DISCUSSION PAPER

ECONOMICS OF IRRIGATION INDUCED LAND DEGRADATION: ISSUES AND THREATS FOR FOOD SECURITY (CASE STUDY OF PUNJAB, PAKISTAN)

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ABSTRACT

As an agro-based economy of Pakistan, increased agricultural productivity is central towards sustainable economic growth, alleviating poverty and ensuring food security in the country. Irrigation plays a significant role in the growth of agriculture particularly crop sector. Irrigation constitutes a mixture of both canal and underground water. The role of groundwater is most important than surface water for irrigation purpose because the dependence on groundwater has been increased which ranged from 65 percent (in the head end) to 90 percent (tail end areas). In Punjab province of Pakistan about 75 percent of the irrigated area is dependent on the pumped/ ground water. The saline groundwater when applied for irrigation purpose causes more salinity in the area which limits the agricultural production and deteriorates the quality of agricultural land. This problem is becoming a serious threat to the sustainability of irrigated agriculture in the country particularly in the Punjab province, wherein about more than 50 percent of the groundwater is saline causing a huge secondary salinization in the irrigated soils. This study has focused on land degradation issues being occurred due to irrigation induced salinity with saline groundwater in a conjunctive water use environment, regarding its consequent effects on crop productivity, resource use and economic valuation of such degraded land. The study was conducted in the selected areas of Punjab province of Pakistan, having irrigation-induced salinity affected soils (with saline ground water) and the area having good soils (fresh groundwater for conjunctive use) for its comparison. Production Function approach and its decomposition analysis was used to address the above mentioned objectives of the study. Economic loss per acre per annum of sample farmers was Rs.30238. This was significant amount/income per acre which was not being received to the farmers annually. So, this is the value of land degradation which was being paid by the farmers in saline areas. If these economic losses were measured in overall study areas, it became about Rs.31.5 million per year and similarly these losses were Rs. 232591 million which comes to US $ 2326 million per year in Punjab's agrarian (crop production) economy.

Key words: conjunctive use, Irrigation, salinity, groundwater, land degradation, Punjab, Pakistan.

1 Background

Being an agrarian economy of Pakistan, increased agricultural productivity is central towards sustainable economic growth, alleviating poverty and ensuring food security in the country. No doubt the share of agriculture sector has been steadily declining than of other sectors, still agriculture remains a dominant sector of Pakistan's economy. Currently, agriculture has about 21 percent sectoral share in total GDP of the country, out of which about 9 percent is contributed by the crop sector (GOP, 2014).

The direct and indirect roles of agriculture are very important in inducing economic growth. A study of Asian countries, where agriculture is the main stay of the economy, found that an increase of 1 percent agricultural growth led to a 1.5 percent increase in growth of non-agricultural sector due to strong backward linkages to industries related to farm inputs, chemicals, fertilizers, machinery as well as food and fibre processing (Rehman *et al*. 2011).

Punjab is the largest province and has major share in agricultural GDP of the country. It has 12.2 million hectares of cultivated area which is about 57 percent of the total cultivated area of the country. As for as irrigated area is concerned about 76 percent of the total country's irrigated area lies in the Punjab Province. Similarly a large share of major crops in lieu of acreage and production comes from this Province. The area under major crops, like wheat is being sown at about 74 percent of the total crop area, and corresponding figures for Rice, Sugarcane and Cotton are 66, 71 and 85 percent, respectively (GOP, 2013). Keeping this background in view, it is evident that Punjab province has pivotal role in agriculture sector (crop sector) of the country.

Irrigation has a significant role in the growth of agriculture particularly crop sector. By increasing world food and fiber demand, irrigation sector is being expanding immensely to cater these needs. Irrigation is being applied worldwide on about 260 million ha. Pakistan is amongst major four countries i.e China, India, and United States, where more than half of the irrigated land of the world exists. Many countries, including Pakistan depend on irrigated land because more than half of their domestic food production is fulfilled from these lands. On these irrigated farms, two or three crops per year are grown. Therefore, by high cropping intensity and safeguarding food security, the irrigation would be the crucial to rise in food production (Ahmad 2002).

Irrigation constitutes a mixture of both canal and groundwater. The usage of conjunctive ground water varies depending upon the availability of canal water and location of the farm i.e at head end and tail end reaches of canal. The surface water availability is decreasing globally and during the last 10- 20 years and a significant increase in the use of groundwater for irrigation has been occurred (Clarke *et al.*, 1996). Groundwater remained the heart of the "green revolution" across many Asian countries and has promoted growing of high value crops in various arid and semi-arid regions. The United States, China, India, and Pakistan are the biggest users of groundwater and day by day, its use is increasing (Postel, 1999). In India, it accounts for 32 percent, Pakistan 30 percent and China 11percent. In some of the most populous and poverty disturbed regions of the world, mostly in south Asia, groundwater usage has arisen at centre of the food agricultural economy (Ahmad 2002).

In Pakistan, Indus Basin irrigation system irrigates an area of about 15 million ha, diverting annually about 128 billion m^3 of surface water to 43 canal systems (GOP, 2013 and Badruddin, 1996). The surface water availability in the country has decreased during last 8 years from 101 MAF (Million Acre Feet) in the year 2005-06 to 89 MAF in 2012-13 (GOP, 2014) (Fig 1.1). By increasing demand of irrigation and shortage of surface water supply, groundwater is being supplemented with surface water as a conjunctive use. The number of tubewells installed for groundwater withdrawals for irrigation purpose in Punjab province during last 10 years has been increased from 610,750 (Nos.) in the year 2001-02 to 954,706 (Nos.) during the year 2011-12 (GOP, 2013). It shows that groundwater is not only supplemental to surface water, but has now become an essential part of the irrigated agriculture in the Punjab province (Fig 1.2).

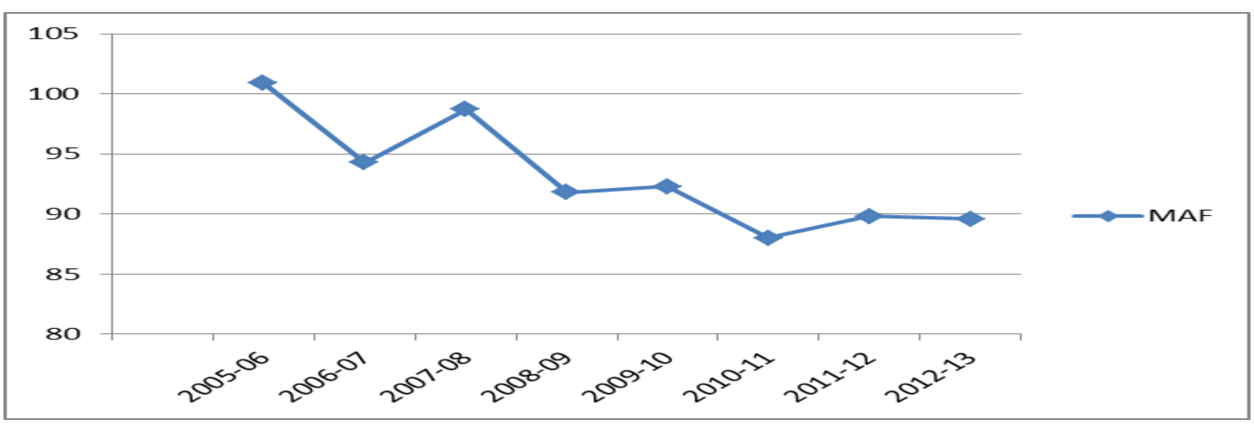

Figure 1.1: Surface Water Availability (MAF)
Source: GOP, 2014

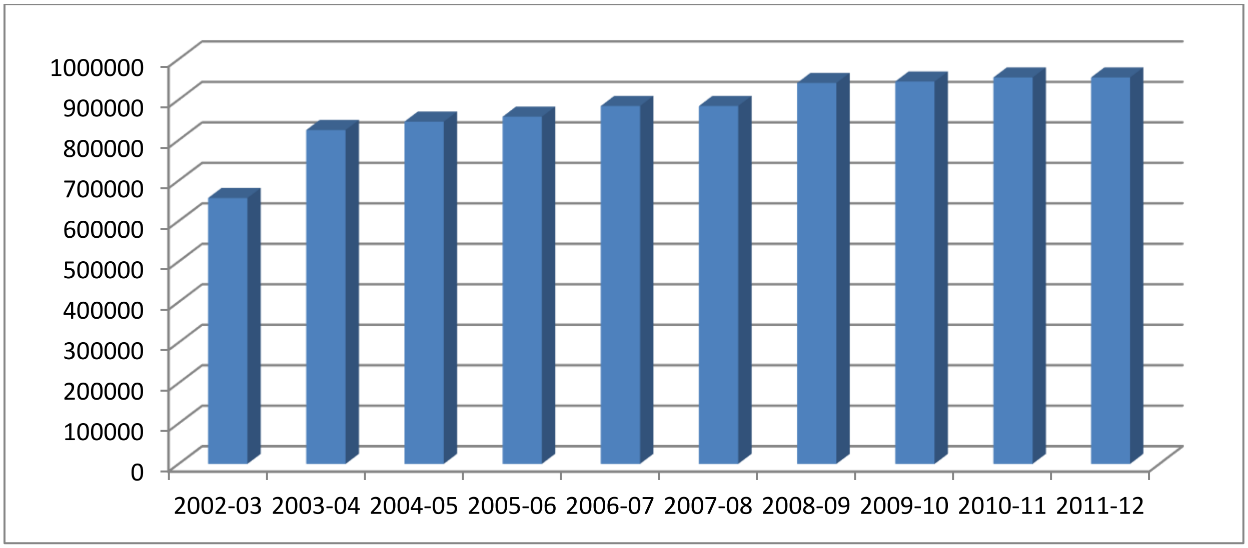

Figure 1.3: Number of tubewells installed in Punjab province
Source: GOP, 2013

In saline lands i.e both irrigated and non-irrigated, surface water an integral part of normal agriculture is scarce and groundwater available is mostly saline or brackish. This saline groundwater when applied for irrigation purpose causes more salinity in the area which limits the agricultural production and deteriorates the quality of agricultural land. This problem is becoming a serious threat to the sustainability of irrigated agriculture in the country particularly in the Punjab province, wherein about more than 50 percent of the pumped groundwater is saline causing a huge secondary salinization in the irrigated soils (GOP, 2009). Based on the groundwater quality monitoring data, a map/ pictorial view of Punjab regarding groundwater quality with respect to fit and unfit for irrigation purpose is made which is shown in Figure 1.3. Blue colour shows fitness, while red colour is marked for unfit groundwater.

In view of all the background information, this study has focused on land degradation issues being occurred due to irrigation induced salinity with saline groundwater in a conjunctive water use environment. The study was conducted in the Rice –Wheat crop production region, one of the important grain producing regions, have 18% of cropped area of Punjab province of Pakistan (FAO, 2004), wherein about 75 percent of the irrigated area is dependent on the pumped/ ground water having more than 50% of pumped water is saline/ unfit for irrigation purpose (GOP, 2014). This problem is becoming a serious threat to the sustainability of irrigated agriculture in Punjab province. Thus, the present study attempts to assess the effects of irrigation induced soil salinity due to saline (unfit) groundwater on crop productivity, resource use, profitability and compute the economic value of such land degradation in a conjunctive water use environment.

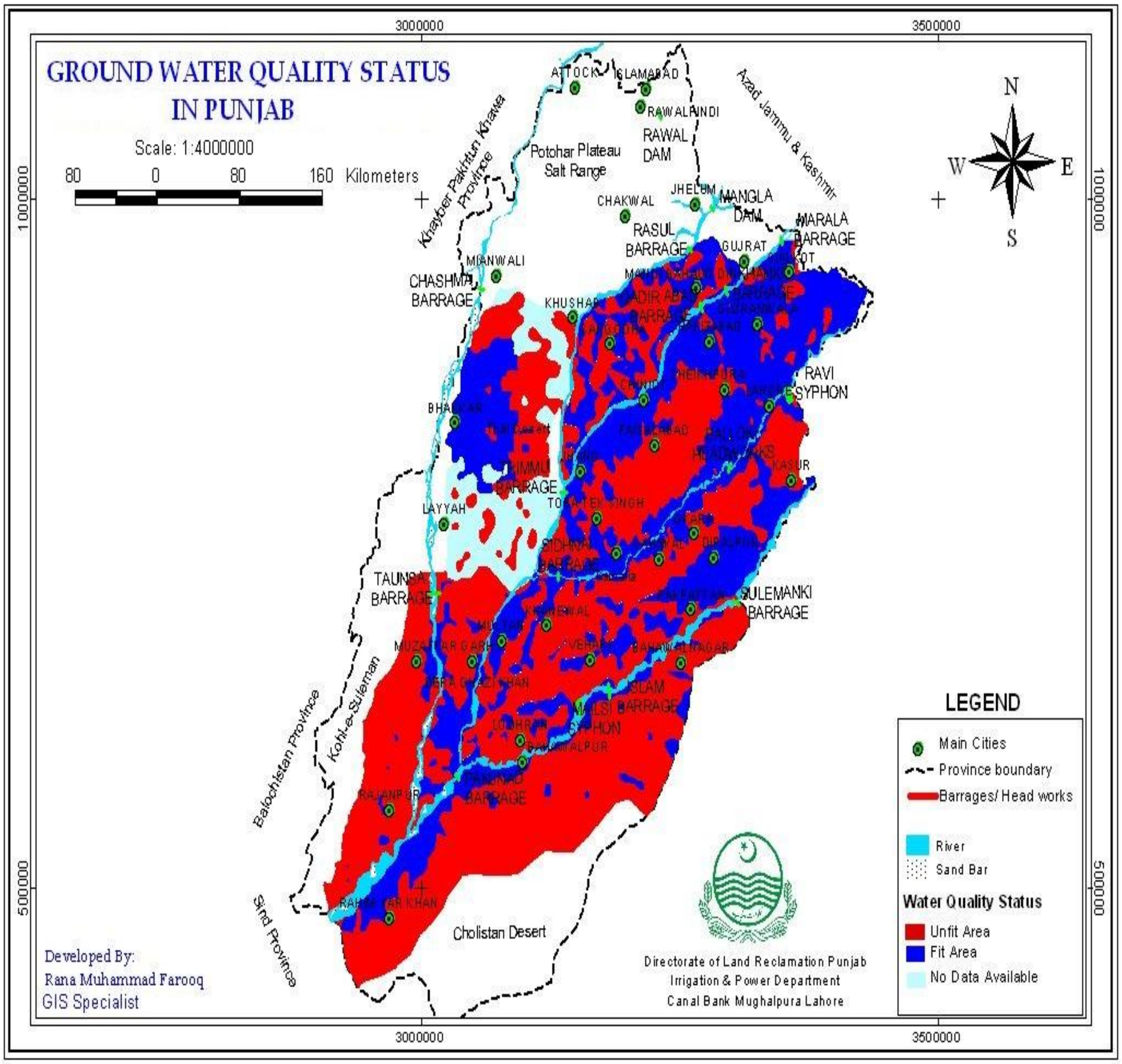

Figure 1.3: Groundwater Quality in Punjab
Source : GOP, 2014

The specific objectives of the study are:

i. To assess the effects of irrigation induced soil salinity on crop productivity, resource use and profitability in conjunctive water use environment.
ii. To compute the economic value of land degradation.
iii. To suggest policy guidelines for maximizing the economic returns under such irrigation induced land degradation.

2 LITERATURE REVIEW

Framji *et al.* (1984) and Ahmed and Chaudhry (1988) elaborated that soil salinity is a worldwide issue and generally its extent is higher in arid and semi-arid environment where often surface water is limited and its supply is unreliable and on the other hand groundwater is also saline. It is a natural phenomenon as well as due to mismanagement of irrigation.

IWMI (1998) reported that soil salinity and non- agricultural use of agricultural lands are major causes of squeezing the precious agricultural lands and have posed a serious threat to the agricultural economy and food security of the country

Kuper (1997) and Qureshi *et al. (*2003) mentioned the salinity has been associated with irrigated agriculture in the Indus Basin The poor and unfit groundwater has turned into an important issue due to the massive deployment of tube wells in the Indus Basin and has imminent threat of secondary salinization and degradation of agricultural lands.

Ghassemi *et al.,(*1995) and Rengasamy (2006) found that poor quality irrigation water accelerates irrigation-induced salinity. Use of highly saline effluent water and improper drainage and soil management increase the risk of salinity in irrigated soils

Food and Agriculture Organization (FAO, 2005) in its report stated high contents of salts are significantly reduced the value and yield of soils causing socio-economic, environmental and food security problems in the long run. By recognizing the symptoms of salt-affected soils in time may save costly reclamation efforts and further land losses.

World Bank (2006) reported that Pakistan is heavily dependent on agriculture sector and thus loss of agricultural production poses serious threats to the economy by reducing national income. Total annual cost of crop losses due to salinity in Pakistan were estimated from Rs. 15 to 55 billion. On an average, economic loss was Rs. 35 billion per annum, which is equal to almost 0.6 percent of the GDP in 2004. It was further highlighted that 25 percent reduction in crop production of Pakistan is mainly attributed to salinity. The loss of livelihood is a major threat to the security of the country as the major issue related to Pakistan's economy is the unemployment and lack of adequate employability in the rural areas.

International Food Policy and Research Institute (2007) in its report stated the increase in agricultural land degradation reduced the cumulative Gross Domestic Product (GDP). These cumulative losses between the year 2006 and 2015 was calculated more than 4 billion US$, which were equivalent to almost 5 percent of the total GDP in 10 years period in Ghana. Whereas, the consequences of agricultural degradation on poverty was also significant at the national level , which were equivalent to rise in 5 percentage points by the year 2015 as compared to the case with no land degradation

IGRAC (2009) reported that groundwater salinization had caused substantial societal and economic costs on a wider scale. The large scale secondary salinization due to poor quality of groundwater had resulted in reduction of agricultural (crop) sector productivity. This decline in agricultural productivity had led to numerous kinds of much costly interconnected socio-economic harms like, food insecurity, unemployment, migration and loss of livelihood in such irrigation induced (groundwater) salts affected areas. The Indus Basin Irrigation System (IBIS) of Pakistan immensely enhanced the agricultural production in the country. However, salinization caused by waterlogging and by application of poor quality groundwater had put serious hazards in relation to decline the crop yields at faster rate over the last decades. It concluded that current estimates of losses of land degradation and decreased yields were about US$ 240 per hectare per year in Pakistan.

Zaman and Ahmad (2009) calculated the economic losses in gross value of agricultural production in Pakistan by salinity and waterlogging during the year 2002 amounting to Rs. 133 billion which was almost 3% of GDP in that year and 23% of the agricultural GDP. This was a significant loss to the agricultural GDP and its contribution to the national economy. This loss was not only in the financial terms but at the same time it was loss of assets of the poor farmers. It reduced the livelihood of the resource of poor farmers who were normally small holders. Some of the small holders and resource poor farmers had lost their livelihood due to salinity and waterlogging and they were forced to turn as baggers. The loss of livelihood was a major threat to the security of the country as the major issue related to Pakistan's economy was the unemployment and lack of adequate employability in the rural areas. The technological and management advancements in the last few decades have demonstrated all over the world that irrigation and irrigated agriculture could be modernized where productivity and sustainability could be enhanced and attained on longer-term basis.

Global Water Partnership (2012) in its report explained that groundwater irrigation boom was observed at various economic levels in various developing and transforming countries. These economic levels involved from subsistence farming to large scale staple crop production as well as commercial cash crop cultivation. This had brought major socio-economic benefits especially to rural people in many countries. These benefits assisted in alleviating agrarian and rural poverty through increasing food security. Besides this economic uplift, it was deeply noticed that in these major areas of irrigated agriculture, irrigation driven salinization hazards had become of serious concerns. The quality of groundwater varied widely with overall hydrogeological setting and climatic regime, and even down the span of major river basins. This implied groundwater salinization and land degradation threats. It suggested that sound diagnosis, close monitoring and careful management was needed so that harmful effects on crop productivity could be minimized.

UNCCD (2013) reported that besides economic aspects of land degradation occurred due to various causes, social aspects were too much important. One of the major aspects could be increase in poverty. This report highlighted that less attention were given to measure the social impacts of land degradation and it was mostly found that their estimation was hindered by lack of social and biophysical data as well as synergies between these impacts and the underlying social causes of land degradation. However, economic modeling has shown how decisions by land users lead to land degradation which could be affected by government policies in unexpected ways.

3 DATA AND METHODOLOGY

The study was conducted in the selected areas of Punjab province of Pakistan, having irrigation-induced salinity affected soils with saline ground water and the areas having good soils with fresh groundwater for conjunctive use, for their comparison. There are mainly five crop production regions exist in the Punjab province as shown in Table 3.1. First three crop production regions namely Punjab-1 (Cotton -Wheat), Punjab-2 (Rice –Wheat) and Punjab-3 (Mixed crops) constitute about 80 percent of the cropped area with the conjunctive use of canal and tubewell irrigation (Table 3.1). About 20 percent of the remaining area is under other crop production regions i.e Punjab -4 and Punjab -5 with crops, like maize, pulses, oil seeds, etc., and these two regions do not fall under conjunctive use of irrigation. Thus, as per focus and objective of the study to assess the effects of irrigation induced soil salinity due to saline (unfit) groundwater on crop productivity, resource use, profitability and land degradation in a conjunctive water use environment, three cropping system/ crop production regions i.e Cotton-Wheat, Rice –Wheat and Mixed crops are relevant because these regions fall under conjunctive use of irrigation of both surface (canal) and groundwater (tubewell).

Table 3.1: Crop Productions Regions in Punjab

Crop Regions	Cropping Pattern	Source of Irrigation	Percentage of cropped area
Punjab -1	Cotton-Wheat	Canal+ Tubewell	35
Punjab -2	Rice-Wheat	Canal+ Tubewell	18
Punjab -3	Mixed Crops	Canal+ Tubewell	26
Punjab -4	Pulses-Wheat	Canal+ Rainfed	12
Punjab -5	Maize/Wheat-oil seeds	Rainfed	8

Source : FAO, 2005.

2.1 The Data

Directorate of Land Reclamation, Irrigation and Power Department, Government of Punjab, Pakistan, is carrying out groundwater monitoring survey each year since 2003, throughout

Punjab in irrigated zones. Within 1-2 Km of radius, they have established their groundwater monitoring points/ units from which they collect water samples for testing. Groundwater data have been arrayed for the assessment of the temporal variability in both depth to water table and water quality in terms of conventional water quality indicators. It was anticipated that groundwater data being documented will be really useful to the policy makers and irrigation managers while embarking on the agricultural sustainability in the province.

After consulting this data and obtaining reports of all monitoring points (GOP, 2014), a multistage stratified sampling technique was used to select sample for the study. First of all three (3) districts of Punjab province i.e one from each cropping system/pattern keeping in view the issues of having saline (unfit) groundwater as well as fresh (fit) groundwater being used as a conjunctive source of irrigation, were selected randomly. In second stage, four (4) villages from each district i.e two (2) villages for saline (unfit) groundwater and two (2) villages for good (fit for irrigation) groundwater were selected randomly. Thus, a total of twelve (12) villages i.e six (6) villages for saline (unfit) and six (6) villages for non-saline (fit) ground water from these three districts ware taken for the study. In the third stage, 25 farmers from each village were selected randomly. In total three hundred (300) farmers i.e 150 farmers who were using saline (unfit) groundwater and 150 farmers who were using non-saline (fit) groundwater for the conjunctive use of irrigation purpose were interviewed for a comparative study. The names of Districts and their corresponding villages covered under the study are detailed in Table 3.5.

Table 3.2 : Name of Districts and Villages

Crop Regions	Name of District	Name of Villages	
		Saline (Unfit) Groundwater	Non-saline(Fit) Groundwater
Rice - Wheat	Nankana Sahib	120 R.B	21 R.B
		182 R.B	87 R.B
Cotton – Wheat	Bahawalnagar	Gardariwala	Chaweka Uttar
		Sansaran	Wazirke Adlana
Mixed Crops	Faisalabad	271 R.B	414 G.B
		168 G.B	116 G.B

2.2 Analytical Approach/ Techniques

2.2.1 Production Function Analysis

A Cobb-Douglas production function mostly used as in agriculture sector is extensively employed to estimate the relationship of an output to inputs. It was proposed by Knut Wicksell and tested against statistical evidence by Paul Douglas and Charles Cobb in 1928. To study the impact of salt-affected soils on farm productivity, Singh *et al*.(1995), Kulkarni (2007) and Thiruchelvam and Pathmarajah (2003) used a Cobb-Douglas production function and separate production functions were estimated for different types of soils i.e normal and salt affected soil.

Similarly, in this study a Cobb-Douglas production function has been used and separate production functions were estimated for two types of soils i.e normal and salt affected soils to sort out the contribution of these effects. These have been specified in a log-linear form as follows:

For normal soil:

$$\text{Log } Y_1 = \log A_1 + b_1 \log X_1 + b_2 \log X_2 + \dots + b_n \log X_n + \mu \qquad (1)$$

For salt-affected soil:

$$\text{Log } Y_2 = \log A_2 + b'_1 \log X'_1 + b'_2 \log X'_2 + \dots + b'_n \log X'_n + \mu' \qquad (2)$$

where :

Y= dependent variable i.e value of gross output obtained

X_i (i = 1,... n) = explanatory variables i.e seed, irrigation, fertilizer, labour, plant protection, etc.

A = scale parameter,

b_i(i = 1,...n) = output elasticity with respect to the ith explanatory variable.

As the analysis was made for Wheat and Rice crops, so independent variables as per their importance/ relationship were used differently for these crops. These variables with regard to each crop are reflected below. The independent variables included for Production function estimate for ***Wheat*** crop were as under:

LnX_1 = Land preparation & tillage cost (Rs.)

LnX_2 = Seed cost (Rs.)

LnX_3 = Fertilizer cost (Rs.)

LnX_4 = Tubewell Irrigation (Nos.)

LnX_5= Canal Irrigation (Nos.)

LnX_6 = Farm Yard Manure (Rs.)

LnX_7 = Plant protection chemicals (Rs.)

LnX_8 = Labour cost (Rs.)

The independent variables included for Production function estimate for ***Rice*** crop were as under:

LnX_1 = Land preparation & tillage cost (Rs.)

LnX_2 = Seed cost (Rs.)

LnX_3 = Fertilizer cost (Rs.)

LnX_4 = Tubewell Irrigation (Nos.)

LnX_5= Canal Irrigation (Nos.)

LnX_6 = Labour cost (Rs.)

The independent variables included for production function estimate for ***Cotton*** crop were as under:

LnX_1 = Land preparation & tillage cost (Rs.)

LnX_2 = Seed cost (Rs.)

LnX_3 = Fertilizer cost (Rs.)

LnX_4 = Tubewell Irrigation (Nos.)

LnX_5= Canal Irrigation (Nos.)

LnX_6 = Plant protection chemicals (Rs.)

LnX_7 = Labour cost (Rs.)

The independent variables included for production function estimate for ***Sugarcane*** crop were as under:

LnX_1 = Land preparation & tillage cost (Rs.)

$LnX_2 =$ Seed cost (Rs.)

$LnX_3 =$ Fertilizer cost (Rs.)

$LnX_4 =$ Tubewell Irrigation (Nos.)

$LnX_5 =$ Canal Irrigation (Nos.)

$LnX_6 =$ Labour cost (Rs.)

2.2.2 <u>Production Function Decomposition Analysis</u>

To compute the economic valuation of land degradation in lieu of difference in productivity, Brzovic *et al*., (2011) used Production Function Approach i.e a Cobb-Douglas linear logarithmic form and obtained elasticity of output relative to each productive factor. Joshi and Jha (1992) and Gummagolmath (2000) used decomposition model to assess the impact of waterlogging and soil salinity on crop productivity and to estimate the difference in output due to soil degradation and input changes. Other studies included i.e Singh *et al*.(1995), Kulkarni (2007) and Thiruchelvam and Pathmarajah (2003), which have used Cobb Douglas production function decomposition analysis in such sort of studies. So, Cobb Douglas production function decomposition analysis is hereby used for this study.

It becomes necessary to confirm whether there existed a structural break in the production relations that explained the output on degraded soils and normal soils. Therefore, to identify the structural break in the production relations that defined the yield levels on degraded soils and normal soils, a dummy variable with (1) for degraded soil and (0) for normal soil was introduced in the production function of Cobb-Douglas setting for each crop.

To analyse the impact of salinity on resource use, Production Function Decomposition Analysis was made by taking the difference between Eqns. (2) and (1) and adding terms ($b'_1 \log X_1$, $b'_2 \log X_2$, ….. $b'_n \log X_n$) and subtracting the same yield. By re-arranging terms, we obtained:

$$\text{Log}\,(Y_2/Y_1) = \log(A_2/A_1) + [(b'_1 - b_1)\log X_1 + (b'_2 - b_2)\log X_2 + \text{---} + (b'_n - b_n)\log X_n] + [b'_1 \log(X'_1/X_1) + b'_2 \log(X'_2/X_2) + \text{----} + b'_n \log(X'_n/X_n)] \qquad (3)$$

Equation (3) has measured the approximate difference in per acre output between normal and salt-affected soils. The sum of the first two bracketed components on the right-hand side indicated the land degradation effect. The third bracketed term measured the contribution of changes in input levels (resource use) between the two soil conditions.

4.0 Results and Discussion

4.1 Farm Characteristics

It revealed (Table 4.1) that farm area in saline areas was 10.15 acres, while in normal (fit) groundwater areas it was 12.14 acres (about 16 percent higher) on an average. An imperative indicator is the effective cropped area in proportion of cultivated area under both categories. Study results have shown that in saline groundwater areas cropped area was 12.54 acres while, it was 21.55 acres in normal areas. Land rent and land value was higher i.e 41 percent and 27 percent, respectively in normal areas as compared to saline areas.

Table 4.1: Farm Characteristics

Characteristics	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Area owned (acres*)	9.02 (10.23)	10.74 (11.47)
Farm area (acres)	10.15 (10.40)	12.14 (10.32)
Culturable waste (acres) (included area not available for cultivation)	0.51 (0.92)	0.34 (0.66)
Cultivated area (acres)	9.62 (8.71)	11.92 (9.85)
Cropped area	12.54 (14.21)	21.55 (22.01)
Land rent (Rs./acre)	17013 (4005.01)	28728 (4138.75)
Land value (Rs./acre)	998,167 (629970.81)	13,75949 (219610.88)

Note : Figures in parentheses indicate standard deviation
*: 1 hectare: 2.47 acres

4.2 Cropping Intensity

It was observed there was significant difference under cropping intensity of both areas. This was much low (129 percent) in saline (unfit) as compared to normal (fit) groundwater areas (182 percent) as reflected in Figure 4.1. The decrease in cropping intensity in saline areas over normal areas was 53 percent (significant at 1% of probability level).

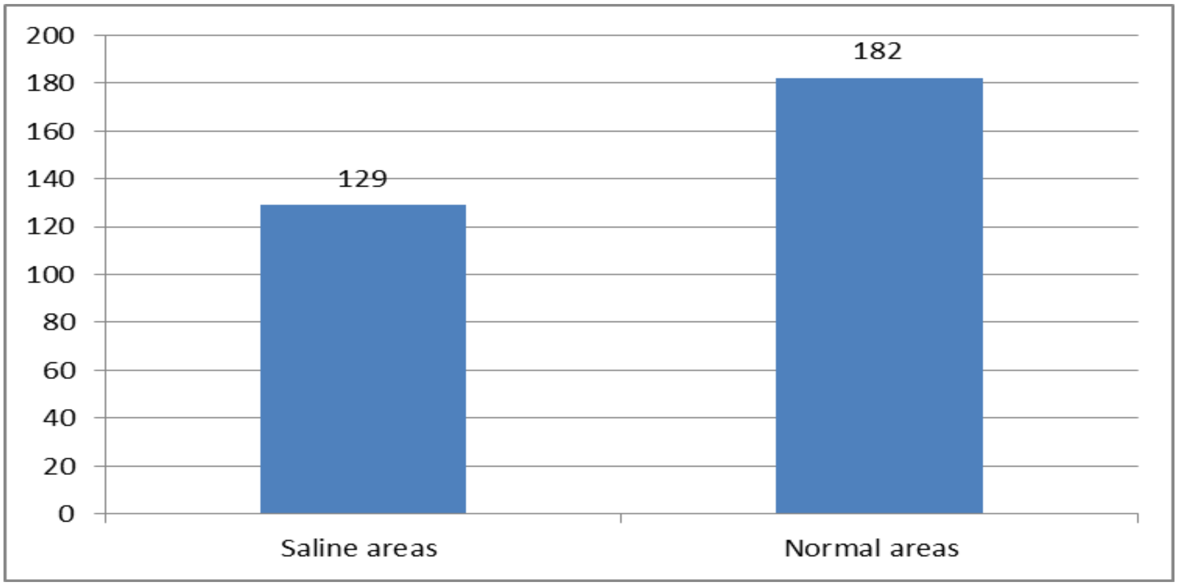

Figure 4.1: Cropping Intensity
*: Significant difference at 1% of probability level

4.3 Cost of Cultivation of Major Crops

As mentioned in methodology section that major crops of these districts/ cropping system i.e Wheat, Rice, Cotton and Sugarcane crops have been used for analysis purpose.

4.3.1 Cost of Cultivation of Wheat crop

Overall cost in normal areas was higher (14 percent) as compared with saline areas. While tubewell irrigation and farm yard manure cost was higher by 5 percent and 14 percent respectively in case of wheat sown in saline areas. Due to less availability of canal water in saline areas, they have to depend more upon groundwater abstraction, which has increased tubewell irrigation cost (Table 4.2).

4.3.2 Cost of Cultivation of Rice crop

The cost of cultivation of rice crop in normal areas was higher (11 %), however cost incurred on seed and land preparation & tillage was almost same in both areas (Table 4.3). Tubewell irrigation cost obviously in saline areas was more (11 %) having less availability of surface water, so their dependence was more on tubewell water. Costs of fertilizer, farm yard manure and plant protection were lower in saline areas. .

Table 4.2: Cost of Cultivation of Wheat crop (Rs. Per acre)

Cost items	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Land preparation and tillage	3389.47 (1038.11)	3738.74 (855.36)
Seed	1775.75 (280.12)	1868.27 (236.95)
Fertilizer	5676.03 (1631.05)	7652.51 (1115.82)
Farm yard manure	662.42 (759.05)	567.27 (903.26)
Plant Protection	373.18 (424.65)	652.13 (435.09)
Tubewell Irrigation cost	1895.36 (944.02)	1797.93 (719.91)
Harvesting and threshing	6180.56 (110.9.46)	6566.61 (763.97)
Labour cost	998.75 (248.16)	1061.50 (239.01)
Total cost	20951.47 (2969.47)	23904.96 (2565.17)

Table 4.3: Cost of Cultivation of Rice crop (Rs. Per acre)

Cost items	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Land preparation and tillage	3759.49 (926.62)	3785.99 (942.98)
Seed	2867.28 (305.89)	2963.25 (387.70)
Fertilizer	6673.97 (1450.16)	7139.03 (1717.31)
Farm yard manure	142.25 (547.63)	537.42 (1154.81)
Plant Protection	675.31 (799.09)	886.09 (777.18)
Tubewell Irrigation cost	7709.15 (2576.11)	6845.51 (2457.72)
Harvesting and threshing	6404.93 (1523.21)	9223.53 (2135.16)
Labour cost	2041.55 (491.35)	2332.01 (415.03)
Total Cost	30277.94 (4229.77)	33712.85 (4546.85)

Note: Figures in parentheses indicate standard deviation

4.3.3 Cost of Cultivation of Cotton crop

The results have shown that under cotton crop overall cost of cultivation was higher (35%) in normal areas as compared with saline areas (Table 4.4). Similarly cost against each category was also higher in normal areas except cost of farm yard manure. Both fertilizer and plant protection costs were too high (42 %) in normal areas. It shows that cotton crop gave fewer benefits/ returns in saline areas, thus farmers were using less quantity of inputs as compared to normal areas.

4.3.4 Cost of Cultivation of Sugarcane crop

In case of sugarcane crop, overall cost of cultivation in normal areas was also higher (20 %), whereas, tillage cost was more (6 %) in saline areas (Table 4.5). Cost on irrigation, labour and fertilizer was higher i.e 21 %, 13% and 25%, respectively in normal areas as compared to crop sown in saline areas.

4.4 Yield of Major Crops

The study results have shown that yield was higher under all crops in normal areas. The difference was calculated as 23 percent more in wheat, 25 percent, 34 percent and 31 percent higher in case of Rice, Cotton and Sugarcane crops, respectively sown in normal areas (Fig 4.2).

4.5 Net Returns

Overall net returns, also called gross margin, were more in all crops sown in normal areas, whereas reduction in yield has reduced net returns in saline areas. It was observed that under wheat crop net returns i.e difference between gross returns and variable costs per acre were higher (64 percent), Rs. 26748 in normal areas as compared with Rs. 16268 in saline areas. Higher cost (13 percent) was incurred to produce one Kg of wheat in saline groundwater areas as compared to normal areas (Table 4.6).

Under Rice crop net returns were 67 percent higher in normal areas, while corresponding figures for Cotton and Sugarcane were 87 percent and 51 percent higher as of saline areas. Similarly to produce one Kg of Rice, Cotton and Sugarcane, cost incurred was 20 percent, 9 percent and 24 percent, respectively more in saline groundwater areas (Table 4.7, 4.8 & 4.9).

Table 4.4: Cost of Cultivation of Cotton crop (Rs. Per acre)

Cost items	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Land preparation and tillage	2931.03 (753.24)	3310.11 (99067)
Seed	1685.40 (308.11)	1914.92 (426.51)
Fertilizer	5220.75 (1828.77)	7418.55 (1077.28)
Farm yard manure	377.50 (792.67)	260.70 (591.63)
Plant Protection	3389.68 (1379.68)	4847.05 (1174.25)
Tubewell Irrigation cost	3123.90 (1167.11)	3972.23 (1502.90)
Harvesting and threshing	4680.00 (1533.25)	7479.02 (1841.07)
Labour cost	2050.62 (370.70)	2458.72 (343.41)
Total cost	23458.87 (5236.48)	31681.28 (4248.73)

Table 4.5: Cost of Cultivation of Sugarcane crop (Rs. Per acre)

Cost items	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Land preparation and tillage	4100.51 (1193.05)	3856.48 (642.48)
Seed	12390.16 (922.04)	13315.02 (1776.77)
Fertilizer	5524.31 (1568.34)	6932.84 (1261.60)
Farm yard manure	843.14 (827.03)	965.04 (1283.15)
Plant Protection	516.18 (549.53)	728.07 (576.26)
Tubewell Irrigation cost	5505.78 (3035.37)	6672.48 (3218.31)
Harvesting and threshing	6786.76 (1226.90)	10799.64 (3732.22)
Labour cost	2174.51 (292.76)	2447.76 (314.79)
Total cost	37841.35 (4763.22)	45717.35 (5835.09)

Note: Figures in parentheses indicate standard deviation

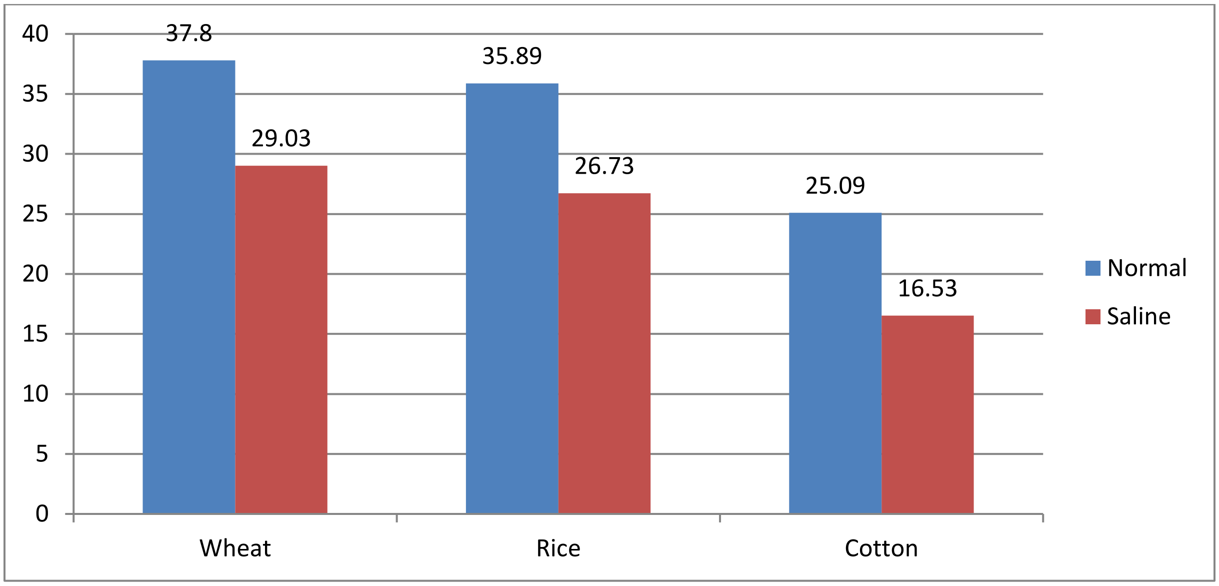

Figure 4.2: Yield of Major Crops
*: Significant at 1% of probability level

Table 4.6: Returns in Wheat Crop

Particulars	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Total variable cost (Rs./acre)	20951	23904
Yield (40 Kgs/ acre)	29	38
Sale Price (40 kgs)	1283	1333
Gross Returns (Rs./acre)	37219	50654
Net Returns (Rs./acre)	16268	26748
Cost per kg (Rs.)	18.0	15.8

Table 4.7: Returns in Rice Crop

Particulars	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Total variable cost (Rs./acre)	30274	33713
Yield (40 Kgs/ acre)	27	36
Sale Price (40 kgs)	1944	1968
Gross Returns (Rs./acre)	52476	70857
Net Returns (Rs./acre)	22202	37145
Cost per kg (Rs.)	28.3	23.5

Table 4.8: Returns in Cotton Crop

Particulars	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Total variable cost (Rs./acre)	23458	31681
Yield (40 Kgs/ acre)	17	25
Sale Price (40 kgs)	2299	2438
Gross Returns (Rs./acre)	39074	60960
Net Returns (Rs./acre)	15615	29229
Cost per kg (Rs.)	34.5	31.6

Table 4.9: Returns in Sugarcane Crop

Particulars	Saline (Unfit) Groundwater area	Normal (Fit) Groundwater area
Total variable cost (Rs./acre)	37841	45717
Yield (40 Kgs/ acre)	447	653
Sale Price (40 kgs)	156	162
Gross Returns (Rs./acre)	69659	105588
Net Returns (Rs./acre)	31818	59870
Cost per kg (Rs.)	1.8	2.7

4.6 Estimation of Cobb-Douglas Production Function

4.6.1 Cobb-Douglas Production Function Estimates for Wheat crop

Model results have shown that value of coefficient of determination (R^2) was 0.56 in case of saline areas, while it was 0.61 under normal areas. This shows that 56 percent variation in dependent variable was attributed by independent variables in saline areas, whereas in normal areas this variation was observed as 61 percent (Table 4.10).

The F- values i.e 7.6 (saline areas) and 5.6 (normal areas) depict that overall model was significant. The estimated coefficients for tillage, fertilizer, canal irrigation and labour were significant at less than 10 percent of probability level, in saline areas. The coefficient of tubewell irrigation was negative. It revealed that 1 percent increase in tubewell irrigation could reduce the gross value of output by 0.012 percent. Under normal areas wheat, the coefficient of tillage, seed fertilizer and tubewell irrigation were statistically significant. However, the coefficient of tillage was negative as over tillage was being used. The cost of labour varies from area to area, so labour cost has been used instead of working hours as these have less variation. In normal soil, farmers employ more labour with the expectation to get better yield, that's why coefficient is positive which means increase in labour would result in increase in yield.

4.6.2 Cobb-Douglas Production Function Estimates for Rice crop

The model results (Table 4.11) have exhibited that value of coefficient of multiple determination (R^2) was 0.39 in case of saline areas, whereas it was 0.45 under normal areas. This shows that more variation (45 percent) in dependent variable was observed by independent variables in normal areas, as compared with saline areas (45 percent). F-values (4.5 and 5.1) have also shown that overall model was significant in both categories.

The coefficients of tillage, canal irrigation and labour were significant in saline areas. Seed, fertilizer and tubewell irrigation coefficients were positive but not statistically significant. On the other side in normal areas, the coefficients of seed, fertilizer, tubewell irrigation and labour were statically significant.

4.6.3 Cobb-Douglas Production Function Estimates for Cotton crop

In cotton crop model, an important variable i.e plant protection (chemical sprays) have been included for both categories of farms. The coefficients of tillage, canal irrigation and labour were significant at 10 percent or below probability level, under saline areas. Coefficients of seed, fertilizer, tubewell irrigation and plant protection were positive but not significant (Table 4.12).
In normal areas, coefficients of seed, fertilizer, tubewell irrigation, tillage, canal irrigation and plant protection were significant at below 10 percent of probability level.

The coefficient of plant protection has shown that plant protection measures (chemical sprays) were more effective (statistically significant) in normal areas. The coefficient of tillage was negative, which reflects that one percent increase in tillage cost will decrease 0.01 percent of gross value of output. Over tillage practices were being applied in these areas (Table 4.12).

The values of coefficient of multiple determinations (R^2) were 0.70 and 0.41 in saline areas and normal areas, respectively. The F-values of 10.7 (saline areas) and 5.9 (normal areas) revealed that overall model was statistically significant.

Table 4.10: Cobb-Douglas Production Function Estimates for Wheat crop

Variables	Parameters	
	Saline (unfit) Groundwater area	**Normal (fit) Groundwater area**
Constant	12.79	10.41
Tillage	0.190** (0.090)	-0.190** (0.093)
Seed	0.118 (0.119)	0.342** (0.142)
Fertilizer	0.242*** (0.090)	0.372*** (0.126)
Tubewell Irrigation	-0.012 (0.055)	0.128** (0.059)
Canal irrigation	0.195*** (0.066)	0.085 (0.067)
Farm Yard Manure	0.004 (0.064)	0.093 (0.084)
Plant Protection	0.058 (0.073)	-0.010 (0.084)
Labour	0.763*** (0.208)	0.233 (0.281)
R^2	0.56	0.61
Adjusted R^2	0.49	0.52
F- value	7.6	5.92

Table 4.11: Cobb-Douglas Production Function Estimates for Rice crop

Variables	Parameters	
	Saline (unfit) Groundwater area	**Normal (fit) Groundwater area**
Constant	6.20	8.16
Tillage	0.228 * (0.199)	0.056 (0.074)
Seed	0.178 (0.238)	0.227** (0.133)
Fertilizer	0.118 (0.094)	0.216** (0.066)
Tubewell Irrigation	0.059 (0.083)	0.145** (0.052)
Canal irrigation	0.128 * (0.072)	0.052 (0.079)
Labour	0.312 * (0.178)	0.210* (0.122)
R^2	0.39	0.45
Adjusted R^2	0.31	0.37
F- value	4.50	5.05

Note: Figures in parentheses indicate standards errors of their respective coefficients
*: Significant at 10% of probability level , **: Significant at 5% of probability level
***: Significant at 1% of probability level

4.6.4 Cobb-Douglas Production Function Estimates for Sugarcane crop

Under Sugarcane crop model, the plant protection (chemicals) variable was not included as very few farmers used this measure in both categories of farms. The values of R^2 for saline areas and normal areas were 0.43 and 0.38, respectively. F- values (5.6 and 5.2 respectively for saline and normal areas) show overall significant of the model (Table 4.13).

In saline areas the coefficients of tillage, fertilizer, canal irrigation and labour were statically significant, whereas the coefficients of seed, tubewell irrigation, canal irrigation and labour were significant in normal area in sugarcane. Under normal areas coefficients of both types of irrigation i.e tubewell and canal were negative, which inferred that any increase in these irrigations will have negative effect on productivity. Thus, over irrigations were being applied in normal groundwater areas.

Table 4.12: Cobb-Douglas Production Function Estimates for Cotton crop

Variables	Parameters	
	Saline (unfit) Groundwater area	**Normal (fit) Groundwater area**
Constant	4.89	3.55
Tillage	0.352*** (0.134)	-0.008 (0.091)
Seed	0.256 (0.210)	0.223** (0.129)
Fertilizer	0.130 (0.128)	0.411** (0.227)
Tubewell Irrigation	0.167 (0.127)	0.603** (0.137)
Canal irrigation	0.185 * (0.095)	0.096 (0.103)
Plant Protection	0.172 (0.123)	0.486*** (0.141)
Labour	0.317 * (0.173)	0.300 (0.318)
R^2	0.70	0.41
Adjusted R^2	0.63	0.34
F- value	10.68	5.94

Table 4.13: Cobb-Douglas Production Function Estimates for Sugarcane crop

Variables	Parameters	
	Saline (unfit) Groundwater area	**Normal (fit) Groundwater area**
Constant	6.74	2.44
Tillage	0.202** (0.087)	0.043 (0.130)
Seed	0.095 (0.293)	0.373** (0.165)
Fertilizer	0.157** (0.076)	0.141 (0.112)
Tubewell Irrigation	0.037 (0.063)	-0.101** (0.053)
Canal irrigation	0.126 * (0.076)	-0.198** (0.086)
Labour	0.221 * (0.112)	0.563*** (0.177)
R^2	0.43	0.38
Adjusted R^2	0.35	0.29
F- value	5.60	5.23

Note: Figures in parentheses indicate standards errors of their respective coefficients

*: Significant at 10% of probability level , **: Significant at 5% of probability level

***: Significant at 1% of probability level

4.7 Decomposition Model Analysis

The results presented so far revealed that, there was significant difference in the yield of these crops between degraded and normal soils. The various sources contributing to yield difference between degraded and normal soils were estimated through decomposition analysis.

It became necessary to confirm whether there existed structural break in the production relations that explained the output in degraded and normal soils. Therefore, to identify the structural break in the production relations that defined the yield levels in degraded and normal soils, a dummy variable (nature of soil) was introduced in the production function in Cobb-Douglas settings. The significant dummy coefficients for such crops implied the structural break in production relationship between the degraded soils and normal soils

The dummy coefficients for wheat (-0.119^{***}), Rice (-0.309^{***}), Cotton (-0.097^{*}) and Sugarcane (-0.333^{***}) in case of normal soils versus saline soils were significant at 1 and 10 percent probability level (Table 4.14, 4.15, 4.16 and 4.17).

The decomposition analysis was used to know the contribution of land degradation and various inputs to the productivity difference between degraded and normal soils using the production function estimates and geometric mean values of inputs and output. The productivity difference attributed was decomposed into its constituent sources namely, productivity difference due to soil degradation and that due to the difference in input use. The results of decomposition analysis for each crop are presented in Table 4.18.

These results have shown that contribution of soil degradation to the productivity difference was higher than that of input use. It was 10 percent, 33 percent, 11 percent and 32 percent under Wheat, Rice, Cotton and Sugarcane crops, respectively, while the difference due to inputs use was 4.5,1, 4 and 6 percent, respectively. Overall productivity difference/ reduction was 14.2, 33.2, 14.8 and 38.6 percent in case of Wheat, Rice, Cotton and Sugarcane crops, respectively.

Table 4.14: Structural Break in Production Relations of Wheat crop

Variables	Parameters Normal (fit) Groundwater area VS Saline (unfit) Groundwater area
Constant	7.88
Tillage	0.059* (0.031)
Seed	-0.038 (0.121)
Fertilizer	0.344*** (0.099)
Tubewell Irrigation	0.027 (0.051)
Canal irrigation	0.035 (0.061)
Farm Yard Manure	-0.095* (0.051)
Plant Protection	-0.028 (0.068)
Labour	0.063 (0.215)
Dummy	-0.119*** (0.042)
R^2	0.37
Adjusted R^2	0.29
F- value	4.74

Note: Figures in parentheses indicate standards errors of their respective coefficients

*: Significant at 10% of probability level , **: Significant at 5% of probability level

***: Significant at 1% of probability level

Table 4.15: Structural Break in Production Relations of Rice crop

Variables	Parameters Normal (fit) Groundwater area VS Saline (unfit) Groundwater area
Constant	7.35
Tillage	0.102* (0.062)
Seed	0.172 (0.113)
Fertilizer	0.191*** (0.053)
Tubewell Irrigation	0.081* (0.044)
Canal irrigation	-0.048 (0.051)
Labour	-0.026 (0.091)
Dummy	-0.309*** (0.036)
R^2	0.45
Adjusted R^2	0.43
F- value	20.02

Note: Figures in parentheses indicate standards errors of their respective coefficients

*: Significant at 10% of probability level , **: Significant at 5% of probability level

***: Significant at 1% of probability level

Table 4.16: Structural Break in Production Relations of Cotton crop

Variables	Parameters Normal (fit) Groundwater area VS Saline (unfit) Groundwater area
Constant	2.036
Tillage	0.019 (0.080)
Seed	0.199* (0.116)
Fertilizer	0.116 (0.110)
Tubewell Irrigation	0.302** (0.094)
Canal irrigation	0.116 (0.075)
Plant Protection	0.311*** (0.098)
Labour	-0.140 (0.257)
Dummy	-0.097* (0.056)
R^2	0.59
Adjusted R^2	0.56
F- value	18.05

Table 4.17: Structural Break in Production Relations of Sugarcane crop

Variables	Parameters Normal (fit) Groundwater area VS Saline (unfit) Groundwater area
Constant	3.72
Tillage	0.128* (0.074)
Seed	0.300** (0.144)
Fertilizer	0.112* (0.059)
Tubewell Irrigation	0.044 (0.041)
Canal irrigation	-0.053 (0.056)
Labour	0.370*** (0.123)
Dummy	-0.333*** (0.042)
R^2	0.69
Adjusted R^2	0.66
F- value	31.5

Table 4.18: Decomposition of Total Difference in Productivity Between Normal Versus Saline Soils (Percent per acre)

Sources of change	Crops			
	Wheat	Rice	Cotton	Sugarcane
Saline (unfit) Groundwater	-9.7	-32.9	-11.2	-32.4
Changes in input use	-4.5	-1.09	-3.6	-6.2
Total change	-14.2	-33.18	-14.8	-38.6

4.8 Economic Losses of Degradation

Study results have shown that there were various types of difference i.e reductions in saline soils over normal soils, like reduction in productivity, land rent, land value, cropping intensity, etc. These reductions are ultimately transformed into monetary losses in lieu of per acre in the study area and Punjab province in totality.

These calculations have shown (Table 4.19) that economic loss per acre per annum of sample farmers was Rs.30238. This was significant amount/income per acre which was not being received by the farmers annually. So, this was the value of land degradation which has to be paid by the farmers in saline areas.

If these economic losses were measured in overall study areas, it became about Rs.31.5 million per year and similarly these losses were Rs. 232591 million which comes to US $ 2326 million per year in Punjab's agrarian (crop production) economy (Table 4.19). Externality cost including reclamation expenditure had not been included in this cost. These losses were also calculated by World Bank (2006) and IGRAC (2009).

Table 4.19: Economic Loss of Degradation

Particulars	Losses (Rs.)
Productivity Difference*	13847
Land Rent Difference	10714
Cropping intensity Difference	5677
Total Difference/ Loss (per acre per annum)	30238
Total loss in study area (Rs. Million per annum) (Total 1043 acres)	31.5
Total loss in Punjab (Rs. Million per annum) (7,692,000 acres)**	232591
Total loss in Punjab (US $*** million)	2326

*= Decomposition Analysis (average of cropping system)
**= Relevant w.r.t irrigated (conjunctive) and extent of unfit (50 %) of groundwater (GOP, 2014).
***= 1 US $ = 100 Pak Rs.

5 CONCLUSIONS AND POLICY IMPLICATIONS

5.1 Conclusions

As focus of this research was to assess effects of irrigation induced land degradation (due to saline groundwater) under conjunctive water use environment, on farm productivity and returns, estimating the economic value of such degradation. Thus, conclusions pertaining to these aspects are inferred as below:

- Cropping pattern under both categories of farms was more or less same, however cropping intensity was very much low (52 percent) in degraded saline (unfit) groundwater areas as compared to normal areas. This was attributed due to less cropped area.

- Yield was higher under all crops in normal areas. The difference was calculated as 23 percent more in wheat, 25 percent, 34 percent and 31 percent higher in case of Rice, Cotton and Sugarcane crops, respectively sown in normal areas.Net returns per acre under wheat, Rice, Cotton and Sugarcane crops were higher 64 percent, 67 percent, 87 percent and 51 percent in normal areas.

- Economic loss (degraded lands) per acre of sample farmers was Rs.30238 per annum. In overall study areas, these losses were Rs.31.5 million per year and similarly these losses were Rs. 232591 million which amounted to US $ 2326 million per year in Punjab's agrarian (crop production) economy.

5.2 Recommendations / Policy Implications

It was evident that there was high threat to these saline lands under prevailing situation. So, there is a dire need to prevent agricultural lands from such sort of irrigation induced (use of saline groundwater) degradation. The followings policy recommendations are hereby suggested.

- Water is generally not perceived as an economic good and therefore revenue recovery from the users is only a small proportion of the cost, resulting in both a drain on government finances as well as deterioration in service. There is a need, both to recover cost and to raise the standard of the service in the surface water sector. Furthermore, the precious water has traditionally been overused and abused. There is a dire need of educating the public of the real value of water to make the users more conscious about it. This would help in reducing demand, would encourage efficiency of usage, and reduce pressure for unnecessary expansion. For this purpose following measures may be adopted:

- Promote appropriate water pricing system to ensure recovery of at least O&M and capital cost.
- Develop a groundwater regulatory framework to control and optimize groundwater abstraction.
- Strengthen monitoring and groundwater modeling to determine sustainable groundwater potential and prepare groundwater budgets for sub-basins and canal commands and to assess the lateral and vertical movement of saline groundwater interface.

- Special projects on Biosaline agriculture (with some relevant interventions, like gypsum, etc) may be launched in these areas for mitigation and remedial measures.

- There is dire need to assess the irrigation system performance and the optimal ratios of saline and non-saline irrigation water for crop production, so that losses may be minimized.

- Government policy should include plans to divert significant quantities of fresh canal water to areas underlain by saline groundwater on the basis that farmers already have adapted to pumping fresh groundwater.

- There is need to enhance storage capacity of water. This will not only enhance the supply of water but also will minimize the cost of tubewell pumping. This will also lessen the salinity chances of the lands as less quantity of tubewell water would be used to irrigate the lands, which are expected to be saline.

- Farmers should be educated and dissemination of technical know-how for adopting coping strategies to the affected farmers through demonstrations on cost sharing basis.

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