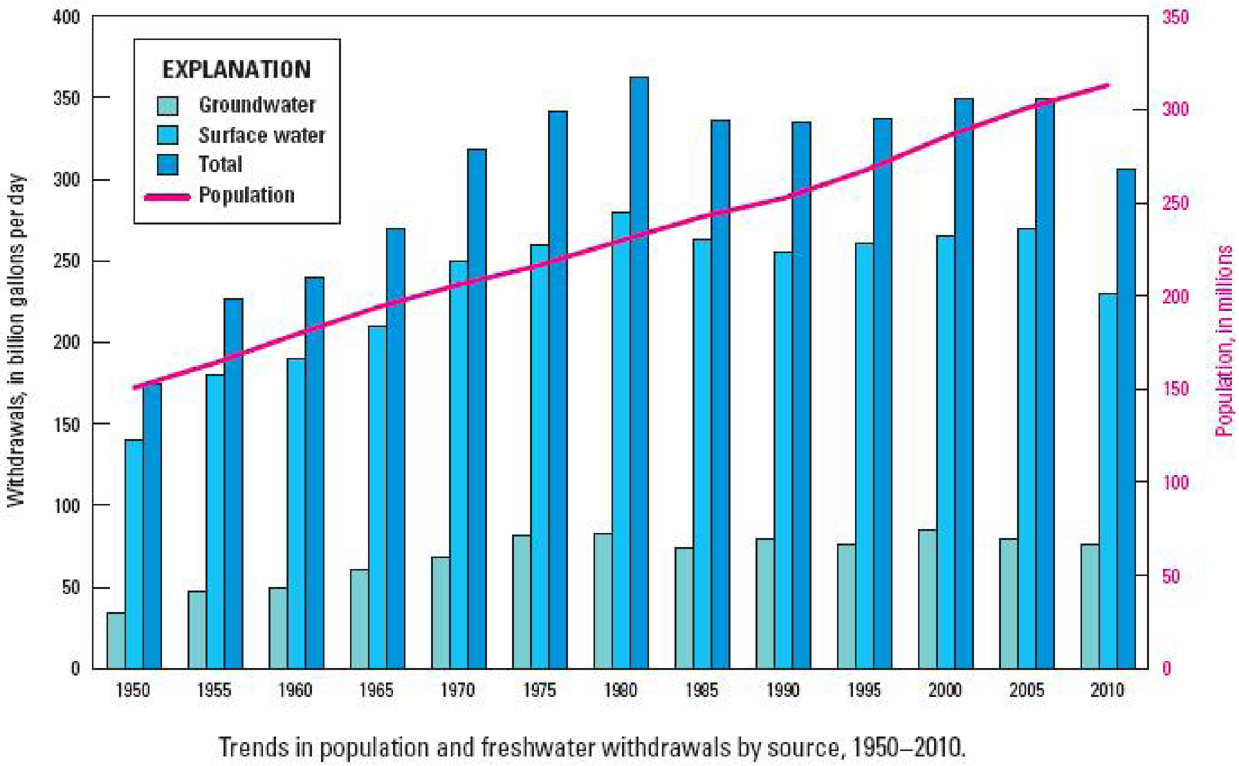

Fig. 1. Population increase and trends of irrigation water use in USA [7].

have more than half of the irrigated land (52 %) of USA. Irrigation water supply and irrigated area for year 2005 by different irrigation methods in the United States is summarized in Table 2 [6]. Nearly 56 percent of total irrigated land in USA is irrigated by HEIS (Sprinkler and micro-irrigation) and 44 percent by surface irrigation methods. Total irrigation diversion/withdrawal is 144 MAF which is only 37 percent of total water supply of USA. The irrigation water supply consists of 84 MAF (58 %) from surface water and 60 MAF (42 %) from groundwater.

Trend of irrigation water use for 60 years from 1950 to 2010 is shown in Fig. 1 along with population growth [7]. It is evident from this figure that maximum water use was in year 1980 and thereafter it remained fairly steady in spite of increase in population, irrigation demands and other water uses. In the last 35 years, increase in irrigation water needs was primarily met through water conservation and by increasing efficiency of the irrigation methods.

Water supply and irrigated areas in top ten States of USA are given in Table 3 as reported by Johnson et al. 2011 [8]. Irrigated area in Nebraska

Table 2. Irrigation diversion (withdrawal) and irrigated land by different irrigation methods in USA in year 2005 [6].

Surface water (million acre-feet)	Ground-water (million acre-feet)	Total (million acre-feet)	Area Surface	irrigated Sprinkler (million acres)	by Micro-irrigation	Total irrigated land (million acres)
84 (74,400)[1]	60 (53,500)	144 (127,900)	26.6	30.5	4.05	61.15
58[2]	42	100	44	50	6	100

[1]The values in parentheses are in million gallons per day.
[2]Values are in percent.

Table 3. Irrigated land and water applied in top ten States in USA [8].

Name of State	Irrigated Land (million acres)	Water Withdrawal (MAF)	Name of State	Irrigated Land (million acres)	Water Withdrawal (MAF)
Nebraska	8.56	6.70	Colorado	2.87	4.54
California	8.02	22.60	Kansas	2.76	3.15
Texas	5.01	6.82	Montana/Arizona	2.01	4.62
Arkansas	4.46	8.63	Oregon	1.85	3.28
Idaho	3.30	6.23	Washington	1.74	3.78

Table 4. Percentage of land irrigated by different irrigation methods in top five States of USA [7–12].

Irrigation Method	California[9]	Nebraska[8]	Arkansa[11]	Idaho[10]	Texas[12]	USA[7]
Surface	43	20	82	40	19	50
Sprinkler	15	80	18	59	78	44
Micro-irrigation	42	-	-	1	3	6

and California is almost same but the water supply in Nebraska is only 30 percent of the later. Average water applied per unit of irrigated land is more in California (86.4 cm per hectare) and much less in Nebraska (less than 25.5 cm per hectare) of the top 5 States in 2008. One reason of more water applied per unit of land may be surface irrigation method which is being used in 43 percent of the irrigated land in California as compared to only 20 percent in Nebraska (Table 4). In Nebraska, sprinkler irrigation is used on 80 percent of its irrigated land primarily by Center-pivot sprinkler systems (98 percent) which are highly mechanized and an efficient type of sprinkler irrigation method.

2.2.1 California

California is one of the main agricultural state situated in west of USA where crops can be grown around the year like in Pakistan. In this state, data were collected from the farmers regarding the irrigation method(s) used by them in year 1991 and 2001. One-page Performa was sent to 58,000 farmers [13]. Data of 2001 indicated 30 percent reduction in surface irrigation and a corresponding increase in drip and micro-systems from 1972 to 2001. This trend was even accelerated in the last decade of the 20th century wherein surface irrigation decreased by 28 percent followed by corresponding increase of HEIS methods. Results of recent survey (2010) are compared in Table 5 [9] for the four irrigation methods (surface, sprinkler, micro-sprinkler and drip, and subsurface). These data indicate that replacing less efficient surface irrigation method with more efficient micro-sprinkler and drip methods is continued but at lower rate than the previous (1991-2001) decade. Data of surface and low volume (micro-sprinkler and drip) irrigation methods are also plotted in Fig.

Table 5. Land irrigated by four irrigation methods in different years in California, (in %age) [9, 13].

Method / Year	1991	2001	2010
Surface	67	50	43
Sprinkler	17	16	15
Micro & Drip	15	33	39
Subsurface	1	2	3
Total	100	100	100

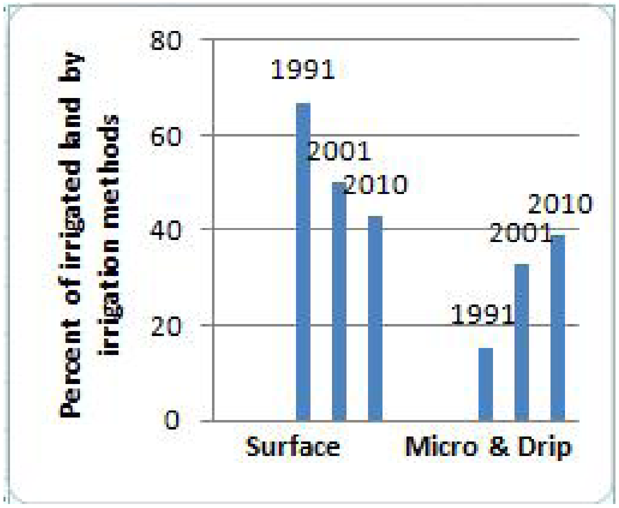

Fig. 2. Comparison of irrigated land by surface, micro-sprinkler and drip irrigation methods in different years in California.

2 which shows clear trend of decreasing gravity irrigation method and corresponding increase of micro-sprinkler and drip irrigation systems.

2.1.2 Texas

Texas is another state situated in south of the United States where crops are mostly grown in summer season (April to November) except grain crops (wheat, barley, etc.) which are also grown in the winter season. Rapid conversion of gravity irrigation into sprinkler irrigation is evident in this state (Fig. 3) for the last fifty years [12]. In year 2008, 78 percent of the total land in Texas was irrigated by sprinkler systems mainly by center-pivot sprinkler systems.

2.2 China

Over the last one-half century, China has made remarkable growth in agricultural which may be called a miracle of China. Presently, China is feeding 22 percent of the world population from only 7 percent of the world arable land and 6 percent of the world water resources [14]. Irrigation is playing a vital role in food security in China by producing 75 percent of its total grain production, 80 percent of cotton, and 90 percent of fruits and vegetables from 48 percent of its irrigated land [15]. In spite of this marvelous contribution of the irrigation sector, proportion of irrigation water has declined from over 90 percent in 1950's to 65 percent in 2009 [16-17] as given in Table 6. Average water use efficiency or water productivity of three main crops (rice, wheat and maize) in China is 1.12 kg per m^3. Increase in crop yield has been attributed to high-yielding crop varieties, irrigation and other farm inputs. Presently, about 8 Mha of land is irrigated by HEIS in this country.

2.3 Australia

Irrigated land in Australia is about 2.5 million hectares which is only 5 percent of its total arable

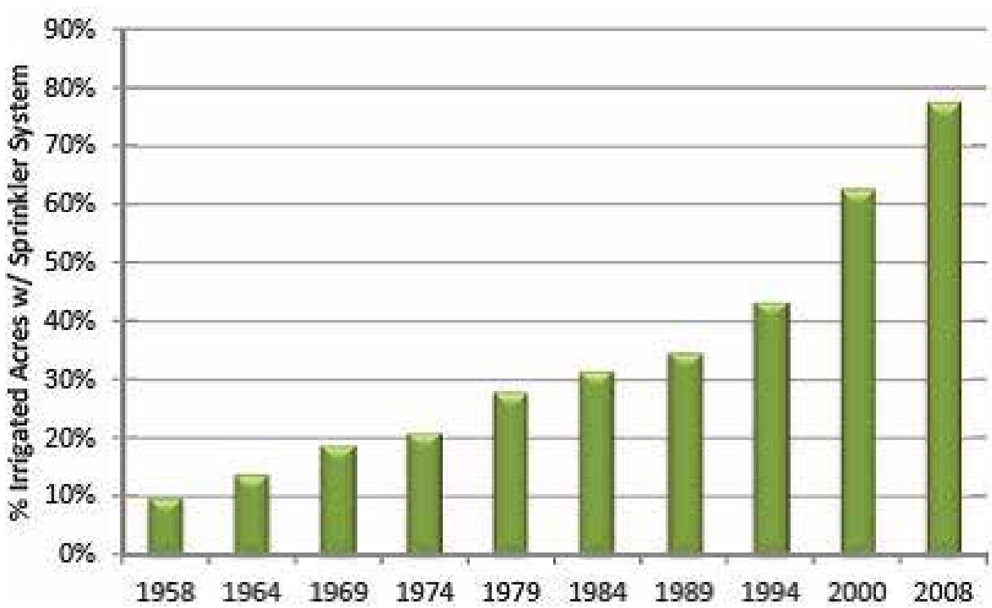

Fig. 3. Development of sprinkler irrigation systems in Texas from 1958 to 2008 [12].

Table 6. Irrigated land, its percent and proportion of irrigation water of total water used in China [16, 17].

Year	Irrigated area	Irrigated area as percent of total arable land	Proportion of irrigation water to total water consumption
	(Mha)	(percent)	(percent)
1949	16	16	92
1957	25	22	90
1965	32	30	85
1980	49	49	80.5
1988	48	50	-
1993	50	52	66.5
2009	59	48	65

land. Although irrigated land is less but it contributes around 30 percent of total agriculture production of Australia [18]. Water used in agriculture varied from 50-70 percent of total water consumption, and 90 percent of this water is used by the irrigation sector. More than 50 percent of the total irrigated land in Australia is irrigated by high efficiency irrigation systems and there is increasing trend of adoption of the pressurized irrigation systems in the country (Table 7). Due to increasing use of HEIS, water consumption decreased by 38 percent over a period of four years (2004-05 to 2008-09) as given in last row of Table 7.

Table 7. Percentage of irrigation methods and water applied in different years in Australia [18].

Method / Year	2004-05	2008-09
Surface	68	44
Sprinkler	23	38
Drip	8	13
Other	1	5
Total	100	100
Water applied (million m^3)	12,191	7,529

2.4 Islamic Countries

Percentage of different irrigation methods in some Islamic countries is given in Table 8. Surface irrigation is the predominated method in most of these countries except Saudi Arabia, Cyprus and Jordan where pressurized methods are more common ranging from 95 percent in Cyprus to 66 percent in Saudi Arabia.

Table 8. Irrigated land and percentage of irrigation methods in some Islamic countries [19, 20].

Country	Irrigated Area (Mha)	Surface	Sprinkler	Drip
Cyprus	0.05	5	0	95
Egypt	3.54	82	8	10
Jordan	0.08	32	8	60
Morocco	1.46	85	13	2
Saudia Arabia	1.73	34	64	2
Syria	1.40	97	2	1
Tunisia	0.46	81	17	2
Turkey	5.34	95	4	0

2.5 India

Total irrigated land in India is 69 Mha which is 36.6 percent of its arable land. A National Mission on Micro Irrigation (NMMI) was formulated to accelerate adoption of Drip and Sprinkler irrigations, and to increase crop water productivity [21]. According to the guidelines of this Mission, subsidy @ of 60 and 50 percent was provided by the Government for maximum area of 5 ha to any beneficiary. Drip irrigation is rapidly developing in India (Fig. 4) and in 2010 area under drip irrigation was approximately 2 Mha. Water saving and increase in yield are the main benefits of HEIS which are evident from Table 9. It is evident from this table that water saving varies from 15 to 68 percent while increase in yield ranges from 10 to 88 percent. Since climate of Pakistan and many developing countries is similar to India, therefore the benefits of adopting HEIS will be achieved beyond any doubt.

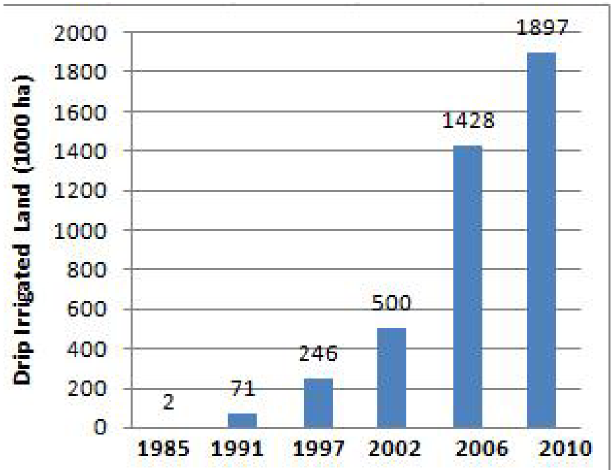

Fig. 4. Increase of drip irrigated land in India.

2.6 Pakistan

Many efforts have been made to introduce pressurized irrigation systems in the country for the last 4-5 decades but unfortunately without any notable success [19, 24, 25, 26, and others]. Shah et al. [27] reported that although drip irrigation system was installed on a few hundred hectares of orchards in Balochistan, but it was not adopted at large scale due to high initial cost of the system. Adoption of drip irrigation in tunnel farming has seen the day of light in the recent past. Similarly, a recent project being undertaken by the Agriculture Department, Punjab may produce sustainable result. Under this project, high efficiency irrigation systems are being installed on 120, 000 acres of land based on 40 percent cost sharing by the beneficiaries and 60 percent by the project funded by the World Bank [28]. Cost of drip irrigation systems installed under this project is presented in Table 10 which ranges from 96,319 to 179,708 rupees per acre. Average cost per acre for orchards is Rs. 103,894 and for vegetables it is Rs. 140,791.

3. CONCLUSIONS

Exploitation of water resources is inevitable for economic stability and sustainable food production of any country. Efficient utilization of available natural resources including water is equally

Table 9. Yield increase and water saving for drip irrigation over surface irrigation in India [21, 22, 23].

Crop name	Yield increase (percent)	Water saving (percent)	Crop name	Yield increase (percent)	Water saving (percent)
Eggplant	18	44	Potato	20	40
Cabbage	34	46	Tomato	25	40
Cauliflower	44	20	Pomegranate	21	51
Chilli	10	68	Cotton	27	53
Okra	27	15	Grapes	23	48

Table 10. Cost per acre of drip irrigation systems installed in different districts under PIPIP project in Punjab, Pakistan [29].

District	Area (Acres)	Cost per acre[1] (Rupees)	District	Area (Acres)	Cost per acre[2] (Rupees)
Attock-1	2	120,713	Faisalabad	3	179,708
Attock-2	7	105,072	Mianwali	15	138,103
Attock-3	8.83	100,211	Pakpattan	10	141,922
Bahawalpur	10	96,319	Bahawalpur	7	118,610
Faisalabad	9.25	103,905	T. T. Singh	15	125,610
Jhelum	15	97,144	Average		140,791
Average		103,894			

[1]Orchards [2]Vegetables

essential as well. Literature search and data analysis revealed that in USA in last 35 years, increase in irrigation water needs was primarily met through water conservation and by increasing use of high efficiency irrigation systems. Therefore, in order to meet future irrigation demands, result oriented efforts must be made to adopt high efficiency irrigation systems in Pakistan as well as in other water starved countries. This will help to lessen water shortage, increase the irrigated land and consequently will help to overcome food shortage.

4. RECOMMENDATIONS

The planners, policy makers and the implementing departments/agencies must formulate practical and sustainable programs for adoption of high efficiency irrigation systems in the country. Efforts should be made to maximize crop yield by using minimum water i. e. to achieve 'more crop per drop'. In nutshell, water use efficiency and water productivity be increased by employing best management practices including but not limiting to mulching, deficit irrigation scheduling and similar other water saving strategies. Outcome of the current on-going project(s) be carefully monitored and similar other projects be under taken for sustainable adoption of high efficiency irrigation systems on priority basis.

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