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Wastewater Use in Cauliflower Production and Farmer's Health: An Economic Analysis

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The present study aims to estimate the economic values of negative externalities of wastewater use in cauliflower production. Cost-benefit analysis is employed to estimate the farmer's health externalities in the production sector. The data are collected from 200 farmers (100 from each group, wastewater and freshwater) in the year 2006 from two peri-urban villages of Faisalabad city. Ignoring the value of negative externalities, wastewater use is profitable in vegetable production but when the economic value of negative externalities are factored in the analysis, the results strongly discourage its use. The cost of health externalities due to wastewater use in cauliflower production (only for a three-month crop) is Rs 3.2 million from the 741 acres planted. In Faisalabad, 5,283 acres of vegetables are cultivated using wastewater, and the value of total negative health externalities amounts to Rs 90.7 million in a year. A huge economic loss due to wastewater use may attract the attention of policy agents to intervene. Among different available options, installation of a water treatment plant appears to be most viable to minimise the external effect of wastewater use in peri-urban agriculture.

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1. INTRODUCTION

The demand of water for household, commercial, industrial, and agricultural purposes has increased remarkably all over the world. The population of Pakistan was 136 million in 1998 [Population Census Organisation (2001)] and is expected to double by 2025. Population and income growth will further boost the demand of water in multifarious sectors and it will lead to severe water stress in the near future [Seckler, *et al.* (1998)]. Growing water scarcity is threatening economic development, sustainable human livelihoods and environmental quality [Scott, Faruqui, and Sally (2004)]. At the same time, due to increased industrialisation, the generation of wastewater will also increase leading to more opportunities for expanding vegetable production on wastewater in peri-urban belts.

Due to increasing pressure on water demand, planners are continually searching for new sources of water that can be used economically and effectively to cope with development process. The use of urban wastewater in agriculture is a centuries-old practice that is receiving renewed attention with the increasing scarcity of freshwater resources in many arid and semiarid regions of the world [Ensink, *et al.* (2004)]. It supports livelihoods

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and generates considerable value in urban and peri-urban agriculture despite the human health, crop productivity and environmental risks associated with this practice [WHO (1989); Pescod (1992); USEPA (1992) and Van der Hoek, *et al.* (2002)]. It is estimated that one-tenth or more of the world's population consumes food produced on land irrigated with wastewater [Smit and Nasr (1992)]. As population continues to grow—the use of wastewater is certain to increase, both in terms of areas irrigated, and volumes applied.

Some form of treatment is needed to meet the water quality standards that are set by international organisations and national governments. A wide range of wastewater treatment methodologies currently exist that can remove all harmful pathogens and other pollutants to make it safe for agriculture and even for domestic use [Von Sperling and Fattal (2001)]. Rudimentary treatments can be adapted to crops that are not consumed by humans, while sophisticated type of treatment is required for unrestricted use [Haruvy (1997)]. However, wastewater treatment method recommended for hot climates is a system of wastewater stabilisation ponds [Mara (2000)]. Most of the developing countries are facing severe financial constraints and thus using wastewater without any kind of treatment for agriculture purpose.

Peri-urban vegetable production is a major user of untreated wastewater in agriculture sector of Pakistan. Nothing is wrong to use treated wastewater because it is profitable even after internalising the cost of externalities [Haruvy (1997)] but there are serious concerns in apply untreated wastewater in vegetable production. Untreated wastewater is not only affecting productivity of agricultural labourers by increasing the probability of getting sick but it also affects the soil productivity in the long run. Further it is affecting the quality of ground water by leaching nitrate and other pollutants from agricultural fields and is also multiplying the expenditures on medical treatment for the poorer of the poor. In order to shift this group above the poverty line Government not only have to take measures to increase their agricultural productivity but also have to provide conducive environment to reduce non-productive expenditures (medical) by improving physical infrastructure.

The story of negative externalities of wastewater is not ending here yet because it also affects the environment and the health of consumers using vegetables grown with untreated wastewater. However, present study did not deal with consumption and environmental related externalities under the assumption that almost all Pakistani eat food after cooking at a very high temperature and majority of the pathogens are either died or became ineffective by cooking at such a high temperature. Secondly, it is difficult for the consumers to differentiate vegetables grown with wastewater and freshwater. Hence, it is extremely hard to identify the consumers who are using vegetables daily grown with wastewater because source of supply of vegetables to the consumers is changing on everyday basis. The data on environmental pollution related variables is not available especially for our study area and therefore, cost of environmental damages of untreated wastewater use is also not included in the analysis.

The costs of health damages of untreated wastewater have not yet been estimated in Pakistan and present study is attempting to fill this information gap by estimating it in terms of loss in earnings, and medical treatment costs.

The rest of the paper is organised as follows. Section 2 delineates the empirical model and discusses the data collection procedure. Section 3, derive the results that are useful to understand the cost of externalities of wastewater use in cauliflower production and it also facilitates the reader's approach to understand the issue of negative externalities of wastewater use in vegetable production. Final section summarises the discussion and recommends policy suggestions based on empirical findings.

2. EMPIRICAL MODEL AND DATA COLLECTION PROCEDURE

2.1. Valuing Benefits and Losses of Wastewater Use in Cauliflower Production

Different types of production function are available to study input-output relationship but Cobb-Douglas (beside its restrictive properties) is more popular and commonly used to study such relationship in the agriculture sector. Hence, the Cobb-Douglas type of production function is employed here and it can be written as follow;

$$Y = AF^{\alpha_1} S^{\alpha_2} L^{\alpha_3} P^{\alpha_4} I^{\alpha_5} E^{\alpha_6} e^{\alpha_7 D_1 + \alpha_8 D_2 + \alpha_9 D_3} + \mu \quad \ldots \quad \ldots \quad \ldots \quad (1)$$

Where

Y = Yield of cauliflower in Kg.
A = Intercept of the model.
F = Fertiliser nutrients in kg per acre (total of N, P and K).
S = Total quantity of seed in kg.
L = Total quantity of labour in hours.
P = Pesticide cost in Rupees per acre.
I = Hours of Irrigation (proxy for the amount of water).
E = Level of education of household head (Proxy for management).
D_1 = Dummy for variety ('1' for early and local variety in wastewater and freshwater areas, respectively and '0' otherwise).
D_2 = Dummy for soil type ('1' for high productive soil and '0' otherwise).
D_3 = Dummy for seed source ('1' for home made seed and '0' otherwise).
μ = Stands for random shocks.

In the above equation α_1, α_2, α_3, α_4, α_5, α_6 are the partial production elasticities and α_7, α_8, α_9 are the coefficients of dummy variables. It is worth noting that in both groups (wastewater and freshwater areas) farmers are growing two varieties of cauliflower but difference in sowing method (transplanting and dibbling) is only observed in freshwater area. Difference in sowing method in freshwater area is mainly depending on variety (local or imported). If farmers are growing local variety then they use transplanting technique, otherwise they employed dibbling method. Therefore, difference in sowing method in freshwater area can be captured by using the dummy for variety. Two varieties (late and early) in wastewater area differs in terms of sowing time but not in terms of sowing methods and therefore, dummy for variety in wastewater area stands for difference in sowing time. To capture the variation in soil types dummy for soil is introduced for both wastewater and freshwater areas. High productive soil includes sandy loam soil and less productive restrains loamy and sandy soil.

A three stage estimation technique suggested by Just and Pope (1978) was employed to obtain unbiased parameters of production function in both wastewater and freshwater areas. The results of third stage in estimation technique are used to estimate the predicted yield of two groups (wastewater and freshwater areas) by using Equation 1. The variation in yield due to difference in input use and management factors has been captured through production function and the remaining variation is purely due to difference in quality of water (wastewater or freshwater) and random shocks. Under the assumption that random shocks are similar in both wastewater and freshwater areas (because respondents who have been selected from both wastewater and freshwater areas are close to each other) therefore, it is reasonable to assume that difference of variation in yield of two groups is mainly due to difference in quality of water. The difference in revenue (predicted yield × price) could be referred to the contribution or loss of wastewater use in vegetable production but there is a difference in costs of production in two groups. Hence, the difference of net profits of two groups should be referred to the contribution or loss of wastewater use in cauliflower production and per acre average net benefit of wastewater use is estimated as given below.

$$NB_w = NVO_w - NVO_f = \frac{\sum_{i=1}^{N}\left(P_{wi}\,\dot{Y}_{wi} - C_{wi}\right)}{N} - \frac{\sum_{j=1}^{M}\left(P_{fj}\,\dot{Y}_{fj} - C_{fj}\right)}{M} \quad \ldots \quad \ldots \quad (2)$$

Where

NVO_W = Average per acre net profit of cauliflower with wastewater use.
NVO_f = Average per acre net profit of cauliflower with freshwater use.
$\dot{Y}_{fi}$ = Predicted yield per acre of i-th farmer with wastewater use.
$\dot{Y}_{fj}$ = Predicted yield per acre of j-th farmer with freshwater use.
P_{wi} =Price of cauliflower of i-th farmer in wastewater area.
P_{fj} =Price of cauliflower of j-th farmer in freshwater area.
C_{wi} = Per acre cost of cauliflower production (cost of inputs and wastewater) of i-th farmer in wastewater area.
C_{fj} = Per acre cost of cauliflower production (cost of inputs and freshwater) of j-th farmer in freshwater area.

The subscripts "i" and "j" stand for the i-th and j-th farmer in wastewater and freshwater areas, respectively while "N" and "M" represents the total number of observations in each group, respectively. The difference of net economic benefit of two groups (NB_w) is called the per acre average net benefits of wastewater use without incorporating the cost of externalities. The emphasis of this study is to incorporate the cost of health externalities in cost-benefit analysis and therefore, first of all it is required to explain how the external cost of health is estimated.

2.2. Economic Value of Labour Productivity Loss

There could be potential risk of disease(s) with wastewater irrigation. Illnesses caused by wastewater pathogens may result in:

- loss of potential earnings; and
- medical costs.

Loss of potential earnings or labour productivity is evaluated by using opportunity cost principle. These losses are quantified in economic terms by using the information on prevalence of disease (number of sick days, full-time or part-time work due to sickness or off-work, generally called restricted activity days in literature) and daily wage rate. Wastewater irrigation creates different kinds of diseases and the value of labour productivity losses (VLPL) due to theses diseases (in both wastewater and freshwater area) is estimated. Annual productivity loss of unemployed and underemployed sick individuals is estimated by employing the equation discussed below;

$$VLPL = (SD * WR * Prob * TP)_P + ... + (SD * WR * Prob * TP)_Q \quad \ldots \quad \ldots \quad (3)$$

Where

SD = Average number of sick days.
WR = Average wage rate in the study area.
$Prob$ = Probability of getting P-th disease.
TP = Total population in a given community or study area.
Q = Total number of diseases attributed to wastewater use i.e. from P=1 to Q.

Medical or healthcare costs and inconvenience costs of wastewater use in cauliflower production should be added to obtain total costs of health related illnesses. The medical costs include, the cost of medical consultation(s), cost of medication, transport cost, cost of defensive expenditure (continued use of medicine, protective measures etc., to avert the disease risk in future) and any other out of pocket illness related expenses. The private treatment cost can be used as proxy (opportunity cost) for medical costs because public healthcare is highly subsidised in Pakistan.

Annual loss of money value due to medical expenditures (*VMEL*) for both wastewater ($VMEL_w$) and freshwater growers ($VMEL_{fr}$) is calculated as follows:

$$\begin{aligned} VMEL = & (CC+MC+TC+PC+OC)_R (\mathrm{Pr}ob*TP)_R + ... + \\ & (CC+MC+TC+PC+OC)_S \ (\mathrm{Pr}ob*TP)_S \quad \ldots \quad \ldots \quad \ldots \quad (4) \end{aligned}$$

Where

CC = Average cost of medical consultation in the sample.
MC = Average cost of medicine in the sample.
TC = Average transport cost in the sample.
PC = Average preventive cost in the sample.
OC = Average other costs in the sample.
$Prob$ = Probability of being affected from a certain diseases.
TP = Total population in a given community or study area.
S = Total number of diseases attributed to wastewater use, i.e., from R=1 to S.

2.3. Cost-benefit Analysis after Internalising the Cost of Externalities

Per acre per crop Average Cost of Health Damage (*CHD*) due to wastewater use in cauliflower production is estimated as follows,

$$CHD_w = \frac{\left(NLPL_w + NMEL_w\right)}{Total\ wastewate\ area\ in\ the\ sample} \quad \ldots \quad \ldots \quad \ldots \quad (5)$$

Where, $NLPL_w$, $NMEL_w$ are Net Labour Productivity Loss and Net Medical Expenditure Loss, respectively due to wastewater use in vegetable production and on per crop basis it is estimated as defined below:

$$NLPL_w = \left(\frac{VLPL_w}{4} - \frac{VLPL_f}{3}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (6)$$

Where, $VLPL_w$ and $VLPL_f$ are values of labour productivity loss of wastewater and freshwater vegetable growers, respectively and are estimated by implying Equation 3 for both wastewater and freshwater growers separately. On an average farmers are growing four vegetable crops in wastewater and three crops in freshwater area in a year and therefore, we have divided $VLPL_w$ and $VLPL_f$ by four and three, respectively because these costs are estimated on per annum basis but our crop productivity analysis is only for one crop (cauliflower) season. That is why it important to maintain the same period of analysis in production and externalities. Net Medical Expenditure Loss due to wastewater use ($NMEL_w$) in cauliflower production is estimated by employing equation as given below.

$$NMEL_w = \left(\frac{VMEL_w}{4} - \frac{VMEL_f}{3}\right) \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (7)$$

Where, $VMEL_w$ and $VMEL_f$ are values of medical expenditure loss for wastewater and freshwater growers, respectively and are estimated by implying Equation 4 for both wastewater and freshwater growers, separately. Here, we have again divided $VMEL_w$ and $VMEL_f$ by 4 and 3, respectively due to the reasons discussed above in labour productivity loss.

Finally, per acre per crop Net Benefit (Loss) of wastewater use (NB_{WE}) after internalising the Cost of Health Externalities (CHD_w) in cauliflower production is estimated with the help of Equation 8 given below.

$$NB_{WE} = NB_w - CHD_w \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad \ldots \quad (8)$$

Where, NB_w and CHD_w are respectively, average net benefit of wastewater use without internalising the health externalities and average cost of health damages (or health externalities) with wastewater use in vegetable production. They are estimated by employing Equations 2 and 6, respectively.

2.4. Sample Data

Stratified random sampling approach is adopted to collect input-output data from two strata (wastewater and freshwater). The input-output data from 100 cauliflower growers in each stratum (wastewater and freshwater) is randomly collected in 2006 from two villages Chakera and Chak No. 4, respectively of Faisalabad city in summer season. These two villages are representative of cauliflower production in wastewater and freshwater areas, respectively. The data on different kinds of sickness and number of days of sickness is also collected from each stratum which is used to estimate the probability of sickness from a particular disease in each stratum (wastewater and freshwater). The detail of medical expenditure on different kinds of sickness is also collected from two groups which allowed us to estimate the total expenditure to get medical treatment for each kind of sickness. The reliability of treatment costs is cross checked by asking expenditure details of different sicknesses from medical doctors. In majority of the cases we observed that information given by farmers are reliable and matches with doctor's perception and where it was not there we took the cost of treatment given by the doctor. This information is used to estimate the cost of health damages for both groups which made it possible to estimate the external cost of wastewater use.

However, it should be noted that the impact of wastewater use on consumer's health has not been considered in the present study because it required laboratory test and more detailed information from consumers which is little expansive to collect and arrange. Due to resource constraints it is decided to exclude it from the analysis. Secondly, we are eating vegetables after cooking at a very high temperature and most of the pathogenic organisms which are dangerous for health die at such a high temperature. Therefore, it is hard to capture the cost of externalities of wastewater use on consumer's health.

3. RESULTS AND DISCUSSIONS

Mean values of different inputs and outputs on per acre basis for two groups (wastewater and freshwater users) are estimated and results are reported in Table 1. A small number of farmers (10–15 percent) used farmyard manure in freshwater area but in wastewater area no farmer observed doing this practice, indicating that wastewater is a substitute for farmyard manure. Farmyard manure is converted into nutrient nitrogen or N[1]. It is evaluated based on the average market price of N assuming that if farmers would have to supply that amount of N from Urea, then they have to pay the market price for it. Average dose of fertiliser nutrients (nitrogen and phosphorous) used by farmers in cauliflower production in freshwater area is 134.5 kg per acre which is significantly higher compared to the amount of nutrients (39.3 kg per acre) in wastewater area because huge amount of nutrients includes in wastewater [wastewater contains 39 percent more nitrogen than the recommended level set by WHO, Ensink, *et al.* (2002)]. It clearly indicates that wastewater works as a substitute of fertiliser and helps to save Rs 3170 per acre for wastewater growers due to less use of chemical fertiliser. Average level of seed in freshwater area is 0.7 kg per acre while in wastewater area it is 0.9 kg per acre which is significantly higher compared to freshwater area. In freshwater area majority of the farmers are purchasing seed from the market while in the wastewater area almost all farmers use home produced seed. The higher amount of seed in wastewater area might be due to lower rate of seed germination in wastewater compared to freshwater area or home produced seed has lower probability of

[1] One ton of farmyard manure generates 10 kg of active nutrient of Nitrogen [Ali (1996)].

germination compared to the market purchased seed. Average labour use in freshwater area is 120 hrs per acre while in wastewater area it is 135 hrs per acre. The labour used in wastewater is slightly higher because wastewater farmers have to plant nursery for cauliflower and also do hoeing practices. Further, farmers in wastewater area face more severe problems of weed due to untreated irrigation water which require more labours to manage the fields. Average irrigation hours in fresh and wastewater areas are 29 and 11 hours per acre, respectively, implying that intensity of wastewater flow is very high compared to freshwater. That is why wastewater farmers require less time to irrigate their fields compared to freshwater users. This implies that wastewater users reduce their costs in two ways, (i) they pay less price for each hour of irrigation compared to freshwater users, (ii) due to high intensity of wastewater flow compared to freshwater, wastewater users required fewer hours to irrigate their fields which lead to reduction in their costs of irrigation and labour. Moreover, timely and surplus availability of wastewater allows farmers to grow more number of crops compared to freshwater growers and they are also enjoying high prices because they are selling a larger part of their crop early in the season. Average pesticide costs in both fresh and wastewater areas are Rs 525 and Rs 1227, respectively, implying that amount of pesticide used in wastewater area is significantly higher compared to freshwater area. The high pesticide costs of wastewater users are due to high cropping intensity and favourable environment for pests to grow. After having information about early harvest and significantly higher amount of pesticide use in wastewater area, consumers need to avoid consuming early cauliflower because toxic chemicals in pesticide could be extremely hazardous for health. Average land rent in fresh and wastewater areas are Rs 10520 and Rs 15610, respectively. Per acre rent of land for wastewater area is significantly higher compared to freshwater area because of high cropping intensity (due to reliable supply of wastewater), cheaper and more nutritious supply of water in the area. Mean predicted yield (i.e., after capturing the impact of different level of input use and management factors) of cauliflower in fresh and wastewater areas is 8975 and 8659 kg per acre, respectively, indicating that yield is higher in freshwater area compared to wastewater area. The wastewater is being used in the study area since last thirty years and low average yield in wastewater area is probably due to deterioration of soil productivity or use of home made seed. Accumulation of poisonous chemicals on upper layer of soil resulted to lower the soil productivity.

Table 1

Average Values of Input-output Quantities on Per Acre Basis for Two Groups (Freshwater, Wastewater) of Water Uses

Variables	Freshwater	Wastewater
Yield (Kg/Ac)	8975	8659
Fertiliser (NPK in Kg)	134.5	39.3*
Seed (Kg)	0.7	0.9
Labour (Hours)	120	135*
Irrigation (Hours)	29	11*
Pesticide Cost (Rupees)	525	1227*
Annual Rent (Rupees)	10520	15610*
Education (Years of Schooling)	6	4

* It represents that values are significantly different from each other for two groups.

3.1. Results of the Production Function Analysis

In the literature various techniques are available to estimate the non-linear model described in Equation 1, and different studies have employed different techniques to obtain consistent and asymptotically efficient estimates [Just and Pope (1979); Antle (1983) and Antle and Goodger (1984)]. There is slightly difference of deriving weights in Just and Pope and Antle's approach but the basic idea is similar in both the techniques. Hence, three stage estimation technique suggested by Just and Pope (1979) is employed to estimate the input and output relationship in cauliflower production and the detail of estimation procedure is given in Appendix-I. In cross section data like the ones employed in this study, problem of heteroscedasticity may generate asymptotically inefficient results [Just and Pope (1979)]. A variety of tests are available to test the existence of heteroscedasticity. In this study, the Breusch-Pagan test, preferable to other tests due to reasons cited in Kmenta (1986), is applied to diagnose the problem of heteroscedasticity.[2] The null hypothesis of homoscedasticity is rejected at the 5 percent and even at 1 percent level, suggesting the presence of heteroscedasticity in each group of data set. To attain asymptotically efficient β's, three stage estimation technique developed by Just and Pope (1979) is employed to establish the input-output relationship as defined in Equation 1 for cauliflower and results are reported in Table 2. In three stage estimation technique the value of multiple determination (R^2) improved from 65 and 72 in the first stage to 85 and 83 in the third stage for wastewater and freshwater areas, respectively. The significance levels of almost all coefficients are also improved in the third stage. The results are of individual groups (wastewater and freshwater) are comparable with the results of pool data i.e., when both groups are pooled and dummy for one group is used. The results of production function for pool data is reported in Appendix-II. The discussion about the production function coefficients of inputs in the following pages is about the individual groups for which the results are reported in Table 2.

The coefficient of fertiliser nutrients (NP) is positive and highly significant in wastewater area but in contrast to our expectations the coefficient of fertiliser is negative and significant for freshwater area as reported in Table 2. The negative sign of fertiliser in freshwater area is due to over utilisation of fertiliser which is clear from the mean value of fertiliser use revealed in Table 1. In wastewater area farmers are using 1 to 2 bags of urea per acre while in freshwater area farmers are using 4 to 6 bags of urea and 1 to 2 bags of DAP. Hence the total amount of nutrients increased significantly than the fertiliser standards set by the Ministry of Food, Agriculture and Livestock, [Federal Water Management Cell (1997)]. It is posing a negative impact on output and thus reflecting in terms of negative coefficients of fertiliser in production function for freshwater area. It represents the third zone of production function which clearly shows negative marginal contribution of fertiliser in production process.

In freshwater area, the negative and significant coefficient of seed implies that might be seed is over utilised or seed is not suitable according to local soil condition and environment. A separate study need to be conducted to provide such evidence. However, coefficient of seed is positive and significant in wastewater area which is according to our priori expectations.

[2] It is based on the sample data that if the hypothesis of homoscedasticity is true, the ordinary least squares estimates of the regression coefficients should not differ significantly from the maximum likelihood estimates that allow the possible heteroscedasticity [Breusch and Pagan (1979)].

Table 2

Results of Production Function for Two Types of Water Groups (Freshwater and Wastewater)

	Wastewater			Freshwater		
Variables	Ist Stage	2nd Stage	3rd Stage	Ist Stage	2nd Stage	3rd Stage
Intercept	6550.44***	1.50^{ns}	2554.53^{ns}	9708.78**	11.65*	3214.33^{ns}
	(2.78)	(0.18)	(0.90)	(1.81)	(1.58)	(0.18)
Fertiliser	0.009^{ns}	–0.004^{ns}	0.03***	–0.04^{ns}	1.16^{ns}	–0.04**
	(0.52)	(–0.01)	(2.16)	(–0.72)	(1.44)	(–1.59)
Seed	0.007^{ns}	–0.59^{ns}	0.20**	–0.20***	2.65***	–0.28**
	(0.32)	(–1.13)	(1.82)	(–2.97)	(2.65)	(–1.67)
Labour Hours	–0.03^{ns}	0.90^{ns}	0.20**	–0.07^{ns}	–1.40^{ns}	0.23*
	(–0.50)	(0.63)	(1.99)	(–0.92)	(–1.32)	(1.51)
Irrigation Hours	0.15**	–0.59^{ns}	0.17***	0.06^{ns}	–0.91*	0.26***
	(2.00)	(–0.36)	(4.83)	(1.34)	(–1.57)	(3.57)
Pesticide Cost	0.00^{ns}	0.02^{ns}	–0.002*	0.00**	–0.01^{ns}	0.003***
	(0.02)	(1.14)	(–1.52)	(1.71)	(–0.41)	(2.19)
Education	0.00^{ns}	0.03^{ns}	0.02**	0.00**	0.06**	0.02***
	(0.13)	(0.79)	(1.62)	(1.62)	(1.98)	(2.01)
Dummy for Variety	–0.02^{ns}	–0.12^{ns}	–0.04**	–	–	–
	(–1.36)	(–0.36)	(–1.97)			
Dummy for Soil	0.10***	0.04^{ns}	0.05***	0.16***	–0.15^{ns}	0.12**
	(6.76)	(0.10)	(2.44)	(8.83)	(–0.62)	(1.75)
Dummy for Seed Source	0.01^{ns}	0.77*	–0.78**	–	–	–
(Home=1, Otherwise=0)	(0.49)	(1.56)	(–1.66)			
Dummy for Sowing Method	–	–	–	0.18***	–1.94***	0.21^{ns}
				(3.20)	(–2.35)	(3.46)
R^2	0.65	0.14	0.85	0.72	0.27	0.83
Adj.–R^2	0.57	0.05	0.80	0.66	0.13	0.79

*** = Significant at 1 percent, ** = significant at 5 percent, * = significant at 10 percent, ns = not significant. Figures in parentheses are t-statistics.

The signs for the coefficients of labour hours in both freshwater and wastewater areas are positive and highly significant. Cauliflower like other vegetables is a labour intensive crop indicating that improvement in labour supply could further enhance the productivity of cauliflower. Similarly the signs for the coefficients of irrigation hours in both freshwater and wastewater areas are positive and highly significant, indicating that water is scarce resource in both areas and additional supply of water could improve the productivity of cauliflower. The contribution of freshwater in the improvement of yield is higher than wastewater. It is because wastewater is contaminated with poisonous chemicals coming from different industries, institutions and households and moreover, it is completely untreated.

The coefficient of pesticide cost is highly significant in both groups and its sign is also consistent with priori expectations. However, coefficient of pesticide cost is larger in freshwater area compared to wastewater area, implying that marginal contribution of pesticide use is comparatively higher in freshwater area than wastewater area. It is due to the reason that wastewater farmers have high probability of being affected their crop from insects because wastewater fields have more conducive environment for insects to survive and breed. This argument can be supported by pesticide cost incurred in both sample groups and it is observed that pesticide cost is more than double in wastewater area compared to freshwater area. The coefficient of education is positive and significant in both groups according to priori expectations, implying that investment on education could help to enhance the productivity of cauliflower.

The dummy for variety (stands for local variety which is also called early sowing variety) in wastewater is highly significant with negative sign implying that farmers who are planting their crop early are getting lower yield. It is surprising then why farmers are planting their crop early? When weekly price distribution in near by market is observed then we get the answer. The price of cauliflower in early weeks of harvest is found to be enormously higher compared to the price in later weeks, implying that farmers in wastewater area are rational and substituting low yield with high price. This clearly indicates that high prices in early weeks of harvest are contributing more than the loss in yield incurred due early plantation. The variety dummy in freshwater area stands for local variety. The positive and significant results clearly depicts that local variety in freshwater area performs better than imported variety.

The dummy for soil (i.e., sandy loam soil) is positive and significant in both groups but contribution is higher in wastewater area. The dummy for seed source is negative and significant, implying that home made seed performs better than other sources. It might be due to the reason that imported seed or certified seed is not being used properly according to the supplier's instructions.

3.2. Cost-benefit Analysis without Externalities

Net benefits of wastewater use in cauliflower production are estimated by employing Equations 2 and results are reported in Table 3. Cost-benefit analysis highlights the differences in net return for two groups (freshwater and wastewater users) in cauliflower production. The gross revenue, which only depends on production and output price, is low in wastewater area compared to freshwater area. Mainly it is due to low predicted yield (yield after capturing the effect of difference in input use, soil characteristic, and management factors etc.). The low average predicted yield on wastewater fields clearly depicts that untreated wastewater has negative impact on cauliflower production in the long run. The impact of differences in input level and management has been captured through production function in both groups and the remaining variation in predicted yield is referred to the difference in quality of water which is affecting the soil fertility. Hence, the difference in average yield of two groups is due to soil fertility loss which is taking place due to wastewater use. The cost of pesticides is more than double in wastewater irrigated site as compared to freshwater irrigated fields. This might be due to high cropping intensity and favourable environment for pests to grow in wastewater fields.

Fertiliser is one of the major contributor in cash cost in freshwater area and it is significantly higher compared to wastewater fields. Freshwater farmers spent four times more on fertilisers compared to wastewater farmers. The low cost of fertiliser in wastewater area is due to the fact that wastewater contains high amount of nutrients (Nitrogen and Phosphorus) and it encourages farmers to use low doses of fertiliser.

The cost of seed is also high on freshwater fields compared to wastewater area because farmers in freshwater area purchased their seeds from market at higher prices while it costs less to wastewater users because they use home produced seed.

Table 3

Comparison of Costs and Benefits (Rs/Ac) of Cauliflower Production in Two Sources of Irrigation in the Study Area

Classification	Freshwater	Wastewater
Gross Returns	42516	37243
Cash Costs		
Pesticide	525	1227
Fertiliser	4094	924
Seed	3692	–
Labour*	2820	2922
Land Preparation	3414	3678
Irrigation	2082	686
Total	16627	9437
	(88)	(74)
Non-cash Costs		
Seed	–	1054
Labour	2197	2266
Total	2197	3320
	(12)	(26)
Total Labour Cost	5017	5188
	(27)	(41)
Total Cost	18824	12757
Net Benefit	23692	24486
Net Benefit Per Unit of Cash Input	1.4	2.6

Figures in parentheses represent the percentage of total cost incurred in cauliflower production.

Note: Labour cost also includes weeding cost (manual).

The total cost of labour (hired+family) in wastewater area is slightly higher than freshwater area due to intensive use of labour for weeding because in wastewater area the probability of germinating weeds is higher than freshwater area. Moreover, labour required to spray pesticide is higher in wastewater area than freshwater area. The contribution of labour cost in total cost of production is 27 and 41 percent in freshwater and wastewater areas, respectively, indicating that vegetable production is a labour intensive enterprise. Even wastewater vegetable production is more labour intensive than freshwater. This suggests that expansion of wastewater vegetable production could expand the absorption of labour in agriculture sector.

In wastewater area land has become more compact and hard due to wastewater use for a long time (since last 30 years) and it requires relatively more cultivation and planking cost. The farmers give more cultivations and plankings to make the land soft and to eradicate weeds. Therefore, land preparation cost for cauliflower is higher on wastewater irrigated farms compared to freshwater irrigated areas.

The cost of irrigation is another major cost. Freshwater farmers have much higher irrigation costs compared to wastewater farmers. The reason of this big difference is less availability of canal water in the freshwater area and it forces the farmers to supplement irrigation with tubewell water which is very costly due to high diesel costs, whereas the farmers who used wastewater had a clear advantage in terms of low priced wastewater.

Cash cost in freshwater area is Rs 16627, contributing 88 percent of total cost but in wastewater area, the total cash cost is smaller than freshwater area and it is Rs 9437, contributing 74 percent to the total cost. However, non-cash cost is higher in wastewater area (Rs 3320) than freshwater site (Rs 2197). The cost of family labour is the major component of non-cash cost. The amount of cash cost is higher than non-cash cost in both areas, implying that farmers depend more on market-base resources for cauliflower production than resources available at home.

The net benefit is estimated after deducting total cost from gross return; it is almost four percent higher in wastewater area compared to freshwater area. The rate of return per rupee of cash cost is estimated after dividing net benefits by total cash costs to observe the rate of return on cash investment in cauliflower production. The rate of return from cash investment is higher in wastewater area than freshwater site (Table 3) because of lower cash cost incurred in wastewater area. Net benefit or value of wastewater use is estimated by employing Equation 4 which is Rs 794 per acre and Rs 588354 (Rs 794 × 741 acres) for the whole study area before internalising the cost of externalities of wastewater use in cauliflower production.

3.3. Economic Value of Externalities

As mentioned earlier, the present study considers the health externalities of wastewater use, i.e., labour productivity loss and medical expenditure incurred on different kinds of sickness and results are discussed as below.

3.3.1. *Estimating the Probability of Different Diseases*

Chakera is the main site, where untreated wastewater is being used for irrigation and contained a high concentration of *helminth* eggs and *faecal coliform* bacteria that exceeded far the WHO guidelines [Ensink, *et al.* (2002)]. This poses a high potential health risk to both farmers and crop consumers. Due to limited available resources we did not get the blood test of the farmers to see the real effect on health of different pathogens and moreover, it would have provided the information at one point in time but we are interesting to get the information of different kinds of sickness over the year. We collected data from 100 farmers and asked them, how many times they get sick and what kind of sickness doctor diagnoses for them. Further, for how many days they could not go to work due to a particular sickness mentioned above. The probability distribution for each kind of sickness in both groups is estimated by applying the sparse data rule [Anderson, *et al.* (1977)] on cross sectional data of 100 farmers and results are reported in Table 4.

The vegetable farmers operating in wastewater area are found to have significantly higher prevalence of hepatitis, vomiting, stomach, skin allergy, cholera, diarrhea, typhoid and dysentery than those who are growing vegetables with canal or tubewell water. This implies that probability of existence of pathogens and being affected from these pathogens is significantly higher among farmers and workers involved in different farming activities on wastewater fields compared to those who are engaged in farming with canal water or freshwater. This clearly indicates that wastewater farmers are at a high risk. Simply, because they have intensive contact with wastewater as they do most of the field works manually and barefooted. However, probability of fever and cold was almost the same in both areas because these sicknesses dose not appear due to wastewater use.

Table 4

Per Year Labour Productivity Loss in Wastewater and Freshwater Areas

	Wastewater			Freshwater		
Disease	Probability	Average Days of Sickness	Real Labour Productivity Loss	Probability	Average Days of Sickness	Real Labour Productivity Loss
Hepatitis	0.12	110	1536612 (25610)			
Vomiting	0.12	1.3	18626 (310)			
Stomach	0.12	108.3	1513330 (25222)			
Skin Allergy	0.14	9.1	127718 (2129)			
Cholera	0.06	5.7	79159 (1319)			
Diarrhea	0.04	2	27938 (466)			
Typhoid	0.06	76.7	1070972 (17850)			
Dysentery	0.04	12.5	174615 (2910)			
Fever	0.22	8.8	123183 (2053)	0.20	7.9	261329 (4355)
Cold	0.16	13.4	186838 (3114)	0.14	7	162974 (2716)
Total		347.8	4858991 (80983)		14.9	424303 (7072)

Note: Figures in parentheses are values of Labour Productivity Loss in Dollar terms.

3.3.2. *Labour Productivity Loss*

By employing the probability and opportunity cost principle (on going market wage rate) as discussed in Equation 3, the value of annual loss of potential earnings or labour productivity loss due to each kind of sickness is reported in Table 4 for both groups. In wastewater area labour productivity loss due to stomach ach and hepatitis is found to be the highest US$ 75667 and US$ 25610, respectively. Among different diseases reported in Table 4 typhoid fever is caused by bacterial pathogen (*Salmonella typhi*) which is present in wastewater and it caused a labour productivity loss of US$ 17850. The farmers during their farming activities remain in contact with contaminated soil which generates a high loss of potential earnings due to skin allergy. Cholera which is a severe form of diarrhea, also a source of labour productivity loss equal to US$ 1319. Total annual labour productivity loss due to different kinds of sickness is Rs 4858991 (US$ 80983) and Rs 424303 (US$ 7072) in wastewater and freshwater areas, respectively and the difference in labour productivity loss is Rs 4.4 million (US$ 73912) which can be referred to annual loss due to wastewater use.

3.3.3. *Loss of Money in Medical Expenditures*

On one side wastewater use causes different kinds of diseases which affects the labour productivity but on the other side the treatment of such diseases required heavy expenditures on medicines. The affected members of the society spend an enormous amount of money to purchase medicines for treatment and it leads to welfare loss to the society. The data on medical expenditures is collected from the diseased farmers. Annual loss of money in terms of medical expenditures is estimated by using Equation 4 and results are reported in Table 5.

Table 5

Per Year Loss of Money to Medical Facilities in Wastewater and Freshwater Areas

	Wastewater		Freshwater	
Disease	Medical Expenditure* (Rs)	Medical Expenditure ($)	Medical Expenditure (Rs)	Medical Expenditure ($)
Hepatitis	2615200	43587	–	–
Vomiting	18900	315	–	–
Stomach	1918000	31967	–	–
Skin Allergy	261800	4363	–	–
Cholera	369600	6160	–	–
Diarrhea	30800	513	–	–
Typhoid	1494500	24908	–	–
Dysentery	955500	15925	–	–
Fever	757400	12623	478265	7971
Cold	598500	9975	249900	4165
Total	9020200	150337	728165	12136

* Medical Expenditure includes cost on medicine, consultation cost, prevention cost, and transport cost.

In wastewater area, medical expenditures for Hepatitis are the highest (US$ 43587) followed by expenditures on Stomach (US$ 31967). The costs of medical expenditure for other different sicknesses are reported in Table 5 for both groups. Total annual loss of money in terms of medical expenditures is Rs 9020200 (US$ 150337) in wastewater area compared to Rs 549665 (US$ 1916) in freshwater area. Annual additional expenditures on medicines due to wastewater use are Rs 8.5 million (US$ 141175). Not a single chance of death is found due to wastewater irrigation in the study area. Therefore, economic value of mortality (deaths) is not evaluated in terms of net labour productivity loss of an individual over the expected life span.

3.4. Cost-benefit Analysis after Internalising the Externalities

The results of cost-benefit analysis before and after internalising the cost of externalities are estimated and reported in Table 6. Cost of health damage (CHD_w), Net Labour Productivity Loss ($NLPL_w$), Net Medical Expenditure Loss ($NMEL_w$) and Net Benefit of wastewater after internalising the cost of externalities (NB_{WE}) in cauliflower production are estimated by implying Equations 5, 6, 7 and 8, respectively.

Table 6

Cost-benefit Analysis before and after Internalising Cost of Externalities in Cauliflower Production

Categories	Cost and Benefit (Rs)	Cost and Benefit (Rs per Acre)
Net Labour Productivity Loss ($NLPL_w$)	1108672	1496
Net Medical Expenditure Loss ($NMEL_w$)	2973009	2798
Cost of Health Damage (CHD_w)	3181681	4294
Net Benefit of Wastewater without Externality	588354	794
Net Benefit of Wastewater after Internalising the Externality	–2593327	–3500

Before incorporating the values of these negative externalities, net benefit or value of wastewater use is Rs 794 per acre and Rs 588354 (Rs 794 × 741 acres) for cauliflower production in the study area under the assumption that cauliflower is grown on the entire wastewater site in Chakera. Although, some other vegetables are also grown in the study area but the cropped area under these vegetables is negligible in our sample.

Net labour productivity loss (forgone labour earnings) and net medical expenditures on treatment due to wastewater use are amounting to Rs 1108672 and Rs 2117634, respectively for cauliflower production. The total external cost of health damage due to untreated wastewater irrigation in cauliflower production is Rs 3181681 for the whole study area (741 acre) and Rs 4294 per acre. Hence, the net benefit after deducting the values of these externalities become negative which is Rs 3500 per acre and Rs 2593327 for the entire study area (Table 6). Under the assumption that similar condition prevail for all the four crops grown in a year in wastewater area, net benefit of wastewater after internalising these cost of externalities is also negative, amounting to Rs 10373307 per annum for the whole study area and Rs 13999 per annum per acre. However, in order to increase the reliability of the results it is preferable to conduct future research based on annual data for all four crops being grown in the study area.

4. CONCLUSION AND POLICY SUGGESTIONS

The main objective of this study is to carry out cost-benefit analysis in cauliflower production with and without externalities due to wastewater irrigation in peri-urban areas of Faisalabad. Total costs of production of cauliflower without externalities are Rs 18824 and Rs 12757 per acre for freshwater and wastewater areas, respectively. Per acre gross revenue for freshwater and wastewater growers are Rs 42516 and Rs 37243, and net benefits are Rs 23692 and Rs 24486, respectively. It is observed that both total cost and gross revenue are higher for freshwater users but net benefits of wastewater users are higher in cauliflower production. The benefit or value of wastewater use is Rs 794 per acre and for the whole study area it is Rs 5882354. The simple cost-benefit analysis (when cost of externalities are not included) clearly indicating that it is profitable to use wastewater in cauliflower production.

Wastewater farmers have high probability of getting sick compared to those who are irrigating their land with canal or tube well water. Total economic value of labour productivity loss due to different kind of sicknesses is estimated to be Rs 1214748

(US$ 20245) and Rs 106076 (US$ 1768) for cauliflower production in wastewater and freshwater areas, respectively. The difference in labour productivity and medical expenditure loss for two groups is Rs 1108672 (US$ 18478) and Rs 2117634 (US$ 35294), respectively in cauliflower production. Total cost of health externalities of wastewater use in cauliflower production is Rs 3181681 and Rs 12.7 million for the whole year in the study area. After internalising the costs of externalities, the cost of cauliflower production in wastewater area has significantly increased compared to freshwater area and the negative value of net profit with wastewater use is Rs 3500 per acre and Rs 2593327 for the whole study area (Table 6). It implies that cauliflower production with wastewater is not economically feasible when cost of externalities is considered. In Faisalabad more than five thousand acre of land is being irrigated with wastewater and population of approximately fifty thousand is exposed to wastewater [Jeroen, *et al.* (2004)]. Under the assumption that per acre cost of health externalities remain the same for all crops and for all seasons then total cost of health externalities in peri-urban vegetable production sector of Faisalabad city (5283 acres) is accounted to be Rs 90.7 million in a year. In order to make the cauliflower production profitable from wastewater use, the price of cauliflower has to increase higher than the existing market price in order to cover the cost of health externalities. Now the question is whether society can pay higher prices? If not, then society has to reconsider the policy of untreated wastewater use in vegetable production. The possible options are as follows:

(1) At the macro level, government needs to interfere to resolve the issue of wastewater use. One possible approach is to supply the wastewater after proper treatment, and the cost of treatment should be paid by the government. The government can install the treatment plant and its cost can be recovered within a couple of years by saving the cost of medical expenditures which is shouldered by the government in terms of providing medical facilities at the rural side.

(2) A second possible option is to impose a tax on different industries which are emitting this polluted water in the drain equal to the cost of health damages. The revenue from taxation can be used to instal the treatment plant. The imposition of tax will also encourage the industrialists to instal treatment plants in their industries to clean polluted water before disposal in the drain. In the present situation owners of those industries omitting wastewater are enjoying high level of profitability due to low cost of production but at the cost to the farmers (in terms of health damages). Since, property rights are not well defined that who will pay for the externalities and therefore, government need to interfere to correct the welfare distribution among different segments of the society.

(3) The last option is that the government should pay a subsidy equal to the labour loss (forgone labour earnings) and medical expenditures to the inhabitants of that area.

Among these options, installation of a treatment plant through taxation on industrialists is one of the most feasible and practically viable options to provide immediate relief to the inhabitants of the area we studied.

APPENDIX-I

Just and Pope (1979) proposed the following three stage estimation technique to get the asymptotically efficient αs of Equation 1.

(1) In the first stage nonlinear least square (NLS) regression of Y_{it} on $F(X_{kit}, \alpha_k)$ is applied to Equation 1 to obtain coefficients $\hat{\alpha}$ and $F(X, \alpha)$ = exp [(ln$X$) α]. The NLS estimation in step 1 leads to consistent estimates of αs, (say $\hat{\alpha}$), the parameter of $F(X)$. There are two reasons that why estimation beyond first stage is important—(i) at the first stage of estimation, we are not in a position to examine the effect of input use on risk; (ii) even if risk is not important, the efficiency of estimates (at least asymptotically) can be improved after taking into account the problem of heteroscedasticity. It is possible to estimate μ by using the αs estimated in step 1 as follows:

$$\mu = Y - F(X, \hat{\alpha}) = \varepsilon h^{-1/2}(X, \beta)$$

(2) In the second stage an ordinary least square (OLS) regression of $\ln|\mu| = \ln|Y - F(X, \hat{\alpha})|\, on \ln X$ to obtain $\hat{\beta}$ is applied as presented below,

$$\ln|\mu| = \beta_0 + \frac{1}{2}(\ln X)'\,\beta + \varepsilon$$

where

$$\ln h(X,\ \hat{\beta}) = (\ln X)'\ \hat{\beta} \text{ and this implies that}$$

$$\ln h^{-1/2}(X,\ \hat{\beta}) = -\frac{1}{2}(\ln X)'\ \hat{\beta}$$

(3) In the third stage, for asymptotically efficient $\tilde{\alpha}$s, Just and Pope (1979) suggested a weighted *NLS* regression of Y on X with weights $h^{-1/2}(X,\ \hat{\beta})$. In mathematical notations, an *NLS* of $\overset{*}{Y} = Yh^{-1/2}(X, \hat{\beta}) = Y \ \exp[(-1/2)(\ln X)'\hat{\beta}$ on $\dot{F}(X, \alpha) = \exp[(\ln X)'\alpha - (1/2)(\ln X)'\hat{\beta}]$ to obtain the consistent and asymptotically efficient $\tilde{\alpha}$s is employed.

APPENDIX-II

Results of Production Function for Pooled Data of Two Groups (Freshwater and Wastewater)

Variables	1st Stage	2nd Stage	3rd Stage
Intercept	8619.613^{***}	13.269^{*}	72.624^{***}
	(3.07)	(1.77)	(9.78)
Fertiliser	-0.005^{ns}	0.008^{ns}	-0.005^{ns}
	(–1.30)	(0.02)	(–0.32)
Seed	-0.026^{ns}	-0.115^{**}	0.045^{**}
	(–1.09)	(–2.24)	(2.70)
Labour Hours	-0.059^{ns}	-1.635^{ns}	0.534^{***}
	(–1.08)	(–1.30)	(15.69)
Irrigation Hours	0.074^{**}	0.021^{**}	0.069^{*}
	(1.98)	(2.03)	(1.87)
Pesticide Cost	0.001^{ns}	-0.011^{ns}	0.010^{***}
	(1.57)	(–0.66)	(6.24)
Education	0.003^{**}	0.016^{ns}	-0.004^{***}
	(2.17)	(0.48)	(–3.32)
Dummy for Soil	0.140^{***}	-0.192^{ns}	0.182^{***}
	(11.42)	(–0.68)	(14.45)
Dummy for Seed Source	0.036^{**}	0.506^{*}	-0.157^{***}
(Home=1, Otherwise=0)	(2.04)	(1.27)	(–11.02)
Dummy for Source of Irrigation	0.037^{ns}	-0.656^{ns}	0.268^{***}
(Wastewater=1, Otherwise=0)	(0.77)	(–0.60)	(7.13)
R^2	**0.62**	**0.10**	**0.83**
Adj-R^2	**0.59**	**0.08**	**0.81**

*** = significant at 1 percent, ** = significant at 5 percent, * = significant at 10 percent, ns = not significant.
Figures in parentheses are *t*-statistics.

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