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Review Article

Climate Resilient Interventions for Improving Food Security in Hill Ecology of Hindu Kush Himalaya

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Abstract

The Hindu Kush Himalaya (HKH) region has significant implications for the agro based economies of eight adjoining countries, because of their large dependence on irrigation water originating in the HKH region. However, the HKH region is extremely vulnerable to climate change impacts, which is evident through frequent floods, droughts and retreating glaciers, thus leaving negative consequences for agriculture and livelihood. It is also evident that the traditional farming methods are no longer sustainable to cope with the changing climatic conditions for sustainable production in hill ecology. Therefore, innovative farming technique and irrigation technologies needs to be adopted for mitigating climate change impacts on agriculture and for ensuring food security. Although some pioneer work has been done in developing and promoting improved farming methods and irrigation techniques, but these improvements were mainly focused in major leveled irrigated areas lying downstream of HKH region. Thus, investment on promoting site specific climate resilient practices in hill ecology of HKH was largely overlooked. Addressing these issues, this study is focused on assessment of agricultural production system of Pakistan, as a case example by having 51% area falling in HKH region and reviewed few promising interventions/technologies successfully adopted in downstream irrigated areas that may be equally beneficial for the hill ecology of HKH region. Anecdotal evidence indicates that promotion of these interventions will improve community resilience to climate change and may lead to increased agricultural production and better livelihood for hill ecology of HKH region. This may also improve sustainable irrigation water supply for the irrigated areas downstream.

Keywords: Irrigation Technology; Sprinkler System; Drip System; Furrow Bed; Climate Change; Small Farmers; Water Use Efficiency

Introduction

The total area of Hindu Kush Himalaya (HKH) region is ~ 3.44 million sq. km spread over eight countries of Asia. The 51% area of Pakistan (~0.4 million sq. km) falls in HKH region, which form around 12% part of the whole HKH region [1]. Pakistan is home to one quarter (~19%) of the total population (~211 million people) of HKH region with an average population density of 97 persons per sq. km. The second (K2) and ninth (Nanga Parbath) highest peaks of HKH region fall in Pakistan. The agro based economy of HKH region in Pakistan is heavily dependent on the production of vegetables, crops and fruits. Current climate change trends and lack of adequate integrated water resource management strategies are causing huge losses to the country due to frequent droughts and floods [2]. Therefore, traditional farming techniques prevalent in Pakistan are no longer capable to keep up with the rapid climate change variability in the HKH region [3,4] and its downstream basins.

The Indus Basin of Pakistan is comprised of one of the largest contiguous canal irrigation systems in the world that lies at the downstream of HKH, thus prone to frequent climatic disasters [5]. For instance, the recent 2010 floods, originated in HKH region, drowned around one fifth of Pakistan, affected ~20 million people and caused more than US $43 billion impact on the country's economy [6]. Irrigated agriculture produces around 90% of crop production in Pakistan and contributes more than 21% in the country's GDP. Moreover, production in Pakistan has global implications, thus may impact on global food security. For instance, Pakistan produces wheat crop greater than the whole Africa and nearly equal to South America. Therefore, agriculture needs to be more wisely managed and traditional farming and irrigation methods needs to be modified according to the changing climatic conditions. This paper reviews some of the salient features of agriculture in Pakistan, its vulnerability to climate change and few promising irrigation technologies capable of improving farming system resilience to climate change.

Salient Features of Pakistan's Agriculture and their Vulnerability to Climate Change

Land use in Pakistan

The province wise land use is presented in Table 1. The total area of Pakistan is 79.61 million hectares (mha) with 23.40 mha cropped area. The current cultivated area is concentrated in Punjab province with 12.46 mha, which is ~50 % of the total cropped area of Pakistan followed by Sindh Province at ~8 % of country's cropped area. However, there is 7.82 mha culturable waste area that is largely concentrated in least developed provinces of Khyber Pakhtunkhwa (KP) and Baluchistan, which can be brought under cultivation to enhance food security. The province wise culturable waste areas are 12%, 23%, 64% and 190% of current cultivated lands in Punjab, Sindh, KP and Baluchistan respectively. Therefore, the agro based economies of KP and Baluchistan has greater potential for improvement by cultivating their culturable waste lands.

Table 1: Land use in Pakistan.

Province	Geographical area	Forest area	Not available for Cultivation	Culturable waste	Cultivated area	Total cropped area
Punjab	20.63	0.52	2.97	1.55	12.46	17.23
Sindh	14.09	1.03	6.80	1.18	5.08	3.45
Khyber Pakhtunkhwa	10.17	1.32	3.93	1.16	1.80	1.59
Baluchistan	34.72	1.36	9.83	3.93	2.07	1.13
Total	79.61	4.23	23.53	7.82	21.41	23.40

The irrigated cropped area in Pakistan is around 18.84 mha (Table 2) according to Agriculture Statistics of Pakistan 2006-07. This includes: wheat 7.34 mha (36.3 % of total); rice 2.58 mha (12.8 % of total); cotton 3.01 mha (15.2 % of total); sugarcane 1.03 mha (5.1 % of total); and fodders 2.00 mha (9.9 % of total). These five crops cover 16.03 mha of total irrigated area in Pakistan, which is 79.32% of the total irrigated area. Therefore, improving water productivity of these five major crops would have major impacts on productivity of irrigated agriculture in Pakistan. Other crops cover 4.17 mha; which constitute around 21.68 % of total irrigated area in Pakistan. The climate change induced floods and droughts significantly impact on crop production, especially during Kharif (summer) season, from both irrigated and rain-fed areas of Pakistan. The current land use methods tend to exacerbate the soil and water degradation and reduce land productivity potential. Similarly damage to standing crops due to lodging caused by heavy winds, water logging and salinity and frequent water stresses at crop critical growth stages causes production losses. Therefore, the traditional farming techniques need to be modified to control crop damage due to climate change induced threats, which is essential for sustainable agriculture in the country.

Table 2: Irrigated cropped area of major crops in Pakistan.

Crop	Season	Irrigated Cropped Area (million hectares)				
	Rabi (R)/ Kharif (K)	Punjab	Sindh	KP	Baluchistan	Pakistan
Wheat	R	5.728	0.938	0.314	0.361	7.341
Rice	K	1.730	0.599	0.061	0.194	2.583
Sugarcane	R	0.712	0.215	0.102	0.000	1.030
Cotton	K	2.465	0.571	0.000	0.042	3.077
Fodders	R/K	1.600	0.286	0.081	0.035	2.003
Total of Five Crops						16.035
Other Crops						4.180
Total of All Crops						20.215
Area Covered by Five Crops as Percent of Total Area						32.126

Temporal Water Availability During Rabi and Kharif Seasons In Pakistan

Temporal surface water availability and deficiency during rabi (winter) and kharif (summer) seasons in Pakistan is shown in Figure 1. Temporal changes indicated up to 23% increase and down to 16% decrease in total annual available surface water since 2001 until 2007. However, the variability in total annual available surface water diminished below 5% since 2009 onward. Interestingly a major flood occurred during 2010, but data show insignificant impact on the total water availability (Figure 1). Thus, climate change cannot be judged from the total water availability. However, the frequency, intensity and distribution of rainfall are important parameters to be considered. Similarly, the average deficiency remained around 6.4% during Kharif (summer season) and around 24% during Rabi (winter season) with an average annual water deficiency of around 13% during the last twelve years.

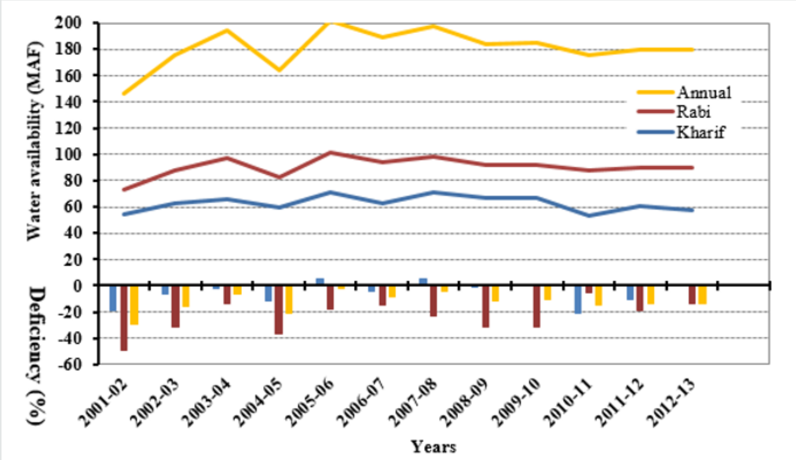

Figure 1: Temporal surface water availability and deficiency during rabi (winter) and kharif (summer) seasons in Pakistan.

Increased Use of Groundwater in Pakistan

Canal water fluctuation and unreliability due to climate change has increased farming community dependence on groundwater during the last decade. The changing trend of water availability is presented in Table 3. The statistics of canal and tube well irrigated area in provinces from 1993-94 to 2010-2011 (Table 3) indicate a decrease of 19% and 26 % in canal irrigated areas and an increase of 26 % and 157% in tube well irrigated areas in Punjab and Sindh provinces respectively. The overall tendency from 1993-94 to 2010-11 indicated a decrease of 17.5 % in the canal irrigated areas and an increase of 33.5 % in groundwater irrigated areas in Pakistan. The overexploitation of groundwater is coupled with saline water up-coning and disposing of deep brackish groundwater into the soil surface thus causing fertile lands barren in Pakistan. It is therefore essential to reduce groundwater usage by utilizing surface water more efficiently for fulfilling irrigation demands of larger areas. Thus, the traditional irrigation methods need to be modified to more efficient methods to reduce groundwater usage.

Table 3: Temporal change in irrigated area under surface and groundwater in Pakistan.

Province	Change in Irrigated areas					
	Canal irrigated areas (mha)			Tubewells/ tanks/others (mha)		
	1993-94	2010-11	%change	1993-94	2010-11	%change
Punjab	4.20	3.40	-19%	8.80	11.10	+26%
Sindh	2.30	1.73	-26%	0.14	0.36	+157%
KPK	0.74	0.75	+1%	0.15	0.15	0%
Baluchistan	0.49	0.53	+8%	0.11	0.67	+509%

Climate Resilient Interventions for Improving Food Security in HKH Region

The existing land use, crops, water availability and usage statistics clearly indicate that the traditional farming techniques are not capable to cope with the climate change induced risks. It is therefore essential to adopt suitable climate change risks mitigation interventions for improving food security in HKH region. Few of these interventions/technologies successfully adopted in irrigated leveled lands downstream of HKH are summarized below:

Furrow Bed (Raised Bed) Irrigation Systems

Furrow bed irrigation system is one of the commonly used form of surface irrigation throughout the world (Figure 2) and is generally considered a more water-efficient system compared with the traditional flat basin because of (i) the speed with which water is conveyed to the low end of a field [7]; and (ii) the relatively small proportion of the soil surface is in contact with the flowing water during irrigation than the basin [8]. Furrow bed irrigation system is important in the current climate change scenario of Pakistan agriculture in particular and Himalaya region in general due to the following reasons:

a) Furrow bed can save up to 50% irrigation water in comparison with traditional flat basin thus can reduce impact of limited water availability on crops in drought prone areas;

b) Furrows can quickly drain excess floodwater thus can reduce crop damage in flood prone areas;

c) Furrow beds reduce crops lodging by providing safe path and exit to speedy wind currents and greater reinforcement due to strong roots and soil grip;

d) Furrow beds laid perpendicular to slope can increase soil infiltration and ground water recharge by delaying runoff down slope and providing larger surface water storage capacity in furrows;

e) Conservation agricultural practices including minimum tillage, ground cover/mulching etc can be conveniently adopted on furrow beds which reduce soil erosion and soil and water degradation;

f) Furrow beds support mechanized farming thus can increase crop production and can be adapted to technological progress.

The Climate, Energy and Water Research Institute (CEWRI) of Pakistan Agricultural Research Council (PARC) has played a pioneer role in evaluation of furrow beds in Pakistan. Research conducted has shown that furrow beds is effective in improving yield of wheat by 20%, cotton 19%, Maize 58%, rice 26% compared with flat basin or ridge irrigation systems [9,10]. Similarly, crop yield per unit area increases by increasing the bed width. For instance, crop yield of maize showed up to 15% increase while wheat crop showed 26% increase on 180 cm bed size compared with flat basin [11], which was the largest increase noted when compared with other bed sizes given in Figure 2. Water saving of up to 50% in wheat, 30% in maize, 40% in cotton, 29% in rice were reported by N Ahmad et al. [9], Gill et al. [10], Hassan et al. [12]. Increase in water saving by increasing bed has been demonstrated in Figure 2 [9], which shows up to 40% and 36% increase in water saving by adopting 180cm bed size for maize and wheat crops respectively. Furrow bed increase crop yield and reduce irrigation application thus consequently crop water productivity is increased. For instance, an increase in water productivity of up to 70% in maize and up to 43% in wheat were reported by Hassan et al. [12] and Akbar et al. [13]. Impact of bed width on water productivity is illustrated in Figure 2, which shows up to 70% and 43% increase in water productivity for maize and wheat crops respectively compared with flat basin [13].

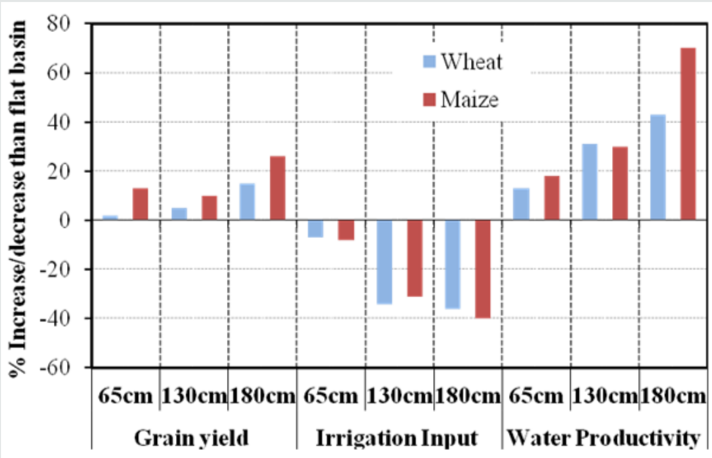

Figure 2: Advantages of furrow bed over flat basin [11].

The CEWRI-PARC in collaboration with Australian Centre for International Agricultural Research (ACIAR) played a pioneer role in adopting furrow bed irrigation system in Maize wheat system of Pakistan. Conservation agricultural practices involving minimum soil disturbance were introduced in the form of permanent raised bed (PRB) farming system. Different bed width and furrow sizes were evaluated and demonstrated at farmer fields. Raised bed machinery imported from Australia was indigenously produced. The furrow bed farming system was disseminated by giving incentive to the farmers in the form of giving subsidies in purchasing raised bed machinery, training and demonstrations in the country. Although there are still issues in the machinery, especially for adopting PRB farming system, but the furrow bed system has been adopted widely for maize, cotton, sugar beat and vegetables crops throughout the country.

Sprinkler Irrigation Systems

In sprinkle irrigation method water is spayed into the air at 70-700 kpa (10-100 psi) pressure that fall on the ground or crop canopy like rainfall [14]. Using sprinkle irrigation system, the crop requirement can be accurately fulfilled through a combination of measures involving careful selection of sprinkle nozzle size, operating pressure and sprinkle spacing, thus adjusting sprinkle application rate to suit the soil infiltration rate. Sprinkle irrigation systems have increased importance for HKH region in the current climate change scenario due to the following reasons:

a) Use limited available water more efficiently as the application efficiency of a well-designed sprinkle system can vary from 60-80% thus can increase crop production and irrigated lands;

b) No land leveling required thus reduce operation cost and protect environment by avoiding cutting and filling of cultivated lands;

c) Irrigation of steep and rolling topography without producing runoff or erosion;

d) Greater potential to increase agricultural production by bringing extra undulating and sloppy HKH terrain under irrigation;

e) Light shower can avoid crop damage due to temperature extremes year around;

f) Timely irrigation of few centimeter using sprinkler irrigation system can double crop yield at critical crop growth stages, especially during wheat germination in HKH region;

g) The pre-sowing irrigation (Rouni) can be applied with sprinkler system for timely planting of crops.

All these factors increase sprinkle irrigation system suitability to the HKH region in the current climate change scenario. However, there are few drawbacks. For instance, these systems are affected by wind and, depending on the size of droplets and the spray trajectory, uniform distribution may be limited. Sprinkle systems have high initial costs and maintenance requirements. They also use high operating pressures, which has large energy requirement. The cost of portable and semi portable system is less but difficult to operate due to movement of laterals. The CEWRI-PARC in collaboration with local industries developed a complete range of rain gun sprinkler irrigation systems, including diesel, electric and PTO-driven pumping systems, couplers, other fittings and joints. To keep the systems portable, the pumping unit along with power unit (diesel engine, electric motor and solar panels) was mounted on a trolley. These systems have been used in the Khanpur Dam area where the rain gun sprinkler irrigation system is being used for establishment of orchards, efficient irrigation of fruits and vegetables, washing of Lychi and citrus, and for cooling and frost control in orchards. Initial investment requirements and un-reliable electricity are restricting wider adoption of this technology.

These rain gun sprinkler irrigation systems have been installed in various parts of Pakistan for demonstration and introduction of the technology. In rain fed areas, these systems are being used for supplemental and life-saving irrigations to fruits, vegetables and field crops. The research conducted by CEWRI-PARC resulted in local fabrication of Poly Ethylene (PE) based irrigation system components, sprinklers and high-pressure pumps. Based on research findings and success of pilot-scale installations, the Government of Pakistan launched a National Program entitled "Water Conservation and Productivity Enhancement through High Efficiency Irrigation Systems in Pakistan" during 2007-12. Drip and sprinkler irrigation systems were installed on an area of 6852 acres in all provinces (PARC 2010). The major area was in Punjab and followed by KP. There were 255 farmers benefitted from the project. There were 80 % sprinkler irrigation systems and 20 % were drip system during the period (Table 4).

Table 4: Drip and sprinkler irrigation systems in provinces, installed under the national project (from 2007-2012).

Province	Farmers (No)	Area (Acres)
Punjab	165	3975
Sindh	35	634
KPK	50	2168
Baluchistan	2	46
AJK	2	12
Gilgilbiltitan	1	17
Total	255	6852

Drip Irrigation Systems

Drip irrigation system applies water close to each plant and the application uniformity depends on the uniformity of discharge from the emitters [14]. It generally comprises of a pumping station, control head, main and sub main lines, lateral lines, emitters, valves and fittings. The drip irrigation system has special agronomical, agro technical and economic advantages that make it a suitable option of irrigation in the HKH and adjoining region. These advantages are as under:

a) Drip irrigation can conveniently and efficiently supply water directly to the individual crop rows or plants, thus can effectively utilize small continuous streams of water in the HKH region;

b) It reduces water requirement by saving up to 50% irrigation water to a young orchard as compared to sprinkle or surface irrigation methods thus can enhance community resilience to drought;

c) It requires less labor, as a well-regulated system can effectively utilize a continuous stream of water, a norm in HKH region, with less farmer supervision thus can increase production;

d) It discourages weeds growth and offers greater control over fertilizer placement and timing thus can save farmer resources;

e) Drip irrigation can be designed for any topography even if the area is rocky with steep slopes and plants are with irregular spacing, which increase its importance for HKH region.

Drip irrigation systems have shown yield gains of up to 100%, water savings of up to 40–80%, and associated fertilizer, pesticide, and labor savings over conventional irrigation systems [15]. The low rate of water application reduces deep percolation losses. The systems have lower energy requirements than sprinkler systems because of lower operating pressure requirement. The water application uniformity of locally developed drip irrigation system was above 85 % [16]. Evaluation of drip systems at CEWRI-PARC showed lowest coefficient of variation of locally developed microtube emitters [17] with application uniformity above 85 per cent [16]. This shows that trickle irrigation systems have potential to use scarce water resource more efficiently if designed properly. The evaluations by Ahmad MM et al. [18] indicated that drip system with micro tube emitters can be operated at low pressure head (3.5 m) with an insignificant loss in uniformity as compared to operating at high pressure head (10 m), which can save energy cost, as given in Table 5. This low head drip system is being used for small scale vegetable production in Pakistan.

Table 5: Microtube emitter discharge and water application uniformity at various pressure heads and distances Ahmad et al. [9].

Distance (m)	Pressure head					
	3.5m		7.0 m		10.5 m	
	Discharge (L h^{-1})	Uniformity (%)	Discharge (L h^{-1})	Uniformity (%)	Discharge (L h^{-1})	Uniformity (%)
0.7-23	4-5	93-96	9-10	94-97	11-12	95-98

These research outcomes are currently being disseminated through training and demonstration in provinces. The provincial governments are adopting drip/sprinkler systems evidenced through various programs, indicating government commitment for accelerating drip/sprinkler system adoption. By successful adoption of these technologies, more water can be saved or efficiently used along with an increase in yield. The saved water will automatically reduce over exploitation of groundwater and consequently mitigating the secondary salinity by improving overall water use efficiency of the irrigation system. This shows that the system has potential to use scarce water resource more efficiently if designed properly.

Conclusion and Recommendations

a) Lack of adoption of climate change resilient practices in the hill ecology of HKH region is negatively affecting their food security and also have negative implications for the irrigated agriculture downstream in adjoining countries;

b) The 51% area of Pakistan falls in HKH region, thus was considered as a representative case example for analyzing their agricultural production system, growing food security and climate change issues and promising climate resilient interventions mainly adopted in downstream leveled irrigated areas of HKH region;

c) Furrow bed, sprinkler and drip irrigation systems has been shown efficient irrigation methods with multiple advantages thus can be instrumental for improving community resilience to climate change by conserving the declining and uncertain available water resources in the hill ecology of HKH region;

d) However, adoption of these technologies is equally important for improving climate change resilience, food security and livelihood of the hill ecology of HKH region.

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