WORKING PAPER 26

A Framework for Analyzing Socioeconomic, Health and Environmental Impacts of Wastewater Use in Agriculture in Developing Countries

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International Water Management Institute

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Summary

Wastewater use in agriculture and its land application for treatment purposes is a global practice. Rough estimates indicate that at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater. Wastewater is a complex resource, with both advantages and inconveniences to its use. To the extent that wastewater and its nutrient contents can be used for crop production and other agricultural enterprises including aquaculture, it can provide significant benefits to the farming communities and society in general. However, wastewater use can also impose negative impacts on communities using this resource and on ecosystems. The widespread use of wastewater containing toxic wastes and the lack of adequate finances for treatment is likely to cause an increase in the incidence of wastewater-borne diseases as well as more rapid degradation of the environment.

The biggest challenge faced by policymakers at present, is how best to minimize the negative effects of wastewater use, while at the same time obtain the maximum benefits from this resource. While most of the impacts of wastewater use, both negative as well as positive, are generally known, a comprehensive valuation of the benefits and costs of these impacts has not as yet been attempted. Conventional cost benefit analysis is not adequate to evaluate wastewater impacts due to the environmental and public good nature of the impacts. To fill this gap in knowledge, this paper attempts to develop a comprehensive assessment framework applying available and tested techniques in environmental economic analysis, for the comprehensive evaluation of the costs and benefits of wastewater. The paper presents an approach for analyzing the socioeconomic, health, and environmental aspects of urban wastewater use in peri-urban agriculture, using typical characteristics of a major city in a developing country. Peri-urban area of Faisalabad is chosen to represent this context.

1. INTRODUCTION

Wastewater use in agriculture and its land application for other purposes is a global practice. Rough estimates indicate that at least 20 million hectares in 50 countries are irrigated with raw or partially treated wastewater. In addition to being a valuable resource as a source of water, the major objective of wastewater reuse has been the effective utilization of its rich stock of nutrients for agricultural and other purposes. The countries in the arid and semi-arid regions are the largest users of wastewater, as water scarcity is a major problem in these regions. With growing water scarcity in other regions, due to increasing population and industrial as well as urban expansion, the production of wastewater and its reuse has grown rapidly. The composition of wastewater has also changed from being predominantly organic (from human wastes) to including more toxic components such as heavy metals, and other chemicals, as industries expand into urban areas.

Wastewater is a complex resource, with both strong positive and negative aspects. To the extent that wastewater and its nutrient contents can be used for crop production and other agricultural enterprises including aquaculture, it can provide significant benefits to the farming communities and society in general. However, wastewater use can also impose negative impacts on the related communities and ecosystems. The widespread use of wastewater with more toxic wastes and the lack of adequate finances for treatment is likely to cause an increase in the incidence of wastewater-borne diseases as well as more rapid degradation of the environment.

The biggest challenge faced by policymakers at present, is how best to minimize the negative effects of wastewater use, while at the same time obtain the maximum benefits from this resource. While most of the impacts of wastewater use, both negative as well as positive, are generally known, a comprehensive valuation of the benefits and costs of these impacts has not been attempted. Conventional cost benefit analysis is not adequate to evaluate wastewater impacts due to the environmental and public good nature of the impacts. The framework in this paper has been developed to apply available and tested techniques in environmental economic analysis for the comprehensive evaluation of the costs and benefits of wastewater. The framework provides practical guidelines for monetizing environmental impacts with special reference to wastewater reuse.

Potential Benefits: Wastewater as a Valuable Resource

The potential benefits of wastewater use in agriculture may be summarized as follows:

- provides a reliable source of water supply to farmers, for crop production;
- conserves nutrients, thereby reducing the need for artificial fertilizers;
- increases crop yields and returns from farming;
- provides source of income through its use in other enterprises such as aquaculture; and
- is a low-cost method for sanitary disposal of municipal wastewater.

Potential Costs: Wastewater as a Harmful Entity

Wastewater could also have harmful impacts in agriculture, with potential costs attached to its use. For example, its use in agriculture could:

- increase exposure of farmers, consumers and neighboring communities to infectious diseases;
- lead to groundwater contamination;
- long-term wastewater use can have negative impacts on soil resources – buildup of salts, heavy metals in the soils, which may reduce soil productive capacity in the long run;
- have negative impacts on property values in the vicinity; and
- have other negative impacts on socio-ecological systems.

While these are the generally perceived potential benefits and costs of wastewater uses, their magnitude and extent may vary from community to community and from region to region; and depends on a range of factors. These include:

- Volume and source of wastewater (residential, commercial, industrial);
- Composition of wastewater;
- Degree or level of treatment before use;
- Management aspects related to disposal/distribution of wastewater – at secondary level;
- Management aspects, including methods of application, related to farm level use of wastewater – at tertiary level.

Policy Questions

Under the changing circumstances of wastewater reuse, policymakers are facing difficult questions:

- Should the traditional practice of wastewater use in agriculture be discontinued?
- Or should it be treated and to what degree and at what cost?
- Should regulatory mechanisms be enforced or incentive based measures be adopted and of what type and at what cost?
- More importantly, what should be the basis of policy decisions?

In the absence of sound scientific research, these and the other policy-related questions remain unanswered, and decisions are often based on unsound ad hoc judgements – which not only lead to litigation but also may result in inefficient and unsustainable use of scarce resources.

The objective of this paper is to provide a framework for the analysis of socioeconomic, health, and environmental aspects of urban wastewater use in the agricultural sector. The specific objectives of this paper are:

1) to identify various impacts (while effects and impacts generally refer to short-term and long-term phenomena, respectively, in this paper we use impacts to mean both short-term and long-term effects) of urban wastewater use in agriculture, and

2) to identify/develop approaches and methods for assessing, valuing and analyzing these impacts.

For the purpose of this paper, the term urban wastewater includes wastewater from all urban sources such as industry, commerce and residences. Impacts of wastewater include impacts on crop production, and on environmental, health, and other socio-ecological systems. The overall aim is to provide a holistic picture of costs and benefits of urban wastewater use in agriculture.

2. BACKGROUND

The framework for the analysis developed in this paper uses the typical characteristics of a major city in a developing country. We have chosen the peri-urban area of Faisalabad to represent this context. Faisalabad, with a population of about 2 million is the third largest city and the industrial capital of the country. It will be used as a case study for application of this framework.

The Faisalabad metropolitan area, which forms part of the Faisalabad-Skeikhupura-Lahore growth corridor has experienced rapid industrial development during the last 2 decades and has emerged as an area of high economic activity and a major growth center in Pakistan. The industrial development has in turn contributed to structural transformation of urban, peri-urban, and rural agricultural industry in the region. More than half the regional population is engaged outside agriculture, with large villages and peri-urban areas experiencing transition from primary agriculture to export based industries. There is also migration from other parts of Pakistan to Faisalabad in search of employment in textile, manufacturing, services, and contractual work (Altaf et al. 1993). People from villages located within a radius of 25 kilometers and merchants from other cities and towns, travel to Faisalabad regularly, for trading.

During the recent past, the regional rural areas have become functionally integrated into the economy of Faisalabad. This structural transformation has changed the face of agriculture in Faisalabad. While sugarcane, wheat, maize, sorghum, fodder crops, vegetables, and citrus orchards dominate the regional cropping pattern, high return crops such as soybean and sunflower are gaining rapid popularity among farmers. It is common for the peri-urban farmers to grow seasonal fruits, vegetables, fodder crops and plant nurseries instead of traditional crops to maximize their returns. Canal irrigation remains the major source of water for agricultural production. However, due to the high water requirements for these crops, farmers in this region often augment canal water supplies with municipal wastewater, and in certain systems, municipal wastewater is being used increasingly as the primary source of water. The untreated wastewater is reported to have high concentrations of pathogenic microorganisms and, therefore, poses a greater than normal risk to public health. However, untreated wastewater also has higher concentrations of plant food nutrients as compared to treated wastewater, thus providing an incentive to farmers, in the form of a reduction in fertilizer cost, to use untreated wastewater.

Given the high cost of treatment and the lack of resources for treatment facilities, the municipality also discharges untreated wastewater into the environment thereby incurring hidden environmental costs, which are not accounted for. The municipality is further encouraged to do so, as the stated objective of wastewater management from an agency's budgetary viewpoint, is cost minimization, rather than enhancement of environmental quality. There seems to be a lack of information or awareness of the public health impacts of wastewater irrigation on the part of the farmers and the municipality of the Faisalabad area. For these reasons, the peri-urban areas of Faisalabad appear to be an appropriate choice for applying a framework for assessing and valuing the wider impacts of wastewater irrigation.

This paper is organized as follows: the introduction provides a brief justification and the objectives of the paper, followed by the background that gives a description of the location where the framework will be applied. Section 3 provides a discussion of the various potential impacts of wastewater irrigation. Section 4 provides a detailed description of the suggested methodological framework for this study, which includes alternative methods for quantification and valuation of impacts and their applications. Study data requirements and various sources are identified in section 5. The last section highlights some of the limitations of the suggested framework.

3. IMPACTS OF WASTEWATER IRRIGATION: AN OVERVIEW

This section provides some discussion on possible impacts of wastewater use in agriculture on crop production, public health, soil resources, groundwater, property values, public health, ecology, and social parameters.

Crop Production

The economic impacts of wastewater on crops may differ widely depending upon the degree of treatment, types and nature of crops grown, and the overall farm level water management practices. Normally, as wastewater is a rich source of plant food nutrients, higher than average crop yields may be possible with wastewater irrigation. If crops are under supplied with essential plant food nutrients, wastewater irrigation will act as a supplemental source of fertilizer thus increasing crop yields. However, if plant food nutrients delivered through wastewater irrigation result in an oversupply of nutrients, yields may actually be negatively influenced. Also, since wastewater contains undesirable constituents such as trace elements and heavy metals, organic compounds and salts, crop yields may be negatively affected depending upon their concentrations in the wastewater and the sensitivity of crops to these elements.

Thus from an economic standpoint, wastewater irrigation may have threefold impacts on crop production: (1) source of irrigation water; (2) influence on extent of irrigated areas, cropping intensity, crop mix, and on crop yields; and (3) fertilizer application. These aspects have implications for cost of production and overall profitability of crop production.

Public Health

Wastewater contains pathogenic microorganisms such as bacteria, viruses and parasites, which have the potential to cause diseases in the user communities, consumers, and the neighboring communities. In particular, human parasites such as protozoa and helminth eggs are of special significance in this regard. The use of untreated wastewater for irrigation poses a risk to human health in all age groups though the degree of risk may vary among different age groups. Given the prohibitively high costs of the wastewater treatment to zero risk levels, prior to reuse for crop irrigation, treatment to this level may not be justified on economic, social, or political grounds. Nevertheless, valuation of public health risk should be an important decision variable in wastewater irrigation policy analysis.

Soil Resources

The use of wastewater for irrigation may add nutrients, dissolved solids and other constituents like heavy metals into the soil over time. Some of these elements may accumulate in the root zone with possible harmful impacts on soil. Long-term use of wastewater could result in soil salinity and waterlogging, breakdown of soil structure and overall reduction in productive capacity of soil and lower crop yields. However, the impacts and their intensity will depend on a range of factors including source, intensity of use and composition of wastewater, soil properties and characteristics of plants/crops grown. From an economic viewpoint, soil-related impacts of wastewater can be grouped under (1) potential yield losses; (2) loss of soil productive capacity; (3) depreciation in market value of land; and (4) cost of additional nutrients and soil reclamation measures.

Groundwater

The use of wastewater has the potential both to recharge groundwater aquifer (positive externality) as well as pollute groundwater resources (negative externality). Percolation of excess nutrients, salts and pathogens through the soil may cause degradation of groundwater. However, the actual impact will depend upon a range of factors including scale of wastewater use, quality of groundwater, depth to water table, soil drainage, and soil characteristics (porous, sandy). In irrigated areas with shallow sweet water tables, impact of wastewater irrigation on groundwater quality is likely to be substantial. However, in places like Faisalabad where the groundwater is brackish in many locations and cannot be used for irrigation or as potable water, the economic significance of pollution may be only marginal in such cases. Hussain and Hanjra (1996) evaluated the impact of industrial wastewater discharges on groundwater quality in Faisalabad. The analysis of groundwater samples, collected from hand pumps and wells located within a radius of one kilometer of industrial effluent drainage, show very high concentrations of dissolved salts, trace elements, and heavy metals. A part of this pollution may be attributed to industrial discharges.

Around the globe, a number of studies have attempted to assess the impact of wastewater irrigation on groundwater resources in various regions. Not only do the findings differ from region to region, they are also site specific. However, the general conclusion is that wastewater irrigation has the potential to adversely affect groundwater resources in the long run.

Property Values

Wastewater irrigation could also influence property values. One could hypothesize that properties neighboring major wastewater irrigation farms may have groundwater quality lower than the properties located some distance away, which may negatively influence property values. Also, the perceived negative impacts on wastewater irrigated soils, groundwater pollution, and potential for loss of soil productive capacity may adversely affect the property values. On the other hand, one could also argue that given the resource value of wastewater, irrigation with wastewater could lead to appreciation of property values – wastewater irrigated lands in this case. For instance, in Haroonabad in Pakistan, the wastewater irrigated land has a higher value than the canal irrigated land, and the land rents of wastewater irrigated farms were on average three and a half times higher than those of canal water irrigated lands (Hassan et al. 2001).

Ecology

When drainage water from wastewater irrigation systems drains into surface water, particularly small confined lakes and water bodies, the remains of nutrients may cause eutrophication, particularly if phosphates in the orthophosphate form are present. Eutrophication causes imbalances in the plant microbiological communities of water bodies. This may in turn affect other higher forms of aquatic life and influence the presence of waterbirds and reduce biodiversity. Insofar as these water bodies serve local communities their needs, the ecological impacts can be translated into economic impacts, which should be included in the analysis. For example, overloading of organic material resulting in decreases in dissolved oxygen may lead to changes in the composition of aquatic life, fish deaths and reduced fishery. The eutrophication potential of wastewater irrigation can be assessed using biological indices or biomarkers, which in turn can be quantified in monetary units using appropriate economic valuation techniques.

Social Impacts

In the context of this analysis we define social impacts as the *concerns/doubts expressed* by the public about their perceptions on wastewater irrigation. These concerns can be classified as follows:

General concerns such as nuisance, poor environmental quality, poor hygiene, odor etc;

Social concerns such as food safety, health and welfare, impaired quality of life, loss of property values, and sustainability of land use.

Natural resource concerns such as pollution of vital water resources, loss of fish, wildlife, exotic species, etc.

Public concerns about the perceived or real risks of wastewater irrigation may create business risks, which have to be addressed adequately to avoid exploitation by lobby groups. Business risk and potential liability can be covered, by obtaining appropriate level of insurance. The premium for general risk assurance against wastewater irrigation is likely to be high at the beginning because most developing countries, including Pakistan, do not have experience in agriculture sector insurance. Moreover, premium and indemnity structures are likely to vary significantly among crops and regions. Nevertheless, wastewater risk assurance premium is a cost worth paying to cover agribusiness against potential risk and liability.

4. GENERAL FRAMEWORK

Analysis of the impacts of wastewater irrigation should incorporate the viewpoint of the following:

- Farmers whose objective is to ensure family food security and maximize profits;
- Treatment and disposal agencies whose objective is to minimize costs; and
- Society as a whole with the objectives of maximization of social gains and minimization of adverse health, environmental and ecosystem impacts.

The valuation approach suggested here is comprehensive cost-benefit analysis that incorporates socioeconomic, health, environmental and ecosystem impacts of wastewater use in agriculture. The framework could be developed for two basic scenarios – with wastewater irrigation, and without wastewater irrigation. Further sub-scenarios could be developed from these basic scenarios – freshwater only, wastewater only, mixed, untreated, semi-treated wastewater etc. The impacts could be analyzed in the context of location, activity, education, and income groups (equity impacts –who wins and who loses).

Figure 1. Framework for assessing impacts of wastewater reuse.

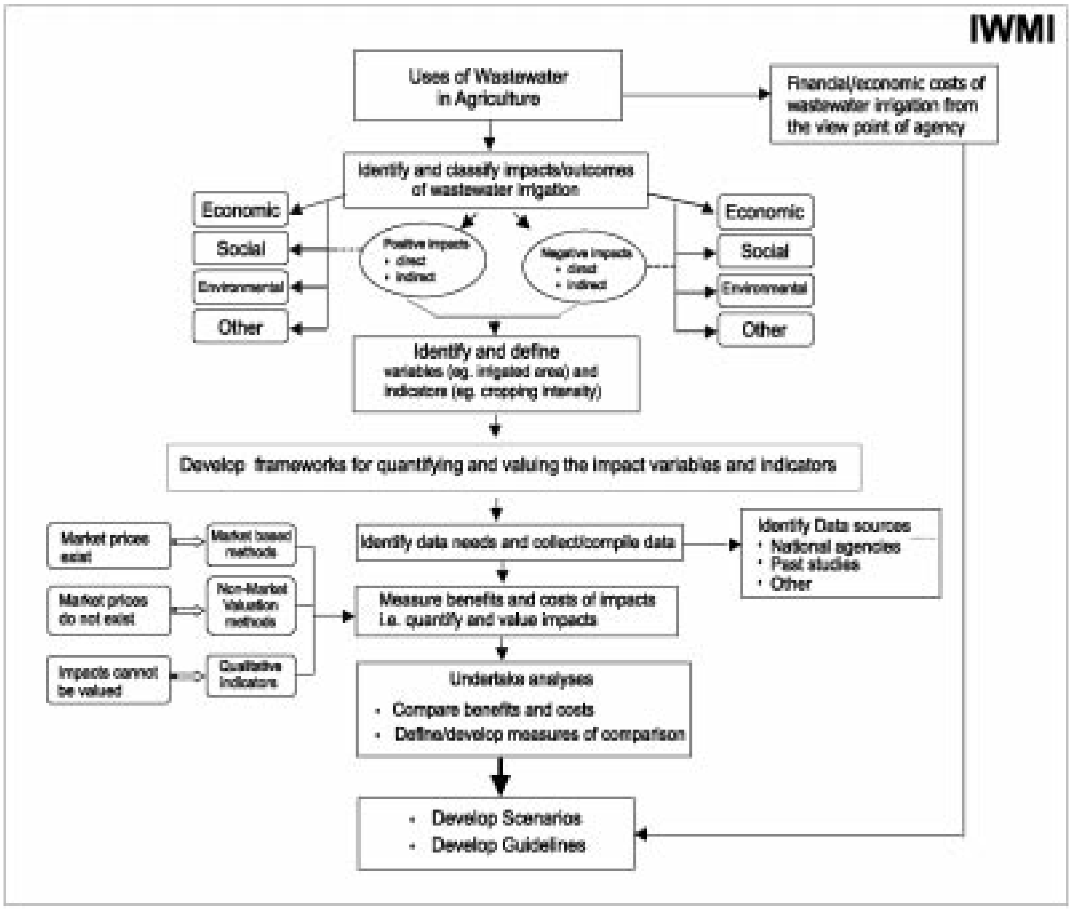
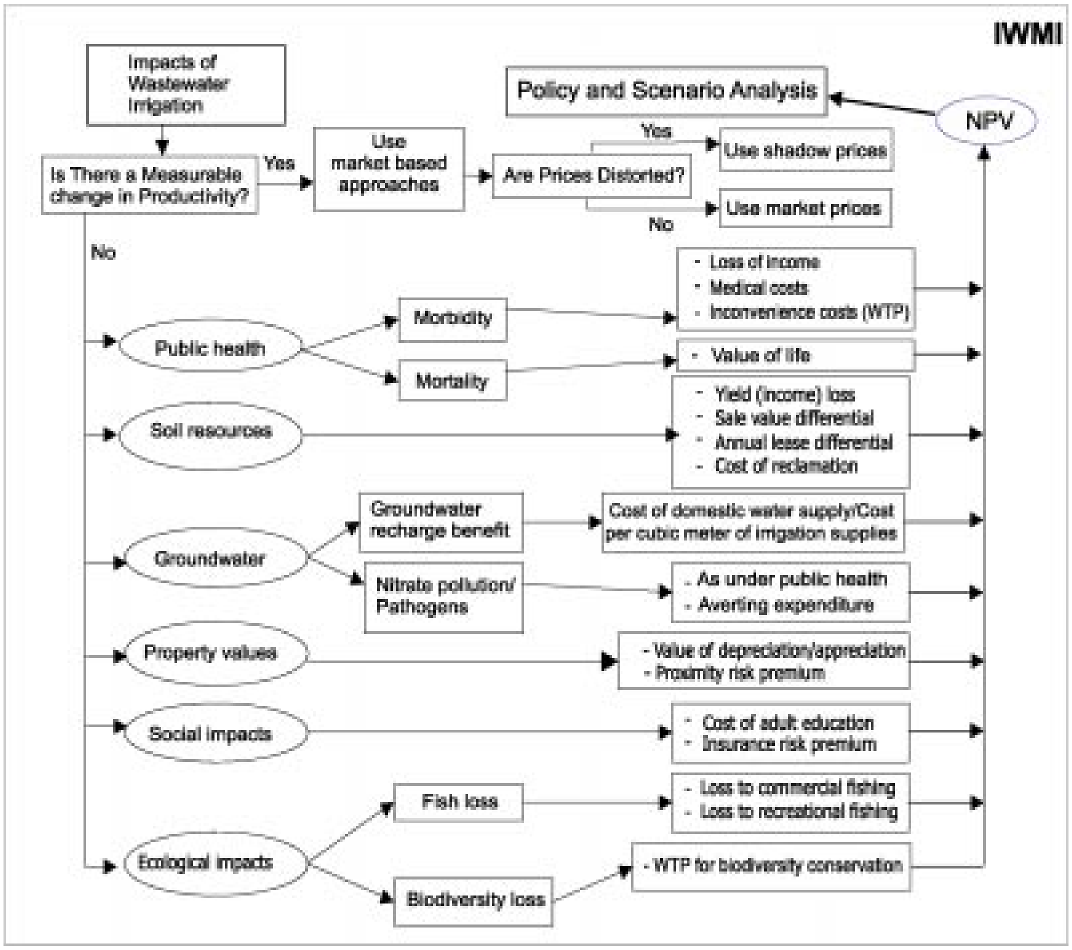


Figure 2. Framework for valuing impacts of wastewater reuse.



WTP = Willingness to Pay

NPV = Net Present Value

It is important to emphasize here that the major issue in the cost benefit analysis of wastewater irrigation is; how to conceptualize and estimate the total value of impacts in a consistent manner and how to integrate various value measures to generate a single representative measure, such as net present value, that may be used for policy analysis.

The suggested overall framework/approach is outlined in figures 1 and 2. There are several logical steps to follow - identification and quantification of impacts; and identification and application of valuation methods to quantified impacts (dollar values). As is clear from the above discussion and the outline in figures 1 and 2, there is no single method or model that can be readily adopted to assess costs and benefits of wastewater irrigation. A range of methods, models or measures, needs to be adopted in this exercise. In some cases, simple variables (such as irrigated crop areas) or a combination of variables, which comprise an indicator (such as cropping intensity) would be necessary to measure the impacts of wastewater irrigation. In other cases, modeling will need to be undertaken and the output from such modeling could then be used to develop impact indicators.

Quantifying Impacts

After identifying all the relevant important impacts (based on input from a multidisciplinary team of experts), the next step would be to quantify them in physical terms where possible. Here the application of "with and without" principle is relevant.

'With and Without Principle'

The impacts of wastewater irrigation can be measured as the differences between the scenarios with wastewater irrigation and without wastewater irrigation—the actual change in impacts. The aim here should be to separate out only the impacts that are clearly associated with wastewater irrigation and not include those impacts or changes that would have occurred even without wastewater irrigation. With and without is a useful tool when quantifying impacts of any intervention or policy. It is important to note that only incremental net impacts should be associated with the wastewater irrigation situation.

Valuing Impacts – Benefits and Costs

Once the impacts of wastewater irrigation are quantified, the next step would be to value them in monetary terms where possible. Dollar based valuations would allow us to directly compare costs and benefits of wastewater irrigation for the different scenarios. Where monetary valuation is not possible, or impractical, non-monetary value indicators need to be developed. However, these indicators may not be particularly useful for determining whether the economic benefits of wastewater irrigation scenarios exceed costs in quantitative terms, but may be useful to compare similar impacts across the different scenarios.

The following economic concepts would provide useful theoretical concepts for monetizing the quantified physical impacts of wastewater irrigation.

Economic Value

The term value in any sense has a meaning in relation to scarcity. Economic value is one of the many possible ways to measure values. In economics, the generally accepted measure of economic value is based on what people want. It is a measure of the maximum amount of one good an individual is willing to forego to obtain more of something else i.e. it reflects people's preferences and choices. Economic value is thus a measure of economic welfare, and it is formally expressed in a concept called Willingness to Pay (WTP). Economic value for the society as a whole is the aggregate of individual values.

For any resource, prices are interpreted as expressions of willingness to pay by consumers or producers. While this is obvious for marketed goods and services, where market price represents the willingness to pay at the margin, it is equally applicable to nonmarket goods and services where WTP is a theoretical basis to determine prices referred to as shadow prices. In any case WTP represents the value of incremental benefit of the impact or output i.e. demand for that output.

While benefit values can be measured from WTP, costs can be monetized using the concept of Opportunity Costs (OC) — which are the returns foregone where a scarce resource is used for one purpose instead of the next best alternative.

General Approaches

Economists over the past 2 decades have developed several methods for valuing benefits and costs of natural resources for which no markets exist or markets are highly imperfect. Valuation methods/ techniques are based on economic theory and applied economic principles. Some of these methods could potentially be adopted for valuing wastewater. These methods may be classified into the following categories:

- Conventional market-based approaches—where goods are traded in the market and prices exist for inputs and /or outputs, prices (or adjusted prices) can be used as expressions of willingness to pay and the benefits and costs can be valued using market prices.

- Alternative/replacement cost approaches—these approaches can be applied to situations where market prices for some inputs or outputs do not exist or where direct estimations of demand and supply functions becomes difficult due to lack of data. Replacement cost approaches are based on the notion that maximum willingness to pay for any good or service is not greater than the cost of producing that good or service with alternative means of production or technology. The cost of producing that good or service is compared with cost of least-cost alternative means of producing that good, and the difference represents the net economic benefit. The minimum replacement cost can be used as an estimate of the value of benefits of the good or service in question.

- Observed indirect or implicit or revealed preference approaches—where market prices do not exist, these approaches can be used to infer willingness to pay based on actual expenditure choices made by consumers revealing their preferences. These approaches are based on actual consumer behavior where willingness to pay for a good or service is estimated indirectly.

- Stated preference approaches—these approaches are applicable to situations where peoples' preferences or willingness to pay cannot be inferred directly or indirectly from the actual behavior in the market. In these approaches, peoples' willingness is obtained through hypothetical markets where people are asked to express their willingness to pay or preferences for a good or service in question through surveys.

All the above four approaches are based on sound theoretical economic concepts. However, in terms of their applications to the real world problems and the related complexities, some are more controversial than others. In general, the more the approach is based on actual market behavior and information, the more accepted it is.

Application of Approaches and Concepts

How do we actually implement the above approaches or concepts? Let us look at some of the specific methods that could be applied to value the benefits and costs of wastewater irrigation.

Valuing Benefits of Wastewater in Crop Production

Wastewater is used as one of the several inputs in production of agricultural outputs. If wastewater were sold in well-functioning competitive markets, value of wastewater or economic benefits of wastewater in crop production could be obtained by analyzing wastewater demand using market price information. In the absence of market prices, value of wastewater can be derived indirectly using the economic concept of production function. The **Change in Productivity Method** (also known as residual imputation method or change in net income method or intermediate good method) can be used to derive the imputed value or shadow price of wastewater given the prices of output and other inputs. The value of wastewater in this method is basically derived from change in revenue of the associated farm output (s). The change in revenue is a measure of the effects of wastewater in crop production. The basic assumption here is that output increases associated with wastewater use lead to only small change in output supply relative to regional market (i.e. additional output produced with wastewater does not significantly influence market prices for the output). Given that wastewater is generally a small proportion of the total water use, this assumption may not be unrealistic.

Benefit or value of wastewater irrigation $= NVO_w - NVO_{wo}$
and $NVO_w = GVO_w - C_w$
$NVO_{wo} = GVO_{wo} - C_{wo}$

Where *NVO* is the net value of output, *GVO* is the gross value of output, *C* is the total cost of production, subscripts *w* and *wo* represent with and without wastewater irrigation. The above equations would provide average value of wastewater. The present value of wastewater irrigation NVO_w can be calculated for a specific number of years using an appropriate discount rate.

Marginal value estimates could be derived with econometrically estimated production functions by modeling wastewater output as a function of major inputs such as fertilizers, labor, seed, wastewater, and the like. For example, a Cobb-Douglas type of production function can be specified to estimate the impact of various inputs including wastewater.

$$Q = A\,(F^{\alpha} S^{\beta} L^{\gamma} WW^{\eta} X_i^{\lambda} \ldots\ldots X_n^{\theta})$$

Where Q is the output, and F, S, L, WW are, respectively, the quantity of the inputs such as fertilizer, seed, labor, and wastewater, while $X_i \ldots\ldots X_n$ *are other inputs and* $\alpha, \beta, \gamma, \eta, \lambda, \theta$*, are the partial elasticities of inputs with respect to output.*

Marginal Product of wastewater is derived as

$$\delta Q/\delta WW = A\eta\,(Q/WW)$$

The above method gives a measure of the impact of wastewater on crop production. The same method can also be used to value benefits of wastewater in fish production.

Valuing Impacts of Wastewater on Soil Resources

As mentioned earlier, wastewater can have harmful effects (accumulation of heavy metals, erosion of soil structure, salinity and sodicity etc.) on soil health and can reduce productive capacity of soil, especially in the long run. These could potentially lead to reduction in soil productivity/ crop yields, and soil fertility, which may result in depreciation in market value of land and/or added cost of soil reclamation measures. The actual and potential yield losses due to wastewater irrigation induced land degradation could be evaluated in economic terms using the Change in Productivity Method, as described above. However, since yield changes may be affected by several factors simultaneously, wastewater induced yield losses may be difficult to isolate and quantify in absolute terms. Expert opinion regarding wastewater induced yield losses can serve as a proxy for estimating income losses associated with wastewater practices.

The depreciation in market value of land, associated with wastewater induced land degradation, has two dimensions: decline in sale value of land- market price per acre; and decline in land rent – annual lease revenue per acre. The present value of differential in market price or annual lease per acre over a defined period, say 20 years, may be used as a measure of opportunity cost of wastewater induced land degradation[1]. This method is suitable, if the wastewater induced land degradation is severe and impacts are of long-term nature. This can be estimated as follows:

Present value of differential in sale value is

$$PV_s = \sum \{P_i A - P_{wi} A/(1+d)^i\} + \ldots + \{P_n A - P_{wn} A / (1+d)^n\}$$

Where
PV_s *is the present value of differential in sale value*
P is the market price of unit of land unaffected by wastewater
P_w *is the market price of unit of land affected by wastewater*
A is the area of land in a given community / project area
d is the discount rate
n is the total number of years of measurement beginning from i = 0 …. n.

Alternatively, if the impact is moderate, annual lease differential may be used as a proxy. A similar equation can be used to estimate the present value of annual rental differences by replacing the land price with the annual rental price variable.

A more consistent and practical measure of the opportunity cost of wastewater induced land degradation, is the cost of soil reclamation measures such as gypsum application or green manuring. This is particularly good proxy for valuation purposes where wastewater induced damage to soil is relatively small and can be corrected with these measures.

In this case, the cost of land degradation or the opportunity cost of wastewater induced degradation can be estimated as follows:

Land Degradation Cost $LDC = \sum \{ C_1 + C_2 + C_3 + \ldots + C_n)$

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[1] Hedonic price analysis could be conducted to understand land price differentials attributable to wastewater induced land degradation and associated reduction in land productivity.

Where $C_1 + C_2 + C_3 + \ldots + C_n$ are the various costs of reclamation. If the reclamation is spread over several years, the present value of the costs over the specified time period should be calculated using the previous formula.

In summary, as the impact on soil resources may vary from severe to moderate to minor, the appropriate proxies for the valuation of wastewater induced land degradation are sale value differential, annual lease differential, and cost of soil reclamation measures, respectively.

Valuing Impacts on Property Values

Impacts on property values also relate to the impacts on soil resources. Wastewater irrigation has the potential to influence property values because of the potential to affect groundwater quality, public health risk, and discomfort associated with odor, nuisance, and poor hygiene. Hedonic pricing method can be used to place monetary values on property attributes such as proximity to wastewater irrigation sites, proximity to roads, market and major population centers, productivity and fertility index or land rent and annual lease revenue, availability of canal/groundwater, agroforestry. Holding the effect of other variables constant, the proximity risk premium for properties located near sources of wastewater-related pollution can be estimated. Secondary data on real estate sales can be used for this purpose. (Note: properties as defined here include both residential and commercial properties, as well as agricultural lands).

Valuing Impacts on Groundwater

As mentioned earlier, two principle impacts of wastewater are groundwater recharge (a benefit item), and nitrate contamination of groundwater resources (a cost item) through leaching and drainage. Based on the amount of wastewater applied and leaching fraction, the annual contribution of wastewater irrigation towards groundwater recharge, (say in terms of cubic meters), can be estimated. These estimates can be used to generate dollar value of benefits of groundwater recharge using appropriate proxies – such as cost of domestic water supply per cubic meter and/or cost of irrigation water supply per cubic meter.

Value of benefits from groundwater recharge (GWR) can be estimated as follows:

$$GWR = (Q_i * L) * C_{dw}$$

Where

Q_i *is the quantity in* m^3 *of wastewater applied per annum*

L is the leaching fraction

C_{dw} *is cost of domestic water, or this can be replaced by the cost of irrigation water*

On the cost side, if the groundwater survey reveals excess nitrate levels in drinking water, the nitrate risk to human health should be evaluated – (identification of risk, estimation of human exposure, risk level based on risk per unit of intake and total potential intake). Alternatively, wastewater nitrogen application rates, nitrogen leaching fraction and base level nitrate concentrations in groundwater can be used to estimate the amount of nitrates (in kg/ha per year) added to groundwater. The leaching fraction can be calculated as the concentration of available nitrogen minus nitrogen required by the crop.

Nitrate risk to human health can be estimated as follows:

Excess Nitrates: $N_e = N_t - N_c$
Nitrate Risk Factor: $RF_n = (N_t - N_c)/(N_c)$
Human Nitrate Exposure Level: $HN_{el} = RF_n * PCWI$

Where
N_e *is the excess nitrate in* kg/m^3 *of groundwater*
N_t *is the total nitrate in* kg/m^3 *of groundwater*
N_c *is the nitrate requirement of crop in* kg/m^3 *of groundwater*
RF_n *is the Nitrate Risk Factor*
HN_{el} *is the human nitrate exposure level*
PCWI is the per capita water intake per year

The incidence of nitrate-related health impacts could be measured as a ratio of human exposure level to total water consumption. The nitrate-related human health impacts could then be evaluated using some of the methods suggested below under the section on valuing public health impacts.

Valuing Public Health Impacts

As mentioned earlier, there could be potential risk of disease (s) or mortality (extreme case) with wastewater irrigation. Illnesses caused by wastewater pathogens may result in:

- loss of potential earnings;
- medical costs; and
- inconvenience costs such as leisure and sleep disturbances.

Loss of potential earnings or labor productivity can be evaluated using opportunity cost principle. These losses can be quantified in economic terms by using the information on prevalence of disease (on number of sick days, both full-time and part-time, and off-work, generally called restricted activity days in literature), daily wage rate and incidence of disease. The productivity loss of children, unemployed and underemployed sick individuals can be estimated using the methodology given below, though the wage rate may require some adjustment.

The loss of potential earnings in the case of employed population, due to morbidity caused by wastewater irrigation can be estimated in the following manner.

The present value of labor productivity losses due to wastewater related diseases PV_{pl}

$$PV_{pl} = \sum \{(SD_i * WR_i * ID_{ww} * TP_i)/(1+d)^i\} + \ldots + \{(SD_n * WR_n * ID_{ww} * TP_n)/(1+d)^n\}$$

Where
SD is the number of sick days attributed to wastewater use per person per year
WR is the average wage rate
n is the total period of employment in years with i = 1 to n
ID_{ww} *is the incidence of diseases or percent of population affected*
TP is the total population in a given community or project area
d is the discount rate

The wage rate can be adjusted for partly employed and unemployed persons or children Medical or healthcare costs and inconvenience costs may 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 as public healthcare is highly subsidized in most developing countries.

Present value of medical costs PV_{MC} may be calculated as follows:

$$PV_{MC} = \sum \{ (CC + MC + TC + PC + OC)_i \, (ID_{ww} * TP_i)/(1+d)^i\} + \ldots\ldots + (CC + MC + TC + PC + OC)_n \, (ID_{ww} * TP_n)/(1+d)^n$$

Where
CC is the cost of medical consultation
MC is the cost of medicine
TC is the transport cost
PC is preventive cost
OC are the other costs
n is the total period of employment in years with i = 1 to n
ID_{ww} *is the incidence of diseases or percent of population affected*
TP is the total population in a community or project area
d is the discount rate

The economic value of mortality (deaths), if any, caused by wastewater irrigation can be evaluated in terms of net labor productivity of an individual over the expected life span. The mortality-related productivity loss is thus present value of difference between production and consumption of an individual over the remaining period of life (using average life expectancy as a reference). The value of life estimates along with the estimated change in mortality for each population cohort, attributable to wastewater pathogens, can be used to generate population wide measures of economic cost of mortality. Although the value of human life approach is contentious, it is more appropriate to combine individual's willingness to pay to save their own lives plus the lives of others (altruistic motive) as the inclusion of latter may significantly increase the value of life estimates.

The net present value of economic losses due to mortality PV_{ml} resulting from wastewater irrigation-related diseases is estimated as follows. The productivity loss should be summed by population cohort and mortality rate of each cohort.

$$PV_{ml} = \sum \{[AN_i-C_i)/(1+d)^i]*[MR_{ij} * P_{ij}] + \ldots..+[AN_n-C_n)/(1+d)^n] *[MR_{nz} * P_{nz}]\}$$

Where

AN is average per capita income per year

C is the average per capita consumption per year

MR is the mortality rate

P is the total population in a given community or project area

n is the average number of years of remaining life period with i=1 to n

z is the number of population cohorts with j=1 to z

The sickness-related leisure and sleep disturbances might cause inconvenience and sufferings to human beings. The value of inconvenience caused by leisure and sleep disturbances may, however, be difficult to quantify in economic terms because of the low value people attach to such losses in developing countries (costs are not well defined).

Valuing Ecological Impacts

Ecological impacts result when drainage water from wastewater irrigation flows into confined water bodies such as lakes and ponds. The nutrients remaining in the wastewater can cause eutrophication, leading to death of aquatic life and reduction in biodiversity. While loss of biodiversity per se, is difficult to value in economic terms, indirect losses due to reduced fishery can be valued in terms of net loss of income from fishing activities. The change in productivity method, as described earlier, can be used to value the losses in this case.

Valuing Social Impacts

Most commonly noticed community concerns about the potential risk of wastewater irrigation include: *general concerns* such as nuisance, poor environmental quality, poor hygiene, odor etc., and *social concerns* such as food safety, health and welfare, impaired quality of life, loss of property values, and sustainability of land use.

Natural resource concerns such as pollution of vital water resources, loss of fish, wildlife, and exotic species etc. The community groups most concerned about the potential risks of wastewater irrigation are farmers, food processing industry, affected community, and general public. Some concerns of these community groups can be addressed using appropriately targeted education and community awareness programs, public involvement in decision-making, and use of market forces. Thus, the cost of public education, awareness and demonstration programs can be used as a proxy for the valuation of social impacts of wastewater irrigation programs. Cost estimates for the above can be developed by using adult learning and education models.

It should be noted that in estimating present values of various costs and benefits, assumptions might have to be made on future values of certain variables. With and without scenarios may be compared for a specified number of years.

After valuing all relevant identified impacts, the net present value may be derived based on costs and benefits using specified time horizon, and alternative scenarios may be developed for analyzing policy decisions. The net present value of costs and benefits may also be derived for a single year by dividing the total present value of costs/ benefits by the appropriate number of years for, which each of the calculations were made.

Financial and economic costs of wastewater irrigation from the viewpoint of the agency may also need to be incorporated in total cost / benefit sides (i.e. costs incurred / saved by using it in agriculture and / or its disposal). Further scenarios may be developed by using, treated, semi-treated or untreated wastewater in agriculture.

5. DATA REQUIREMENTS, SOURCES AND ANALYSES

Both primary as well as secondary data and information are required to carry out an economic valuation of the costs and benefits of wastewater irrigation. Existing studies of economic valuation from the selected region would reduce the need for primary data collection.

Secondary Data Sources: secondary data sources include both published and unpublished sources of data and information. For example, a list of site specific sources for the selected location (Faisalabad) may include:

- Studies on willingness to pay for water supply (Altaf 1993; Hanjra and Hanjra 1995)
- Industrial wastewater treatment costs data (Hanjra 1999), and
- District Population Census Reports, Health Statistics, Agricultural Statistics, Economic Survey, Faisalabad Municipal Corporation, Local EPA data set on industrial effluent quality, from Revenue Department, Irrigation Department and the Water and Sanitation Authority.
- UAF Data Base: Department of Farm Management, University of Agriculture, Faisalabad, Pakistan has a wide and extensive data set on yields, inputs, and outputs of agricultural and livestock products.

Rural Appraisals: Rural appraisal methods can be applied to characterize the selected communities/ sites, including irrigation systems, sources of irrigation, irrigation infrastructure, pattern of water use and distribution. General information on the agricultural situation, cropping patterns, characteristics of soils in the area, general socioeconomic status of the area, health aspects, community education, land tenure arrangements, land values and the related aspects may also be obtained through this method. Such information must be collected from both farming community as well as from the wastewater agency.

Primary Data: Detailed questionnaire surveys may need to be undertaken twice a year (both wet and dry seasons) on randomly selected farms (sample size will depend on the population of the area) in both wastewater and non-wastewater irrigated areas to collect detailed information on farm location, resource endowment including land resources, farm machinery and assets. Other data needed include, demographic information, source of water supply, sources of irrigation water, health statistics including type of illness, days of illness, treatment costs, preventive expenditures, employment, agricultural practices including cropping and other farm enterprises, farm inputs and outputs, production costs and income and product marketing.

Stakeholder Interviews: In addition to farmers, surveys may need to be conducted with several stakeholders including government officials, Water and Sanitation Authority WASA officials, and other members of the community to obtain their views on wastewater situation and improvement strategies. Other stakeholders include: farming families, agricultural laborers; treatment plant operators, disposal agency workers; and crop consumers, handlers, processors and service providers.

Data Analyses: In addition to quantitative cost-benefit analyses, the analysis of the following aspects may provide useful information and insights into the impacts of wastewater use in agriculture.

- Resource utilization patterns: land use and cropping intensity, input use, land tenure arrangements;

- Resource rent variations: returns to land, water, labor, and capital resources, property values (investment returns);

- Input demand changes: fertilizer, farmyard manure, green manure, other fertility enhancement measures, traditional and high yielding varieties, water, mechanization, agricultural credit, on farm and off farm labor, extension services etc.;

- Output supply changes: crops mix, ratio of commercial, subsistence and cash crops, animal husbandry, farm forestry;

- Welfare changes: consumption patterns, lifestyle, human capital formation, on farm and off farm employment, income levels, income distribution, social standing, community welfare, institutional changes;

- Quality of life: access to basic human needs, water, sanitation, healthcare, and education, awareness towards basic rights and obligations, sources of leisure and information etc.

6. LIMITATIONS OF THE FRAMEWORK

In addition to the general issues in valuation measures, additional problems may arise in assessing various impacts of wastewater use in agriculture. The use of human capital approach may be problematic particularly when the cause and effect relationship between the disease and wastewater irrigation in not known or when the sickness is of long duration. Market imperfections may affect resource prices (fertilizer, green manure, animal dung), wages (disguised and open unemployment, value of life), capital costs (market rate and inflation).

The simulation of environmental and ecological impacts may be another area of potential difficulty. We can consider the example of certain water quality problems such as nitrate pollution of groundwater. In principle it is very difficult to quantify the health impacts for a variety of reasons. For instance, some impacts like the ‘blue baby’ syndrome are well documented but are extremely uncommon. Other impacts such as cancer risk are presumed, but no quantitative data is available. Valuing morbidity and mortality can also pose some problems in certain circumstances. In those instances, it would be justifiable to consider a simplified framework, where the focus is on the most important public health problem in relation to wastewater reuse, which is worm infection. One option of controlling worm infections is to implement a regular deworming campaign i.e. provide treatment to exposed populations every 6 months or so. The cost of such campaigns would be relatively easy to estimate and would provide a simple and practical valuation of the health impact.

Additional valuation difficulties may include treatment of risk and uncertainty, population size, and selection of social discount rate.

Despite all these difficulties and shortcomings the utility of the proposed framework should be seen in the context of its contribution in decision making process and especially its holistic evaluation approach in pursuit of sustainable development, which includes economic, environmental and social elements possibly measured with a common monetary yardstick.

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Working Paper 25

Child Diarrhea and Hygiene: Mothers' Perceptions and Practices in the Punjab, Pakistan

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and Wim van der Hoek

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