Valuation of Socio-Economic and Environmental Impacts of Wastewater Irrigation in Developing Countries

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1. INTRODUCTION

Wastewater is both a resource as well as a problem. To the extent wastewater and its nutrient content can be used for irrigation and other ecosystem services, wastewater reuse can deliver positive benefits to the farming community, society, and municipalities. However, wastewater reuse also imposes negative externality effects on humans and ecological systems[1]. Thus, from an economic perspective, both the benefits and costs of wastewater reuse should be evaluated. Conventional cost benefit analysis quite often fails to quantify and monetize externality effects associated with wastewater reuse. Hence, environmental valuation techniques or other tools are employed to guide decision making. Moreover, due to inter-temporal nature of wastewater reuse impacts, the economic effects of wastewater irrigation need to be evaluated from social, economic, and ecological sustainable development perspective, as the incidence of these benefits/costs may fall differently on various socio-economic groups, and would thus have clear implications for poverty reduction.

This report presents a selective review of recent empirical studies to identify major effects of wastewater irrigation, both positive and negative, to help set the stage and then discusses the application of cost benefit analysis and environmental valuation techniques to monetize these impacts from a holistic and sustainable management perspective. An implicit objective of this exercise is to identify areas of concern in the valuation of wastewater irrigation impacts and suggest ways to improve these caveats. The over all purpose is to promote the use of environmental valuation for economic decision making so as to assure an adequate environmental policy response, and address equity concerns, with an overall objective of enhancing agricultural productivity for reducing poverty faster.

To help achieve these goals, a comprehensive methodological framework is developed for the valuation of environmental impacts of wastewater irrigation in a developing country setting like Pakistan. The possibility of using benefit transfer protocol, complemented by a field research program, as a tool for environmental valuation of wastewater impacts in a developing counties is also outlined.

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[1] For a comprehensive review of these impacts, see IWMI study: Hanjra, M. A. (2000) *Socio-Economic and Environmental Effects of Wastewater Irrigation: State of the Art, Problem Area and Policy Implications*. Unpublished Report. International Water Management Institute, Colombo, Sri Lanka.

About the Study

IWMI's project on improving the potential of wastewater irrigated peri-urban agricultural systems in surrounding areas of Faisalabad Division, Pakistan and Vietnam seeks to analyze socio-economic and environmental aspects of urban wastewater use in agriculture sector. The main purpose of this report is to develop a comprehensive methodological framework for analyzing socio-economic, environmental, and ecological aspects of urban wastewater use in agriculture. Some specific objectives are to:

- Identify various effects of urban wastewater use in agriculture, and identify/develop approaches/methods for quantifying and valuing these effects;

- Identify data needs, with specifics of variable to be included in the study; and

- Develop a comprehensive modeling framework, with emphasis on integrating various components.

For the purpose of this study, urban wastewater includes wastewater from all sources including industrial, commercial and residential, and agricultural effects of wastewater include effects on crop production (yield, input use, cost of production etc.) and economic aspects of other effects including environmental effects, health effects, groundwater effects, social effects (employment, income, poverty etc.) and ecological effects. The overall aim is to provide a holistic picture of costs and benefits of urban wastewater use in agriculture

About the Study Area

Faisalabad, the third largest city of Pakistan, houses a population of about 5 million and by far remains the industrial capital of Pakistan. During the last two decades, rapid industrial development has lead to the emergence of Faisalabad-Skeikhupura-Lahore growth corridor as a major and well recognized area of economic activity in Pakistan. The industrial development has in turn contributed to structural transformation of urban, peri-urban, and rural agricultural industry in the region. Large villages and peri-urban areas are experiencing transition from primary agriculture to export based industries. Not only more than half of the regional population is engaged outside agriculture, people from other parts of Pakistan are migrating to Faisalabad in search of employment in textile, manufacturing, and services, and contractual work (Altaf *et. al.*, 1993). People from near by villages, located within a radius of upto 25 kilometers, and merchants from other cities and towns, regularly travel to Faisalabad for trading.

While over the past decades, the regional rural areas have become functionally integrated into the economy of Faisalabad, this structural transformation has changed the face of agriculture in Faisalabad. For example, cotton, once an overly dominant regional commodity, is rarely grown now a days and has largely been replaced by sugarcane and other crops. While canal irrigated agriculture still remains the dominant cropping pattern, other supplemental sources of irrigation such as tubewell water and municipal wastewater are being increasing exploited by the farmers. While sugarcane, wheat, maize, sorghum, fodder crops, vegetables, and citrus orchards dominate regional cropping pattern, new 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, and fodder, and ornaments and plant nurseries instead of traditional crops. Due to high water demand, these farmers often augment canal water supplies with municipal wastewater, and probably without much regard for public health and environment, to maximize their returns. As the freshwater resources are unpriced in Pakistan, a mechanism for regulation and pricing of wastewater supplies remains off the agenda. A question arises that can Faisalabad, with its irrigated agriculture at cutting edge of technology, benefit from wastewater irrigation, and if yes, to what extent and what these benefits are likely to be? This study provides a methodological framework to answer this question.

Organization of the Study

After elucidating a brief introduction of this report in section 1, in Section 2, the effects of wastewater irrigation are identified in detail. Section 3 presents a general theoretical framework for the valuation of environmental impacts of development programs and policies such as wastewater irrigation. A taxonomy of environmental valuation techniques, along with their strengths and shortcomings, and potential areas of application is also presented. Section 4 presents a stepwise procedure for the valuation of impacts of wastewater irrigation in a holistic perspective. An optimization model and its estimation under various scenarios is given in Section 5. The existing and additional data resources for the study are identified in Section 6 and the last section presents a list of literature cited in this report.

2. IMPACTS OF WASTEWATER IRRIGATION

Effects on Public Health

Wastewater contains pathogenic microorganisms such as bacteria, viruses, and parasites which have the potential to cause the disease. In particular, human parasites such as protozoa and helminth eggs are of special significance in this regard as they prove to be most difficult to remove by treatment processes and have been implicated in a number of infectious gastrointestinal diseases in both developed and developing countries.

A review of the available literature on wastewater irrigation and patterns of wastewater borne disease suggests that WHO (1989) quality treated wastewater can be used for crop irrigation with a minimal risk to public health and agricultural workers and their families. For example, secondary treated and chlorinated wastewater can be used for irrigation of vegetable crops such as summer squashes and onions with no delectable coliforms on squashes and onions after one day and 15 days of harvest respectively (Ali, 1987). After 24 hours of harvesting, no faecal coliforms were found on tomato when wastewater treated to WHO standards is used for irrigation (Shahalam, *et. al*., 1998). The advanced levels of wastewater treatment, though very expensive, can eliminate health risk altogether. In fact, present wastewater treatment systems are capable of producing effluent of an equal or even better quality than existing potable water supply with no additional health risk (Olivieri *et. al*., 1996)-there by offering the prospects of potable reuse of wastewater in future though any such potable reuse will be contingent upon cost effectiveness, community support, and political will. Given the prohibitively high costs, the wastewater treatment to zero risk levels, and subsequent reuse for crop irrigation, can be hardly justified on economic, social, or political grounds, however.

However, the use of untreated wastewater for irrigation poses real risk to human health in all age groups though the degree of risk may vary among various cohorts. Risk assessment studies based on detection of pathogens (e.g., coliform concentrations in ground and surface water resources), probability of their ingestion, and morbidity patterns show that frequent diarrhoea and skin irritation are correlated with high total coliform concentrations (Downs et. al., 1999). And, untreated wastewater irrigation leads to relatively higher prevalence of giardia and Ascariasis infections among children (Cifuentes et. al., 2000 and Habbari et. al., 2000). Furthermore, higher infection risk is principally associated with direct contact with wastewater and wastewater irrigated land and in particular the contamination of drinking water resources.

These studies also show that risk exists both within and outside the irrigation zone and exposure to untreated wastewater poses no excess risk. And, there is empirical evidence to suggest that pathogens, such as coliforms, are more virulent if they originate from outside the household, e.g. through contamination of water supplies (VanDerslice and Briscoe, 1993 and Alberini et. al., 1996). Evidently, the real risk comes from the contamination of drinking water supplies and not from the mere exposure or proximity of population to wastewater, there by, in turn, justifying the inclusion of population residing inside and outside the wastewater irrigation zone for health risk assessments.

These findings have important implications for valuation of public health risk associated with wastewater irrigation. They indicate that not only valuation of public health risk is an important decision variable in wastewater irrigation rather both adult population and well as children should be considered as the potential exposure group. And secondly, the entire population, both living within and outside the wastewater irrigation zone, should be enumerated as potential risk exposure group for economic valuation purposes.

Effects on Crops

In general, treated wastewater can be used for crop production without any adverse impacts on crops. The treated wastewater can provide (1) moisture needed for crop growth -therefore a substitute for conventional irrigation water resources (energy savings), and (2) plant food nutrients -thus a substitute for expensive chemical fertilizers (input cost savings). Thus, from an economic standpoint both the water and nutrient content of wastewater are important as discussed later.

In general, wastewater is a rich source of essential plant food nutrients and can, therefore, be used as a substitute for chemical fertilizers. Most crop plants give higher than potential yields with wastewater irrigation there by eliminating the need for chemical fertilizers and delivering net cost savings to farmers. However, if the total nitrogen delivered to the crop via wastewater irrigation exceeds the recommended nitrogen doze for optimal yields, it may stimulate vegetative growth, delay ripening and maturity, and in extreme circumstances cause yield loss. Alternatively, nutrient deficiency may also translate into lower than potential crop harvests and consequent economic loss. Thus, for optimal utilization of wastewater nutrients, careful agronomic management is essential.

Crop scientists have attempted to quantify the effects of treated and untreated wastewater on a number of quality and yield parameters under various agronomic scenarios. An over view of these studies suggests that *treated wastewater* can be used for producing crops of better quality and higher yields than otherwise. For example, application of treated wastewater gave higher wheat grain yield and improved grain protein contents (Day *et. al*. 1975) and higher sorghum grain and forage yields (Day and Tucker, 1977) as compared to conventional fertilizer doze.

Many forage crops such as alfalfa and reed canarygrass can effectively recycle wastewater nutrients, as they can utilize all available nitrogen and phosphorous, and produce higher than normal forage yields. Alfalfa is very efficient in nutrient recycling (double nitrogen yield) where as reed canarygrass is highly efficient in wastewater recycling ((Bole and Bell, 1978). In fact, in effluent irrigated systems, reed canarygrass can yield more protein tonnage and least digestible dry matter content per hectare. High protein and low digestible matter content is a desirable attribute for animal feed formulations. Maize, a principle ingredient in most cattle fattening feed, gives higher grain yield when treated wastewater is used (Marten *et. al*., 1980) for irrigation. Maize, a mesophytic plant with high water requirements, is also very efficient in wastewater recycling. Thus, wastewater irrigation for maize production offers the potential for higher forage tonnage and more grain bushels while, at the same time, alleviating the stress on fresh water irrigation supplies.

In addition to maize and reed canarygrass, other forage crops such as brome grass, wildrye, and tall wheatgrass can also be grown using treated wastewater as a source of irrigation.

As nitrogen and water requirements for most vegetables are generally higher than commercial crops, the nitrogen rich wastewater is considered to be a valuable resource for vegetable production in peri-urban agriculture in Pakistan. The use of wastewater for vegetable production may, however, pose a higher than normal risk to human health as some of these vegetables, such as carrot, radish, cucumber, tomato, onion, coriander etc. may be consumed raw or semi-cooked. However, studies show than secondary treated and chlorinated wastewater can be used for the production of vegetables, such as onions and summer squashes, not only to achieve higher than normal yields, but with no or minimal additional risk to human health (Ali, 1987). A variety of vegetables crops such as tomato and radish can be grown using treated wastewater for irrigation with average yields higher than the normal yields achieved with freshwater and fertilizer application (Shahalam, *et. al*., 1998)

As Faisalabad is an industrial city, effluents from industrial sources constitute a major proportion of daily municipal wastewater load. While effluents from some industrial units, such as leather tanning, paper and pulp, vegetable oil mills etc. may have potentially harmful constituents, and may therefore warrant special treatment before any reuse, effluents from other industries, may be used for crop irrigation after adequate treatment.

Aziz *et. al*. (1995) show that crude oil refinery wastewater can be used for wheat cultivation with higher growth, protein and carbohydrate content, and grain yield. Although, the response of various cultivars of wheat varies, consistently higher wheat yields are achieved due to the availability of additional plant food nutrients in treated wastewater. The long terms use of petrochemical industry wastewater gave higher wheat, triticale, chickpea, lentils, and pigeonpea grain yields. More importantly, in contrast to the conventional belief, after eight years of irrigation, accumulation of heavy metals in the grains remains negligible (Aziz *et. al*., 1996) there by making the latter fit for human consumption.

Thus, we can conclude that treated wastewater irrigation has a positive effect on growth, quality and yield of most crops in general and therefore may increase farmers income and revenue.

In many countries, including Pakistan, *untreated wastewater* has been used for crop irrigation for a very long time. Peri-urban agriculture in Faisalabad utilizes a substantial amount of primary and/or untreated wastewater. The untreated wastewater has very high concentrations of pathogenic microorganisms and, therefore, poses a higher than normal risk to public health. Nevertheless, untreated wastewater also has higher concentrations of plant food nutrients, as compared to treated wastewater, therefore, there is an incentive for the farmers to use untreated wastewater as it reduces the fertilizer costs (though higher nutrient concentrations may not necessarily affect crop yields positively as discussed later). On the other hand, as marginal treatment cost increase at increasing rates, higher levels of treatment come at exceedingly higher costs. Thus, for the cash starving municipalities, such as Municipal Corporation Faisalabad, there is an incentive to discharge untreated wastewater into the environment especially when the wastewater management objective is cost minimization and not enhancement of environmental quality (due mainly to the lack of accountability for negative externality effects in developing countries).

Untreated wastewater has higher concentrations of plant food nutrients but most crops, including those grown in peri-urban agriculture, need specific amounts of NPK for maximum yield. Once the recommended level of NPK is exceeded, crop growth and yield may be negatively affected. For example, urea plant effluents are a rich source of liquid fertilizer but in concentrated forms they have adverse effects on seed germination, dry matter and pigment contents, and yields rice and corn (Singh and Mishra, 1987). Hence, fertilizer factory effluents need to be adequately diluted for crop irrigation to avoid crop damages. Like untreated urea plant effluents, higher concentrations of nutrients in untreated wastewater may cause crop damage, and therefore, a net loss to the farmers.

The management and reuse of *industrial wastewater* for crop irrigation may pose additional problems in our study area. Faisalabad, the Manchester of Pakistan, is host to a large number of textile plants and thus textile effluents constitute a major proportion of industrial wastewater discharges. These untreated textile factory effluents are highly alkaline, normally rich in BOD, COD, Cl, SO4 and trace elements such as Na, K, Ca, Mg etc. The untreated textile effluents, therefore, are unsuitable for crop irrigation as they may inhibit germination and growth of vegetable crops, such as kidney beans and lady's finger(Ajmal and Khan, 1985). Equal mixing of untreated effluent with canal water may help to alleviate undesirable crop growth effects, however. The negative impact on soil may still be a factor limiting textile effluent reuse for long term crop irrigation. Similarly, pulp and paper industry effluents have very high pollution loads and hence they are not suitable for crop production. The use of pulp and paper industry effluents can led to accumulation of sodium in the soil with adverse impacts on soil and crop yields. Rice growth, yield, and protein content are negatively affected with paper and pulp effluent concentrations in irrigation water (Misra and Behera, 1991). However, paper industry effluent may be used for irrigating crops such as cottonwood if gypsum is applied to the soil as the gypsum application ameliorates pH levels and improves water and air infiltration rates (Howe and Wagner, 1996).

Thus, untreated industrial wastewater may not be beneficial for crop production as it may reduce farmer income and revenue.

Domestic wastewater is normally rich in salts and hence due to its highly saline nature, it has the potential to affect crop yields negatively though the magnitude of salinity effect may differ depending upon the sensitivity of the crop. For salt sensitive crops, such as cucumber, turnips, and cucumber etc., yield may be badly affected due to high salinity where as in case of salt tolerant crops, such as such as alfalfa, corn, zukini, beans, and tomato etc., yield may be moderately affected (El Hamouri, 1996) only. Among the salt sensitive fruits, citrus plants are notoriously sensitive to salinity and boron contents in wastewater. However, studies show that wastewater irrigation does not affect citrus fruit yield or quality though higher concentrations of nutrients in untreated wastewater promote excessive vegetative growth and delay ripening (Reboll *et. al.*, 2000). The delayed ripening of citrus may reduce farmer income and revenue (because of higher competition and lower market prices). Thus, raw wastewater can have a very limited and selective irrigation use with high stakes for public health.

However, raw urban wastewater can be used for the production of some less known, but potential commercial, crops such as of Jerusalem artichoke at costs much lower than normal crop irrigation and fertilizer costs. The artichoke biomass may be used for the production of ethnol which may serve as a source of pollution free renewable fuel for cars (Parameswar, 1999). Thus, wastewater irrigation requires careful agronomic management of both macro and micro plant food nutrients and trace elements for optimum recycling and successful crop production.

The above discussion shows that the economic impacts of wastewater on crops may differ widely depending upon the degree of treatment and nature of the crops. From an agronomic standpoint, however, in addition to pathogenic microorganisms, wastewater contains undesirable constituents such as trace elements and heavy metals, organic compounds and salts which may have adverse impact on crops. Depending upon their concentrations in the wastewater and the sensitivity of the crop to these elements, crop yields may be negatively affected. The potential yield losses in turn may affect farmer's income.

Normally, however, as wastewater is a rich source of plant food nutrients higher than potential crop yields can be achieved with wastewater irrigation (though nutrients deficiency or over supply may cause phototoxicity and adverse effects on crop yields). Also, with appropriate management practices, wastewater can serve as a source of essential plant food nutrients and irrigation water there by delivering net cost savings to the farmers. Thus, from an economic standpoint wastewater irrigation may have three fold effect/value for crops: (1) higher yields, (2) source of irrigation water, and (3) fertilizer value. These effects will be elaborated in detail later.

The impact of wastewater irrigation on yield varies from crop to crop. If the crops are undersupplied with essential plant food nutrients, wastewater irrigation will act as a supplemental source of fertilizer thus increasing crop yields. Alternatively, if plant food nutrients delivered through wastewater irrigation result in nutrients over supply, yields may be negatively affected. In the absence of any chemical fertilizer application, wastewater nutrients will act as a sole source of fertilizer delivering fertilizer cost (farm gate price plus application charges).

Effects on Aquaculture

Wastewater is a rich source of nutrients for fish production, howevere, public health concerns remain a key factor in limiting the use of wastewater for aquaculture. As fish and other aquaculture products are normally consumed directly after harvest, the heavy metals and pathogens present on fish tissues are likely to be ingested by human beings with potential health impacts. However, these potential health effects can be avoided if adequately treated wastewater is used for aquaculture. In fact, low cost systems could be designed to use on-farm and domestic effluents for crop production, dairy farming, and aquaculture in an integrated manner to achieve water use efficiency and optimal resource utilization. Studies conducted in Suez, Egypt show that stabilization pond treated wastewater can be used in fish ponds with yields higher than average fresh water fish yield in Egypt. More importantly, fish harvested from wastewater irrigated ponds is pathogen free, fit for human consumption and have high quality. The nutrient rich effluent from fish ponds can be used for growing barley, maize, beets, and ornamental crops (Easa, 1995 and Shereif *et. el.* 1995).

Irrigation of fish ponds with wastewater can deliver net cost savings to farmers by freeing up limited freshwater supplies and reducing the need for supplemental feeding. The fish feeding on nutrient rich wastewater can recycle the nutrients into protein rich food. Promoting the use of wastewater for aquaculture may also save treatment expenditure to the municipalities and their communities. An other benefit would be enhanced supply of protein rich fish food for human consumption or poultry feed formulations.

However, in situations, like Faisalabad, where industrial effluents constitute a major proportion of wastewater, farmer need to be very careful when using wastewater for aquaculture. This is because some substances present in industrial effluents may induce undesirable effects. For example, news print mill effluents may retard growth and cause liver damages in fish (Johnsen, 1998). Wastewater irrigation may have determinantal impact on temporary pond breeding amphibians (Laposata and Dunson, 2000). As fish preys on some of these amphibians, a decline in their egg and larvae survival, and hence recruitment, may decrease natural feed supplies for fish in wastewater irrigated ponds. Thus, farmers has to be careful about the source of effluents and level of treatment received before using wastewater for aquaculture.

In brief, the economic benefits of wastewater reuse for aquaculture are: (1) saving fresh water resources; (2) nutrient recycling value; (3) higher than normal fish yields and protein supplies; and (4) treatment cost savings. The valuation of these economic benefits is discussed in detail later.

Effects on Soil Resources

Wastewater is a rich source of nutrients, dissolved salts, and other trace elements and heavy metals. Hence, effluent irrigation may add large amounts of salts and heavy metals and nutrients to the soil over time. Some of these salts may accumulate in the root zone with possible harmful impacts on soil health and crop yields and the leaching of these salts below the root zone may cause soil and ground water pollution. The major impact of high saline content of wastewater on soil is the menace of soil salinity which in turn brings the twin evil of waterlogging. Once the soil become saline and water logged, their ability to support normal crop production is severely affected.

Wastewater also contains high concentrations of sodium ions which may interact with saline salts to make insoluble compounds and increase exchangeable sodium percentage in the soil which in turn may breakdown soil structure. A prolonged use of saline and sodium rich wastewater is a potential health hazard for soil as it may erode the soil structure, and hence productivity, permanently there by making the land use non-sustainable in the long run. Though the problem of soil salinity and sodicity can be resolved by the application of natural or artificial soil amendments, the soil reclamation measures have costs which are in addition to the crop productivity loss. Moreover, it may not be possible to restore full health, and hence productivity, of the soil using these soil amendments. Hence, wastewater irrigation may have long term economic impacts on the soil which in turn may affect market prices and land values of saline and waterlogged soils.

Wastewater induced salinity may reduce crop productivity due to general growth suppression at pre-early seedling stage, growth suppression due to nutritional imbalance, and growth suppression due to toxic ions (Kijne *et. al.*, 1998). The net effect on growth impacts is a loss in crop yields and potential income for the farmers.

Wastewater irrigation may lead to transport of heavy metals to soils and may cause crop contamination and affect soil flora and fauna. Some of these heavy metals may bioaccumulate in the soil while others, e.g., Cd and Cu, may be redistributed by soil fauna such as earthworms (Kruse and Barrett, 1985). Studies conducted in Mexico (Assadian *et. al.*, 1998), where wastewater mixed with river water has been used for crop irrigation for decades, indicate that polluted water irrigation may account for upto 31% of soil surface metal accumulation and lead to heavy metal uptake by alfalfa though . However, heavy metal concentrations in alfalfa pose no risk to animal or human health.

In a critical assessment of US EPA heavy metal guidelines, McBride, (1995) argues that heavy metals applied through sewage use can be available in quantities sufficient to harm sensitive plants and soil microorganisms with possible loss of soil productivity in the long run. An exposure assessment of heavy metals resulting from farmland application of wastewater sludge in Tianjin, China shows the necessity of reexamining the national environmental quality standards for soil and emphasizes the need for comprehensive surveys and monitoring programs for assessing heavy metal accumulation in crop tissues and soils for examining the risk to human health (Cao and Ikeda, 2000).

In general heavy metal accumulation and translocation is more a concern in sewage sludge application than wastewater irrigation because during the treatment process most heavy metals are settled or adsorbed and thus removed into the sludge.

The impact of wastewater irrigation on soil may be affected by a number of factors such as soil properties, plant characteristics and source of wastewater. For example, marginal soils with shallow depth and restrictive layers are very efficient in wastewater and nutrient reuse and recycling and pose no risk of nutrient leaching (Monnett *et. al*., 1996) as opposed to heavy soils. Similarly, some plants such as reed canarygrass and Appalachian hardwood forest can withstand highest wastewater irrigation rates and effectively remove nitrogen that would otherwise leach to the subsoil (Kim and Burger, 1997). The impact of wastewater from industrial. commercial, domestic, and dairy farm sources are likely to differ widely. The use of dairy factory effluents for 22 years in New Zealand shows that nearly all applied P is stored in the soil while nitrogen storage is minimal there by implying nitrogen leaching and consequent nitrate pollution of the groundwater (Degens, 2000).

Thus, we conclude that the most significant impacts of wastewater irrigation on soil resources are soil salinity and sodicity and excessive nitrate leaching to sub-soil and groundwater (discussed below).

From an economic perspective salinity related impacts of wastewater irrigation on soil resources are: (1) potential yield loss; (2) loss of soil productivity; (3) depreciation in market value of land; (4) cost of additional nutrients and soil reclamation measures.

Effects on Groundwater Resources

As noted earlier, wastewater contains nitrogen, phosphorous, and other plant food nutrients in excess of the crop requirements, hence wastewater irrigation may result in nutrient loadings to the soil. The excess nutrients and salts may leach below the plant root zone and hence cause groundwater pollution. The leaching of saline salts and nitrates have the potential to affect the quality of groundwater resources in the long run. However, the actual impact depends on a host of factors including depth of water table, quality of groundwater, soil drainage, and scale of wastewater irrigation etc. In irrigated areas with shallow water table, such as Faisalabad, the effect of wastewater irrigation on groundwater quality is likely to be substantial but not detrimental. At present, the quality of groundwater in Faisalabad varies from sweet fresh to saline and brackish fresh and thus a high degree of potable water pollution already exists in most areas of Faisalabad (Hanjra and Hanjra, 1993). And, as groundwater is a major source of drinking water supplies for households, the potential of groundwater pollution through wastewater irrigation needs careful evaluation.

Hanjra and Hussain (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 one kilometer radius of industrial effluent drain, show very high concentrations of dissolved salts, trace elements, and heavy metals therefore, rendering the groundwater unfit for any potable use or irrigation.

Farid *et. al*. (1991) report that in Gabal el Asfar farm in Greater Cairo region, where untreated or primary treated wastewater has been used for irrigation since 1915, the long term use of wastewater for crop irrigation has lead to an improvement in the salinity of the groundwater (than it would have been higher otherwise). The study predicts that an extension of the wastewater irrigation to adjacent areas (higher scale) may affect groundwater flow systems and impact regional water quality. Due to coliform contamination of groundwater -remember untreated wastewater has also been used for irrigation- groundwater in the area is not suitable for drinking purposes. A companion study (Rashed *et. al*., 1995) reveals that regional groundwater salt concentrations are higher than average salt concentrations in sewage. A doubling of groundwater chloride concentrations during 1991-94 has changed groundwater quality from fresh to brackish fresh. Thus, wastewater irrigation has lead to pollution of groundwater resources and may therefore, affect sustainable use of regional water resources.

Shatanawi and Fayyad (1996) find that in Jordan Valley, the mixing of treated wastewater has adversely affected river water quality there by rendering the river water supplies unfit for unrestricted crop irrigation. Furthermore, accumulation of trace elements may become a concern in the long run. However, the use of treated wastewater for the recharge of groundwater in Dan Region, Israel has no adverse impacts on groundwater resources (Kanarek and Michail, 1996). Nevertheless, as the feasibility of wastewater reuse for groundwater recharge is site specific (Bouwer, 1996), the findings of Dan Region and other case studies may not be generalized for policy making in other areas.

Vidal *et. al*. (2000) find evidence of groundwater contamination due to the use of livestock waste and municipal wastewater use in Lugo, Spain. The saline contamination of rural wells and saline and organic pollution of urban springs indicates that use of livestock waste and municipal wastewater networks has affected potable water resources adversely.

In additional to the risk of nitrate pollution and heavy metal contamination, wastewater irrigation has the potential to cause pathogenic bacterial and viral contamination of groundwater resources (NRC, 1996) with potential public health impacts. Downs *et. al*. (1999) noted that untreated wastewater recharges has led to contamination of groundwater resources in Mezquital Valley,Mexico. High coliform levels and nitrate concentrations pose a risk to human health, and especially children, both within and outside the irrigation zone. Leon Vally groundwater also has high concentrations of coliforms which indicates subsurface transportation of coliforms (Gallegos et. al., 1999). These studies show that wastewater irrigation in Mexico have a negative impact on groundwater quality.

The leaching and drainage of wastewater, applied for crop irrigation, to groundwater aquifer may serve as a source of groundwater recharge. As in some regions, 50-70% of irrigation water may percolate to groundwater aquifer (Rashed *et. al*., 1995), the influence of percolated wastewater on groundwater quality and its recharge is likely to be substantial. The groundwater recharge through wastewater application can be a vital environmental and economic service in regions where freshwater supplies are limited and groundwater removal rates exceed replenishment rates. Hence, groundwater recharge through wastewater irrigation should be viewed as a benefit item.

In general higher the percolation rates, higher the groundwater recharge benefit and vice versa. But, higher percolation rates may also pose higher risk of groundwater contamination and associated costs (especially in case of raw wastewater use). Thus, there is an obvious trade off between groundwater recharge benefits and groundwater pollution costs unless land application or soil aquifer treatment can effectively remove dissolved salts, nutrients, and pathogenic microorganisms to below acceptable levels.

Around the globe, a number of studies have attempted to assess the impact of wastewater irrigation on groundwater resources in various regions. Not only the findings differ from region to region, they are site specific. However, the general conclusion is that wastewater irrigation has the potential to adversely affect groundwater resources in the long run. And, as the pollution of groundwater and freshwater resources have important public health, environmental, social, and economic implications, the negative impact of wastewater irrigation on groundwater resources should be accounted as a cost item in the valuation of any major wastewater irrigation program. The monetary valuation of effects of wastewater irrigation on groundwater resources is discussed later.

Effects on Property Values

In the last section, we conclude that wastewater irrigation has the potential to adversely affect the quality of groundwater resources. Also, Hanjra and Hussain (1996) found that the proximity of drinking water sources to wastewater disposal drains severely affects the quality of groundwater in Faisalabad. The groundwater quality infact varies inversely with the distance from the pollution source. Thus, we can conclude that proximity to water pollution source is a key determinant of groundwater quality. The two conclusions combined together would mean that properties neighboring major wastewater irrigation farms may have groundwater quality lower than the properties located distant apart. Thus, proximity to wastewater irrigation fields, from groundwater quality perspective alone, should be viewed as a negative externality. In fact, proximity to pollution sources such as hazardous waste sites or major wastewater storage and disposal works may negatively affect property values because of the potential risk to human health, disamenity associated with odor, nuisance, noise, and poor hygiene.

There is documented evidence to suggest that groundwater contamination, say with toxic chemicals, can negatively affect property values because groundwater contamination and other associated forms of environmental pollution, may impose many costs on the society. These costs may include health risk, clean up costs, legal liability and loss of tax base (Page and Rabinowitz, 1993). Properties located along the polluted stream command significantly lower market price than the properties located along clean streams (Epp and Al-Ani, 1979). Pollution related beach closures are known to reduce property values in New Jersey by about 23 percent (Polhemus *et. al*., 1985). Where as, groundwater pollution negatively affects the values of industrial and commercial properties (Page and Rabinowitz, 1993) though residential property prices remain unaffected. Even the perception of risk of groundwater contamination can affect property prices. Kiel and McClain (1995) report that the *rumor* of sitting of an obnoxious facility, such as an incinerator, affects house prices and residents continue to discount the property values even seven years after the incinerator began operation and it became clear that there was no actual risk involved.

Leggett and Bockstael (2000) provide a more precise, concrete, scientifically based and a 'significant and defensible' effect of fecal coliform levels on residential property values in Chesapeak Bay, Maryland, USA. They use waterfront concentration of coliform bacteria as a measure of water quality. The study shows that water quality matters to the waterfront residents and they are willing to pay higher utility prices for it.

The studies on willingness to pay for water quality improvements (Smith *et. al.* 1983, Mitchell and Carson, 1984, and Carson and Mitchell, 1993) suggest that a positive price premium exists for higher quality and people discount the risk of water pollution while making decisions. However, price premium, in terms of willingness to pay, for higher water quality are likely to be low in developing countries. For example, the residents of Faisalabad, Pakistan (Hanjra and Hanjra, 1995) and Davos, Philippine (Choe *et. al*., 1996) has a positive but low willingness to pay mainly because of low income levels. Nevertheless, the willingness to pay for water quality improvements suggests that people are aware of environmental problems but water pollution control is not a very high priority for the urban poor of Faisalabad.

The wastewater induced salinity and sodicity may also negatively affect the soil productivity which in turn may affect land prices and lease revenues. Thus, we can conclude that wastewater irrigation has the potential to negatively affect property values and it should, therefore, be enumerated as a cost item in analyzing the impacts of wastewater irrigation.

Ecological Impacts

Wastewater is rich in plant food nutrients such as nitrogen and phosphorous and a proportion of the nitrogen is in excess of the crop nutrients requirements. The surplus nitrogen may accumulate in the soil, translocate to the surface water, volatilize to the atmosphere, or leach to the groundwater. Phosphorous may similarly be translocated to various parts of the ecosystem. The continued use of nutrient rich wastewater for irrigation can lead to eutrophication, a process by which water bodies become more nutrient rich over time. Eutrohpication can occur through both point sources or nonpoint sources. Wastewater irrigation constitutes a point source of eutrophication because it is localized and easy to monitor and control. The leaching of excess nitrogen and phosphorous from wastewater irrigated fields has serious environmental consequences such as degradation of water resources, loss of species and biodiversity, loss of amenity and ecosystem services, and economic loss due to degradation of natural resources (Smith *et. al*. 1999). Of these, loss of biodiversity is of special significance and is considered later in detail in this report.

Eutrophication can affect various types of ecosystems such as lakes and reservoirs ecosystem, streams ecosystem, estuarine and coastal ecosystem, and terrestrial ecosystem. The effects of eutrophication on terrestrial ecosystem, a typical of the environment of Faisalabad, are summarized in **Table 1**.

It is to be noted that to the extent regulatory regime effectively restricts the use of wastewater irrigation for the production of certain crops (e.g., restricted vs unrestricted crops) in developing countries, regulated wastewater irrigation has the potential to promote monoculture of high yielding and high return crops. Theoretically, monoculture effect is unlikely to cause any serious imbalances in the ecosystem because the crop acreage would automatically adjust in response to the forces of supply and demand in the agricultural product (and input) markets. However, to the extent agricultural markets perform poorly, short term imbalances can not be ruled out. The monoculture argument, however, can in no circumstances be used to abandon Wastewater regulation in developing countries rather the concerns, if any, should be addressed using appropriate agronomic and management practices for wastewater irrigation.

Table 1: Likely Effects of Eutrophication on Terrestrial Ecosystem

▪Increase in total production of vascular plants ▪Increase in susceptibility of some plant species to disease, cold stress and herbivory ▪Changes in soil chemistry ▪Nitrate leaching and accumulation in groundwater ▪Changes in plant and microbial community structure -Decreased dominance by legumes -Increased dominance by grasses -Decreases in asymbiotic nitrogen fixing bacteria ▪Changes in animal community structure -Increase in wild boar, winter geese and swans, wood pigeons, and ducks (and deer-not found in Faisalabad) -Decrease in quail, partridge, rabbit, hare, and open vegetation birds.

Source: Smith et. al. (1999) as modified from Tamm, 1981

We conclude that as the wastewater irrigation has the potential to cause eutrophication damages to the already fragile and stressed ecosystem in Faisalabad, the eutrophication potential should, therefore, be accounted as a cost item in environmental valuation.

The eutrophication potential of wastewater irrigation can be assesses using biological indices or biomarkers which in turn can be quantified in monetary units using appropriate economic valuation techniques (forthcoming).

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, odour, noise, reduced visibility, and higher probability of accident 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, 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 (NRC, 1996). The business risk and potential liability can be covered by seeking appropriate level of insurance. The premium for general risk assurance against wastewater irrigation are likely to be high in 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.

3. TECHNIQUES FOR ECONOMIC VALUATION OF IMPACTS

What They Value?

Economics is concerned with the allocation of scarce resources among competing alternatives in order to maximize the welfare of the society. Thus, economic efficiency and optimality is central to economic decision making regarding alternative projects, policies or programs. Tools of conventional cost benefit analysis can be used for decision making when the inputs and outputs of alternative projects, policies or programs can be bought and sold in the market place, i.e. costs and benefits can be evaluated in monetary units. However, when the project input and outputs are not traded in market place, cost benefit analysis alone can not be used as sole decision tools. This is particularly true in case of programs with environmental dimensions, for example wastewater irrigation, because environmental goods and services possess attributes of public goods such as non-rivalry and non-excludability which is turn leads to market failure; i.e., environmental goods and services are not sold in the market and hence market prices for these goods and services do not exist which in turn creates difficulty for the monetization of project costs and benefits.

As the non-marketability and non-existence of market prices creates difficulty for using the conventional cost-benefit analysis framework for decision making on programs and projects with environmental dimensions, economists have developed other non-market based techniques for evaluating the costs and benefits of projects with environmental externalities. These techniques evaluate the change in consumer welfare considering with project and with out project scenarios. If the project leads to a positive change in consumer or community welfare, the consumers should be willing to pay for the project. Thus, the consumers willingness to pay for the project becomes the basis for judging the economic feasibility of the project in the absence of market prices and non marketable outputs. All economic and environmental valuation techniques, whether market based or non-market based, measure the change in consumer welfare with status-quo and with project and program scenarios to evaluate the socio-economic and environmental feasibility of various programs and policies.

Theoretical Frameworks

A number of frameworks have been used for decision making in resource allocation projects. These decision making frameworks evaluate the benefits and costs of alternative programs and policies in a systematic manner to as to express net project benefits in comparable monetary units such as net present value. The programs and policies with highest net present value are considered superior over the others. The most commonly used decision making frameworks include:

Cost benefit analysis

Cost effectiveness analysis

Multicriteria analysis, and

Mathematical programming models.

The impacts of wastewater irrigation projects have been analyzed using:

- Environmental impact assessment
- Input-output models
- Simulation models, and
- Mathematical optimization models such as:

  Linear or Quadratic programming models

  Dynamic programming models.

Economic valuation of environmental impacts depends on careful estimation and measurement of biophysical changes. The systematic methodologies of Environmental Assessment, for example, the World Bank's *Environmental Assessment Source Book* (1994), have been designed to produce this information. Natural systems are holistic and interconnected, therefore a holistic environmental analysis would seek to study a physical or ecological system in its entirety. Complications do arise because such natural systems tend to cut across the decision making structure of human society (Dixon *et. al.*, 1994).

Three criteria suggested in the World Conservation Strategy (IUCN, 1980) for identifying significant impacts on the environment are:

Length of time and geographic area: this criteria would include an assessment of the number of people affected, how much of a particular resource would be improved, degraded or eliminated.

Urgency: how quickly a natural resource or ecosystem would deteriorate and how much time is available for its stabilization.

Degree of irreversible damage: are the impacts on plants, animals, land, water and soil resources, and more importantly, on life support systems reversible or irreversible and to what degree.

Valuation of environmental impacts involves a two stage process. First, the baseline or "without" and "with" project scenarios are compared in order to identify the possible biophysical and socioeconomic impacts (ecological and social effects). A multidisciplinary team of experts is required to estimate such impacts. Economic valuation, placing monetary values on such physical impacts, is the second step in environmental economic analysis.

Theoretical Framework for Environmental Valuation

In this section we develop a general theoretical framework that can be used for economic valuation of environmental impacts. The term environmental impact here refers to economic, social, and ecological impacts of development projects, programs and policies such as wastewater irrigation.

Resource allocation problems involving public goods[2] turn out to be quite different from resource allocation problems involving private good. Competitive markets are an effective social institution for allocating private goods in an efficient manner. However, it turns out that private markets are often not a very good mechanism for allocating public goods and environmental resources.

Demand for Environmental Goods

When the environment changes consumers may be made better off or worse off[4]. Let us consider a household that derives satisfaction from n different private goods and m different public goods and possesses a continuous and increasing utility function $U = U(x, G)$, where $x = 1, \ldots, n$, is a vector of private goods and $G = 1, \ldots, m$, is a vector of public goods (environmental goods). Suppose that the household has income y (an exogenous budget constraint) which is spent on some or all of the private goods bought in non-negative quantities at given, fixed, and strictly positive prices p_i for $i = 1, \ldots, n$. Then, the household maximizes its utility subject to the resource constraint

$$\max U(x,G) \text{ s.t. } px = y$$

2 Goods that are not excludable and are nonrival are called public goods. For example, street lights, fire and police protection, national defense, highways, clean air, radio and television broadcasts etc.

4 Some of the content in this section is based on Johansson, 1993 and Varian, 1992.

The constrained optimization yields

$$V = U\,[x(p,y,G),G] = V\,(p,\ y,G)$$

where the vector x is interpreted as $x(p,y,G) = \{x_1(p,y,G),\ldots,\ x_n(p,y,G)\}$, i.e. as a vector of demand function for private goods with quantity demanded as a function of price, income, and the quality or provision of environmental goods. The indirect utility function is decreasing in prices, and increasing in income and the quality of the environment. Let us assume a change in the environmental quality from G^0 (status quo or baseline) to G^1 (proposed change or with project). The corresponding change in utility is:

$$\Delta V = V\,(p,\ y,G^1) - V\,(p,\ y,G^0)$$

Given the ordinal nature of utility theory, there is no unambiguously right way to quantify such utility changes. A convenient measure of changes in consumers welfare is the (indirect) money metric utility function. The measures used here are compensating variation (Cv) and equivalent variation (Ev).

The compensating variation gives the maximum amount of money that can be taken from the consumer while leaving it just as well off as it was before an improvement in environment quality (for $G^1 > G^0$) such that:

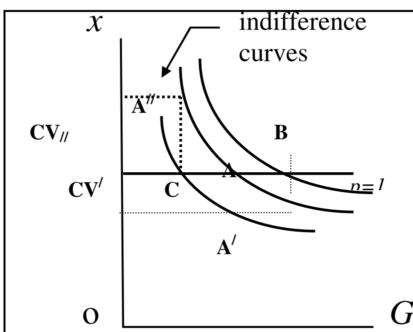

Figure: The compensating variation for public good

$$V\,(p,\ y\text{-}Cv,\ G^1) = V\,(p,\ y,G^0)$$

Thus Cv is a measure of willingness to pay (WTP) for an improvement[5]. If environmental deteriorates ($G^1 < G^0$), Cv is the minimum amount of money that must be paid to the consumer to compensate it for the loss of environmental quality. Thus, Cv measures the willingness to accept (WTA) for deterioration in environment quality. This definition is shown in Figure 1.

The second measure of change in consumers utility is equivalent variation (Ev) given by:

5 Since the environmental good is presumably a public good, total WTP is given by aggregating over the individuals, though it is not always clear who should be included in the aggregation especially where passive use values are concerned as discussed later.

$$V(p, y+Ev, G^0) = V(p, y, G^1)$$

The *Ev* is the minimum amount of money that must be given to the household to make it as well off as it could have been after an improvement in environmental quality. If environmental quality deteriorates, *Ev* is a measure of the maximum amount the household is willing to pay to prevent that deterioration. This is illustrated in Figure 2.

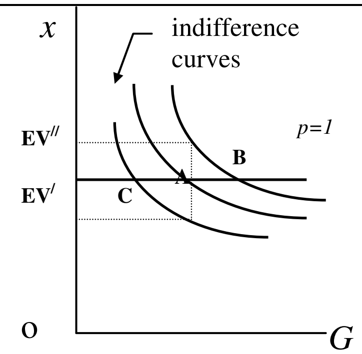

Figure: The equivalent variation for a public good

The *Cv* and *Ev* measures impute different monetary values to a change in consumers utility. These measures are sign preserving because they have the same sign as the underlying change in utility, however, their magnitudes will differ because the value of a dollar will depend on what the relevant scenario prices are.

The compensating and equivalent variation are in fact observable if the demand functions are observable and if the demand functions satisfy the conditions implied by the utility maximization. The observed demand behavior can be used to construct a measure of welfare change, which can then be used to analyze environmental policy alternatives. Many environmental goods are public goods and are therefore appropriately measured by the compensating variation and equivalent variation measures of consumer surplus (Mitchell and Carson, 1989).

The choice of the measure depends on the circumstances involved and the questions to be answered. Freeman (1979) suggested four criteria viz: *practicability, implied property rights, the uniqueness of the measure,* and *the consistency*.

The choice between these two measures will depend upon the characteristic of the welfare change being analyzed. For example, compensating variation will be an appropriate choice where a price change which affects the prices of other goods but is the only policy option available to the social planner (compensation scheme at the new prices). If one is trying to get a reasonable measure of willingness to pay, the equivalent variation is probably the better. However neither of these measure is readily observable from the market data. On the other hand the Marshallian consumer surplus is observable and lies between the two measures.

This suggests the possibility of using consumer surplus[6] as an approximation to the more theoretically justified measures.

In the utility function, $V = U[x(p,y,z),z]$, $U(.)$ is increasing in both arguments. The first, $U(.)$ is utility from using z; it depends not only on z but also on the market good necessarily employed-x. The second argument z gives rise to utility that is not related to the complimentary use of market goods: the passive use values. These can be estimated by revealed preference method (discussed in the next section) that rely on prices and quantities of complimentary market goods. However, passive use value as a component of total value can only be measured by CVM.

Conceptually, the total economic value (TEV) of a resource consists of its use value (UV) and non-use value (NU). Use values may be subdivided into the direct use value (DUV), the indirect use value (IDU) and the potential use value or option value (OV) (Munasinghe, 1993). Thus:

$$\begin{aligned} \text{TEV} &= \text{UV+NUV} \\ &= [\text{DUV+IUV+OV}]+[\text{NUV}] \end{aligned}$$

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6 If x(p) is the demand for some good as a function of price, then the consumer's surplus (CS) associated with a price movement from p0 to p1 is:

CS=

Ev = U(p0 ; p1, y1) - U(p0 ; p0, y0) = U(p0 ; p1, y1) - y0

Cv = U(p1; p1, y1) - U(p1 ; p0, y0) = y1 - U(p1 ; p0, y0)

Thus consumer surplus is simply the area to the left of the demand curve between p0 and p1 . When the consumer preferences can be represented by a quasilinear utility function, then CS is an exact measure of welfare change. When utility is quasilinear, the Cv equals the Ev and both are equal to the consumers' surplus integral. For more general forms of utility function, the compensating variation differs from equivalent variation and the consumer surplus is not an exact measure of welfare change. The compensating variation is the integral of Hicksian demand curve associated with the initial level of utility, and the equivalent variation is the integral of Hicksian demand curve associated with the final level of utility. The correct measure of welfare is an integral of demand curve, but one have to use the Hicksian demand curve rather than the Marshallian demand curve. In practice Marshallian and Hicksian estimates of willingness to pay are in good agreement for a variety of conditions, and in a few cases the Hicksian function can be derived once the Marshallian demand function has been estimated (Willig, 1976, Kolstad and Braden 1991). However, consumer surplus is used as an approximate measure of consumer welfare in applied work.

Direct use value is given by the contribution an environmental good makes to current consumption or production; for example, output that can be consumed directly including food, biomass, health, and recreation etc.

Indirect use value refers to the benefits derived from 'functional services' that environmental assets render to support current production and consumption. For example, functional benefits such as recycling of nutrients, flood control, storm protection, natural filtration, and other ecological functions.

Option value may be considered as the premium that the consumers are willing to pay for an unutilized asset to avoid the risk of not having it in future. Thus, it is the future direct and indirect use value attributed to biodiversity and conserved habitats.

Existence value stems from the satisfaction that the consumer derives from the knowledge that the asset exists although the valuer has no intention of using it. For example, existence of whales, koalas, and other endangered species.

Non-use values tend to be linked to more altruistic motive as noted by Schecter and Freeman (1992) and various forms of altruism include: bequest motive (intergenerational altruism); benevolence towards friends (interpersonal altruism); sympathy for people and animals; environmental linkages; and environmental responsibility (Boyle and Bishop, 1985).

Supply of Environmental Goods

Public goods present problems for a decentralized resource allocation mechanism. This is also true for environmental goods. In this section, based on Varian (1992), we discuss the social optima for the provision of public goods, both discrete and continuous, and show why the markets are inefficient. Later, this framework is drawn upon to shed light on the major weakness of our valuation measures.

Let us consider a simple model with two agents and two goods, x_i, a private good, and a public or environmental good G. The agents have an initial endowment of the private good w_i and decide how much to contribute to the public good. If agent i decides to contribute g_i, his private consumption will be $x_i = w_i - g_i$. Assuming that the utility is strictly increasing in the consumption of both the goods the agent i's utility function will be $U_i(G, x_i)$. If c is the cost of provision of public good, the technology is given by:

$$G = 1, if\{g_1 + g_2 \geq c\} \textbf{\textit{and}}\ G = 0, if\{g_1 + g_2 \leq c\}$$

Providing public good will Preto dominate not providing it if:

$$g_1 + g_2 \geq c \text{ and } \quad \begin{matrix} U_1(1, w_1 - g_1) \rangle U_1(0, w_1) \\ U_2(1, w_2 - g_2) \rangle U_2(0, w_2) \end{matrix}$$

Let r_i be the maximum amount of private good that agent i would be willing to pay to get one unit of public good, then

$$U_i(1, w_i - r_i) = U_i(0, w_i) \Rightarrow U_i(1, w_i, g_i) \rangle U_i(0, w_i) = U_i(1, w_i, r_i)$$
$$\Rightarrow w_i - g_i \rangle w_i - r_i$$

for i = 1, 2 $\quad \Rightarrow r_2 + r_2 = g_1 + g_2 \geq c$

That is, *provide discrete public good if the sum of the willingness to pay for the public good exceeds the cost of providing it.*[7] However in case of private provision of discrete public good a private market is not efficient because each *consumer prefers to free ride* on the other consumers. Hence, purely independent decisions will not necessarily result in efficient allocation of public goods and we need to have some corrective mechanism.

Let us consider continuous public good where $G = f(g_1 + g_2)$ is the production function, and the consumers utility function is:

$$U_i[f(g_1 + g_2), w_i - g_i] \Rightarrow U_i[f(g_1 + g_2, w_i - g_i)]$$
where $U_i(G \ , x_i) = U_i(f(G \ ), x_i)$.

Taking weighted sum of utilities:

$Max_{g_1, g_2} a_1 U_1[(g_1 + g_2), w_1 - g_1] + [a_2 U_2(g_1 + g_2, w_2 - g_2)$ and solving for first order conditions :

$$\frac{\partial U_1(G \ , x_1)/\partial G}{\partial U_1(G \ , x_1)/\partial x_1} + \frac{\partial U_2(G \ , x_2)/\partial G}{\partial U_2(G \ , x_2)/\partial x_2} = 1 = MC \Leftrightarrow MRS_1 + MRS_2$$

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7 This is different from the efficiency conditions of providing a private good. In that case if individual i is willing to pay the cost of producing a private good, it is efficient to provide it. Thus, here we need only the weaker condition.

The efficiency condition in the case of continuous provision of public good is that the sum of marginal willingness to pay should be equal to the marginal cost of provision. The marginal WTP, in general, depends on the amount of private consumption. However, in case of quasilinear utility $[U_i(G) + x_i]$ efficient provision of public good ($U_1'(G) + U_2'(G) = 1$) will be independent of private consumption.

If the income level of the consumer is very low, as is the case in the LDCs, this may not be the case. Thus, in developing countries the ability to pay becomes a concern. Especially, in low income groups and areas with skewed distribution of income the monetary values placed on environmental goods and services are traditionally low.

Assuming that each consumer independently decides how much to contribute to the public good and if agent 1 thinks that agent 2 will contribute g_2, he wants to:

$$\max_{g_1} U_1(g_1 + g_2, w_2 - g_1) \qquad g_1 > 0$$

Thus agent 1 can voluntarily increase the amount of public good but can't unilaterally decrease it. Using Kuhn Tucker[8] first order condition;

$$\frac{\partial U_1(g_1 + g_2, x_1)}{\partial G} - \frac{\partial U_1(g_1 + g_2, x_1)}{\partial x_1} \leq 0 \quad \text{and} \qquad \text{if} \qquad g_1 > 0,$$

$$\frac{\partial U_1(g_1 + g_2, x_1)}{\partial G} - \frac{\partial U_1(g_1 + g_2, x_1)}{\partial x_1} = 0$$

$$\frac{\partial U_1(g_1 + g_2, x_1)/\partial G}{\partial U_1(g_1 + g_2, x_1)/\partial x_1} \leq 1$$

That is, if agent *i* contributes a positive amount ($g_1 > 0$), his marginal rate of substitution (MRS) between public and private good must equal his marginal cost, 1. If his MRS is less than his cost he will not contribute rather *free ride*.

This can also be solved in terms of reaction function of agent *i* (which gives the amount that agent *i* wants to contribute as a function of other agent's contribution.

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8 For an explanation of Khun Tucker conditions, see Alpha C. Chiang, Fundamental Methods of Mathematical Economics, 3rd ed., McGraw-Hill, New York, 1984, section 21.2.

$$\max_{G, x_1} U_1(G \;, x_1)$$

$$\text{s.t} \quad \begin{array}{l} G \;+ x_1 = w_1 + g_2 \\ G \;>\; g_2 \end{array}$$

That is agent 1 is effectively choosing the total amount of public good subject to the budget constraint and the constraint that the amount he chooses must be as large as the amount provided by the other. The budget constraint implies that the total value of his consumption must be equal to the value of his endowment $(w_1 + g_2)$. Assuming $f_1(w\;)$ to be the agent 1's demand for public good as a function of his wealth, he seeks to:

$G = \max\{f_1\;\;(w_1 + g_1), g_2\}$, and the reaction functions for agent 1 and 2 are;

$g_1^* = \max\{f_1(w_1 + g_2^*\;) - g_2, 0\;\;\}$, and $\quad g_2^* = \max\{f_2(w_2 + g_1^*\;) - g_1, 0\;\;\}$

When utility is quasilinear:

$U_1^{'}(g_1^* + g_2^*) \leq 1$ and, $U_2^{'}(g_1^* + g_2^*) \leq 1$

Suppose that agent 1 places a higher marginal value on the public good than agent 2 so that; $U_1^{'}(g_1^* + g_2^*) \leq 1$ and $U_2^{'}(g_1^* + g_2^*) \leq 1 \qquad \forall G$

Only agent 1 will ever contribute while agent 2 will always free ride. Both agents will contribute only when they have the same tastes, at the margin of consumption, for public goods. Given the highly skewed distribution of income, this can't be ensured in the developing countries. In case of quasilinear utility the demand for public good is independent of income, i.e.,

$f_i\,(\overline{w}\,) \equiv \overline{g}$

$\Rightarrow g_1^* = \max\{\overline{g}_1 - g_2^*, 0\}$ and, $g_2^* = \max\{\overline{g}_2 - g_1^*, 0\}$

If; $\overline{g}_1 > \overline{g}_2$, then

$g_1^* = \overline{g}_1$ and $g_2^* = 0$

Sometime voting may be used to make a resource allocation decision but the *efficient* amount of public good exceeds the amount provided by majority voting if the average consumer values the public good more highly than the median consumer.

Incorporating Environmental Externalities into the Decision Making Framework

Market mechanism fails to record environmental effects properly because environmental goods frequently display public good aspects, non-rivalry and non-excludability. Thus the actions of one person may directly affect the environment / productivity of others. Consider the impacts associated with the consumption externality, where the utility of one person is directly affected by the consumption of other(s), such as drugs, tobacco, smog caused by automobiles, or congestion etc. Similarly, in case of production externality, where the production activities of one firm are directly affected by the actions of the others, for example, air pollution load in the vicinity of industrial estates and crop yields, quality of irrigation (waste) water and crop production etc. General market equilibria are inefficient in the presence of externalities.

The external effect occurs when the utility of a household depends on the consumption and production levels of other agents in the economy. Samuelson's (1954) public goods can be interpreted as a type of externality in consumption. The externalities may be either positive, in conferring benefits, or negative in exacting costs[9]. The consumer surplus measure can be used for an analysis of positive external effects and, with reversed signs, negative external effects such as water and air pollution. This is simply because an externality, like a public good, is usually modeled by including the externality as a separate term in the utility function of the households.

Let us suppose that firm 1 produces x units of output which can be sold at price p. However, the production of x units of output generates x units of pollution such that it imposes a cost of $e(x)$ on firm 2 (society). The profits of the two firms are:

$$\pi_1 = \max_x px - c(x)$$

$$\pi_2 = -e(x)$$

9 For a full discussion of externalities and public goods, see Baumol, W. and W. Oates (1989) *The theory of Environmental Policy*, Cambridge University Press. The discussion of externalities is based on Varian, 1992.

The equilibrium amount of output is given by the price being equal to the marginal private cost, ($p = c'(x)$) the cost that firm imposes on itself and thus ignores the social cost. However, when the externality is internalized, e.g. the merger of two firms, the firm would now seek to maximize the total profits $\pi = \max_x px - c(x) - e(x)$ with first order condition $p = c'(x_e) + e'(x_e)$. Thus the out put x_e is an efficient amount of out put at which the market price equals to the marginal social cost.

Thus the firm imposing an externality faces the wrong price for its action and this can be corrected by imposing a corrective tax that will lead to efficient resource allocation. If t is the tax the firm faces on its output, then the first order conditions (FOC) for profit maximization is: $p = c'(x)$

Assuming the cost function to be linear, we can set $t = e'(x_e)$, however, if the cost function is not convex we can impose a non linear tax of *e(x)* on the firm so as to internalize the cost of externality. The difficulty in using such a mechanism, however, is that the taxation authority, say EPA, must know the cost function *e(x)* in advance (and if it does, it can in the first place tell the polluters how much to produce).

A second view is that the inefficiency is attributable to *missing markets.* According to this view firm 2 (society) is affected by the pollution generated by firm 1 (polluters) but there is no way for firm 2 to influence upon firm 1. So adding a market for firm 2 to express its demand for pollution loads, or for a reduction in pollution, can provide a mechanism for efficient resource allocation. If the market price of pollution is *r*, then firm 1 can decide how much pollution it wants to sell, x_1, (produce) and firm 2 can decide how much it wants to buy, x_2. Our model becomes:

$$\pi_1 = \max_{x_1} px_1 + rx_1 - c(x_1)$$
$$\pi_2 = \max_{x_2} -rx_2 - e(x_2)$$

FOC:

$$p + r = c'(x_1)$$
$$-r = e'(x_1)$$

When demand for pollution equals supply (x_1=x_2), $p = c'(x_e) + e'(x_e)$. Since pollution is “bad” or not good, the equilibrium price of pollution ,r, is a negative number.

If firm 1 (polluter) produces *y* units of output for every unit of *x*, then the cost function is *c(x, y)* and in the absence of any pollution control mechanism, our model becomes:

$$\max_{x,\, y} \quad px - c(x, y)$$

FOC:

$$p = \frac{\partial c(x, y)}{\partial x}$$

$$0 = \frac{\partial c(x, y)}{\partial y}$$

In the absence of any market for pollution, firm 2 will equate the price of pollution to its marginal cost (zero), so it will pollute upto the point where the cost of production are minimized. Adding market for pollution with y_1 and y_2 as supply and demand of the firms, the maximization problems are:

$$\pi_1 = \max_{x,\, y_1} \quad px + ry_1 - c(x, y_1)$$

$$\pi_2 = \max_{y_2} - ry_2 - e(y_2)$$

FOC:

$$r = \frac{\partial c(x, y_1\ )}{\partial y_1}$$

$$-r = \frac{\partial c(x, y_2\ )}{\partial y_2}$$

Equating supply and demand, $y_1 = y_2$, will give FOC for an efficient level of output and pollution. However, the problem with such a solution is that the markets may be very thin.

Coase (1960) argued that *regardless of who holds the property rights, there is an automatic tendency to approach the social optimum. If this is correct, we have no need for government regulation of externality, for the market will take care of itself.* It is argued that the basic problem is that property rights are not conductive to full efficiency and if both technologies are operated by the same firm there should have not been any problems. Hence, there is a market incentive for one firm to buy out the other, coordinate their production plans, and internalize the externality. The firm expands until it internalizes all production costs. This mechanism works well for some sort of externalities but not for consumption externalities, or the externalities that are public goods.

Mechanism for Internalizing the Externalities

Due to information asymmetry, the taxing authority may not know the costs imposed by the externality but it may be that the agents that produce the "bad" or externality have a reasonably good idea of the costs they impose on the society. And if so, the externality may be internalized by setting opposite incentives for the firms.

Rule: Set up a market for the externality so as to encourage the firms to correctly reveal the costs they impose on society. In the first instance, *announcement stage*, the firms i=1,2 announces a Pigovian tax t_i which may or may not be the efficient level of tax. In the second phase, *choice stage*, if firm 1 produces x units of output it has to pay a tax t_2x, and firm 2 gets compensation of t_1x. In addition each firm pays a penalty depending upon the difference between their two announced tax rates. The penalty is zero if $t_1=t_2$ and positive otherwise. Assuming a quadratic penalty, the payoff matrix is:

$$\pi 1 = \max_{x} px - c(x) - (t_1 - t_2)^2$$

$$\pi 2 = t_1 x - e(x) - (t_2 - t_1)^2$$

The firm 1 will choose x to satisfy the condition $p = c'(x) + t_2$ and in the first stage each firm chooses tax rates so as to maximize the profits at $t_1=t_2$.

Taking into account that the choice of t_2 affects firm 1's out put through the function $x(t_2)$ and differentiating firm 2's profit function gives

$$\pi' 2(t_2) = (t_1 - e'(x))x'(t_2) - 2(t_2 - t_1) = 0$$

$\Rightarrow p = c'(x) + e'(x)$ is the efficiency condition.

Suppose that there are two goods, x and y, and two agents only such that each agent cares about the other agent's consumption of x good but neither agent cares about the other agents consumption of y good. Assuming that there are initially

$\bar{x}$ and $\bar{y}$ of the two goods, a Pareto efficient allocation would maximize the sum of the weighted utilities subject to the resource constraint

$$\max_{x_i, y_i} a_1 U_1 (x_1, x_2, y_1) + a_2 U_1 (x_1, x_2, y_1)$$

$$\text{s.t.} \quad \begin{aligned} x_1 + x_2 &= \bar{x} \\ y_1 + y_2 &= \bar{y} \end{aligned}$$

The solution to the FOC are:

$$\frac{\partial U_1 / \partial x_1}{\partial U_1 / \partial y_1} + \frac{\partial U_2 / \partial x_1}{\partial U_2 / \partial y_2} = \frac{\lambda}{\mu}$$

$$\frac{\partial U_1 / \partial x_2}{\partial U_1 / \partial y_1} + \frac{\partial U_2 / \partial x_2}{\partial U_2 / \partial y_2} = \frac{\lambda}{\mu}$$

Thus the efficiency condition is that the sum of marginal rates of substitution equals a constant (same as the efficiency condition for a public good).

$\partial U_2 / \partial x_1 = p_1$ is the price of x_1 and $\partial U_1 / \partial x_2 = p_2$ is the price of good x_2 such that in determining whether or not it is a good idea that agent 1 should increase his consumption of good 2, he takes into account not only how much he is willing to pay for this additional consumption, but how much agent 2 is willing to pay. Thus, if each agent faces the appropriate price for his actions, the market equilibrium will lead to an efficient resource allocation.

An Over View of Competing Techniques of Environmental Valuation

A variety of valuation techniques may be used to quantify environmental impacts. The basic concept of economic valuation underlying all these techniques, however, is the willingness to pay of individuals for an environmental resource or service[10].

10 Measuring the demand for conventional goods and services is rarely easy, the problems are more complex in the case of environmental goods. An environmental good is defined as having at least one of the two characteristics: either it is negative good - a "bad"- which carries no price and thus is inefficiently allocated by the market; or it is public good endowed upon the society (rather than purchased) such as biodiversity or national park. In these cases, the aggregate quantity of good or bad supplied is observable but the individual or aggregate expenditures or valuation of the good are not. Thus in general the researcher knows the cost of supply of public goods and trades off monetary costs with benefits, but they don't know the cost of environmental goods. In the case of environmental goods all that can be observed is how the consumption of private good changes with the level of the environmental goods. Thus the challenge is to recover the underlying demand for environmental commodity. Alternatively, artificial or hypothetical

Table 2 gives an overview of environmental valuation techniques. The valuation methods are categorized according to: (a) which type of market they rely upon; and (b) how they make use of actual or potential behavior of economic agents.

Table 2: Taxonomy of Economic Valuation Techniques

Conventional Market	Implicit Market	Constructed Market
Based on Revealed Preferences		
Private goods sold in the market (conventional price and quality analysis) The Productivity Approach Effect on Health or Earnings Defensive Expenditures Averting Expenditures	*Public Goods / Government Services* *(collective choice analysis)* Hedonic Prices Direct Use of Environmental Resources Travel Cost Analysis Wage Difference or Household Production Function Approach Hedonic Property Values Approach Proxy Marketed Goods or Supply and Demand Analysis of Related Goods	Artificial Market
Based on Stated Preferences		
Potential Market Goods (experimental economics, conjoint analysis) Repair / Replacement Cost Shadow Project Analysis	*Indirect or Passive Use of Environmental Resources* Contingent Valuation Method, Conjoint Analysis Habitat Equivalency Analysis Direct Use of Environmental Resources Contingent Valuation Method, Conjoint Analysis Habitat Equivalency Analysis	Contingent Valuation Method Bidding Games Trade off Games Take it or Leave it Experiments Costless Choice Delphi Technique

Source: Partly Adapted from Bjornstad and Kahn (1996) and Munasinghe (1993). For a brief description these techniques, see Appendix 1.

Generally speaking, environmental valuation techniques are of two types: those relying on revealed preferences or what humans *actually do* in the markets; and

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markets may be constructed to elicit implicit prices or valuations for environmental goods and services. In the later, demand estimation is easier although eliciting preferences becomes harder (Kolstad and Braden, 1991) those relying on stated preferences or what humans say they *would do* in a hypothetical market context. Thus both of these approaches attempt to evaluate human behavior in economic terms but they differ in the sense that the former is based on actual or observed behavior while the latter is based on potential or likely behavior. As the revealed preference methodologies are based on actual expenditures, they, however, are better able to predict the underlying human preference structure though data difficulties and statistical problems can affect the quality of results.

The revealed preference techniques include production cost analysis (applied to a wide range of impacts including crops, livestock, forest, and ecosystem), travel cost method (applied mainly to recreation demand studies), defensive/averting cost analysis (applied to healthcare studies) and hedonic price analysis (used for property prices and attribute analysis).

Where the development projects, say a wastewater irrigation scheme, leads to a measurable change in quantity, quality or cost of production, the resulting change can be measured in monetary units using market or shadow prices. This is called production cost analysis. The travel cost method seeks to quantify the value of travel time and out of pocket or actual travel expenses to provide a measure of the value people place on leisure activities such as angling and sight seeing. The health effects resulting in morbidity and mortality can generally be quantified by using human capital approach and defensive/preventive cost analysis. The value of output foregone due to mortality (pre-mature death) or morbidity (sickness) is a proxy for human productivity loss to which actual cost of medical visits, defensive expenditures, and inconvenience cost can be added to derive a cumulative measure of health effects. The mortality related productivity loss or the value of human statistical life is estimated to be 120 times GDP per capita (Miller, 2000)[i]. The sickness related expenses can be calculated from clinical and personal records.

The hedonic price analysis seeks to decompose property prices into: component attributable to property characteristics such as size of the plot, number of rooms, parking spaces, type of heating, north/south aspect, land tax, utility rates, and proximity to civic facilities; and component attributable to environmental variable such as proximity to a landfill or hazardous waste site. Thus the willingness to pay higher property price for being located away from the waste site, for comparable property characteristics, represents the price premium of disamenity associated with proximity to waste site.

The stated preference methodologies, commonly called contingent valuation techniques, are based on surveys where humans are directly questioned by the researchers to place monetary values on goods and services normally not sold in the common market place. Thus, contingent valuation method seeks to replicate hypothetical market conditions to elicit consumer preferences about non-marketed goods: that is, how would they behave if the goods in question *were actually* sold in market. The consumer preferences are sought either in terms of willingness to pay (WTP) or willingness to accept (WTA). Sometimes, a variant of the contingent valuation method, such as Delphi technique, is used for valuation purposes where experts, instead of consumers, are approached to seek their opinion about a particular environmental resource or issue (see Edward-Jones *et. al*; 1995 for an illustrative example)[ii]. Contingent valuation techniques can be used to evaluate a number on non-marketed public or environmental goods such as water quality and quantity improvements projects, natural resource conservation projects, assessment of natural resource injuries such as water pollution due to hazardous waste or oil spills, enhancement of environmental quality, ecosystem change, and endangered species conservation etc.

The environmental valuation techniques seek to place monetary values on both marketed and non-marketed goods and services and environmental resources: that is; e*verything* in dollars. The ensuing ethical concerns with the use of contingent valuation method have, hence, lead to the evolution of two *nonmonetary* approaches to valuation: conjoint analysis; and habitat equivalency analysis (Braden, 2000)[iii]. The habitat equivalency analysis simply seeks to identify which bundles of natural resources are considered equivalent to the others, damaged resources for example, by the public. No attempt is made to determine their relative importance to the humans, even in physical terms. The conjoint analysis, on the other hand, goes a step further and seeks to: (1) quantify the equivalence in terms of physical units; and (2) assign relative importance in terms of human preference structure. Both habitat equivalency analysis and conjoint analysis do *not* attempt to translate physical units into monetary terms, however.

The prohibitively high costs of conducting a contingent valuation study has lead researchers to look for existing studies in literature that are sufficiently comparable to the case under question and use the findings of these studies to make inferences about the new situation. This techniques is called Benefit Transfer. Benefit transfer presents a promising valuation alternative in situations where data are hard to come by and public agency has to make strategic policy decisions. It is very timely for the IWMI to seize on the opportunity to undertake a major study on the *feasibility of using benefit transfer protocol for water resource planning and management in developing countries*.

A detailed description of the valuation techniques, their application, and problem areas can be found in appropriate text such as James, 1994; Hanley and Spash, 1993; and Pearce and Turner, 1990.

However, Maler (1992) has classified the valuation methods into two broad groups: (1) surveys of willingness to pay like CVM, and (2) production function based approaches. The category two is divided into two subcategories (2a) output measurable in markets (corresponding to second column -conventional markets-in Table 1); and (2b) out put not measurable in markets (other techniques in column 2 and 3 of Table 1.

Each of the environmental valuation techniques has its own strengths and weaknesses. **Table 3** presents a comparison of competing environmental valuation methodologies.

Environmental goods can differ from market goods in four dimensions: (1) degree of publicness; (2) nature of economic commitment faced by the consumer while deciding a value for the good; (3) nature of the information set determining consumer's preferences; and (4) the type of use from which utility arises (i.e, direct or passive use). Hence, some environmental valuation techniques are generally applicable while others are potentially applicable and still others may be selectively applicable. Table 3 gives a summary of different techniques that may aid in specific environmental and resource valuation issues.

Table 3: Applicability of Valuation Techniques to Environmental Impacts

Valuation Method	**Health Impacts**		**Aesthetic Impacts**	**Ecosystem Impacts**	**Recreational Impacts**	**Production Impacts**
	Illness	**Mortality**				
Productivity Approach	Yes		Yes	Yes	Yes	Yes
Opportunity Cost	Yes		Yes	Yes		Yes
Preventive Expenditure and Replacement Cost	Yes	Yes	Yes	Yes		Yes
Hedonic Pricing		Yes	Yes		Yes	
Wage Differential	Yes	Yes	Yes			May be
Travel Cost			Yes		Yes	
Contingent Valuation	Yes	Yes	Yes	Yes	Yes	Yes
Delphi Technique	May be		May be	Yes	May be	May be

Source: Modified from EPA, NSW, 1993.

Limitations of Environmental Valuation Techniques

Each of the environmental valuation techniques has some advantages and some limitations. For example, some techniques are highly developed to generate highly reliable estimates of economic value though they are more expensive but less time consuming where as others are not. **Table 4** presents a comparative overview of main advantages and limitations of various valuation techniques.

Table 4*:* Comparison of Valuation Methodologies

Valuation Method	Reliability of Results	Data Requirement	Timing	Ease of Application	Technical Development	Accumulated Experience
Productivity Approach	High	Medium	Low	High	High	High
Opportunity Cost	High	Medium	Low	High	High	High
Preventive Expenditure	High	Medium	Low	High	High	High
Replacement Cost						
Special features: based on market transactions, assumes no distortions in market prices						
Hedonic Pricing	High	High	Medium	Medium	High	Medium
Special features: assumes mobility and perfect information						
Wage Differential	Medium	High	Medium	Medium	Medium	Medium
Special features: main technique for valuing risks to life, assumes mobility and perfect information						
Travel Cost	Medium	Medium	Low	High	High	High
Special features: use limited to recreation benefits						
Contingent Valuation	High	Medium	High	Low	High	High
Special features: the only technique that measures existence values, can suffer from a lot of biases						
Delphi Technique	Medium	Low	Low	Medium	Medium	Low
Special features: applicable to wide range of impacts						

4. ECONOMIC VALUATION IN PRACTICE

General Approach

Some studies have evaluated the benefits of wastewater irrigation by taking into consideration: (1) the market value of water, and (2) market value of wastewater nutrients. To the extent resource input and output markets perform poorly, such approach can yield suboptimal results only. This is because water is a common good and hence it is rarely priced and allocated at its opportunity cost in most developing countries, including Pakistan, rather water allocation is determined by a host of legal, political, and historical factors. Endemic social problems, for example, water theft, can create additional issues for efficient working of water markets (Ray and Williams, 1999). The absence of well functioning water markets can create two problems: loss of efficiency gains due to difficulty in reallocation, and lack of price signals to assist reallocation. Thus, even in the presence of formal and informal water markets, water prices at best may reflect only suboptimal opportunity cost of water. Using water price as a yardstick for evaluating the benefits of saving fresh water resources through wastewater irrigation will, hence, yield suboptimal estimates only.

There are two possible alternatives to water pricing viz: using hedonic price analysis to reveal implicit price of water, or using the cost of energy required to deliver a unit of water to farm-head. Using hedonic price analysis of irrigated farm property sales is advantageous because the implicit price of market will be based on market transactions rather than estimates of crop yield, prices, and costs. Nevertheless, hedonic analysis reveals market value of water rather than agricultural production value (Faux and Perry, 1999). Moreover, if the property markets are imperfect, as is the case in developing countries, market value of water will be a gross estimate only.

Using the cost of energy required to deliver a unit of water (pumping, transport, storage, delivery, and application etc) to farmhead seems better approximation to the opportunity cost of water, and hence its market value, but even this estimate is partial firstly because its does not entail any cost for depletion of water resources (buffer value) and secondly energy prices are highly subsidized, especially for agricultural tubewells in Pakistan. Thirdly, negative externality effects of fossil fuel energy, such as green house gas emissions, or even hydropower such as sedimentation and water logging and salinity, are rarely reflected into market prices of energy in developing countries.

Similarly, fertilizer prices are highly subsidized in Pakistan.

Hence, the use of irrigation water cost savings and chemical fertilizer cost savings as a measure of benefits of wastewater irrigation can at best give a suboptimal and partial measure of the full benefits.

Another problem with the use of water value and fertilizer value approach is that it does not take into account off-farm effects (negative and positive externality effects) such as effects on public health, soil resources, groundwater resources, property values, ecosystem impacts, and social concerns. Given these shortcomings, we develop a simple, systematic, comprehensive, and theoretically consistent approach to evaluate the effects of wastewater use in agriculture from a holistic ecosystem perspective as below.

Our Approach

In general, the economic valuation of projects and programs, such as wastewater irrigation, is carried out in two phases. In the first phase, baseline scenarios are compared to with project scenarios in order to identify the socioeconomic and ecological impacts of alternative projects, programs and policies. In the second phase, the identified impacts are valued in monetary units. For the purpose of analyzing the socioeconomic and environmental impacts of wastewater irrigation, the theoretical framework employed in this report consists of:

1. Identification of impacts and proxies
2. Identification of valuation techniques
3. Generating Dollar value estimates, and
4. Aggregating various economic value measures.

The impacts include both actual and potential impacts of wastewater irrigation. For each of the identified impacts, same analytical sequence is repeated to determine if the impact leads to a measurable change in productivity or not. If the impact leads to a measurable change in productivity and non-distorted market prices are available, the impact can be monetized using the change in productivity approach. However, if the market prices are distorted, shadow prices may be used to measure change in productivity.

Alternatively, if the identified impact does not lead to a measurable change in productivity, then the change in environmental quality is identified and valued using appropriate proxies and valuation techniques. The proxies are not the exact variables rather they are quasi-variables that can be used as 'near representations' of the actual variable to quantify the change in economic terms. Thus each of the impacts, whether economic, social, or ecological, is valued in dollar terms which in turn can be aggregated to generate dollar value estimates of holistic impacts. The approach therefore, attempts to estimate the economic, social, and ecological sustainability of wastewater irrigation in terms of its aggregate costs and benefits to the society. In order to keep with the convention of cost benefit analysis, the impacts can be classified into costs and benefits and discounted[11] to a single period to calculate the net present value of programs, wastewater irrigation in our case. As wastewater irrigation in one period generates impacts in the next period or over certain future periods, the impacts should be estimated in a dynamic analytical framework to address equity and sustainability concerns.

Economic Valuation of Impacts

The general approach followed in this report is that an expenditure saved is a benefit and a benefit foregone is a cost item. For example, wastewater is a rich source of plant food nutrients and therefore, wastewater irrigation eliminates the need for inorganic chemical fertilizers, that is, wastewater irrigation saves fertilizer costs: therefore, the nutrient contents of wastewater represent a benefit item. And, appropriate numeraire or for the fertilizer cost savings is the market value of fertilizer. On the other hand, wastewater contains pathogenic microorganisms which pose a potential risk to human health. The morbidity caused by the wastewater pathogens results in loss of earnings and extra healthcare expenditure and inconvenience cost for the affected population. The earnings forgone due to illness caused by wastewater pathogens therefore, represent a cost item. And, the appropriate numeraire for the loss of earnings is the market or shadow price of labor.

The second, convention followed in this study is that costs or benefits identified and valued under one effect are not valued under another effect to avoid the possibility of double counting. For example, wastewater is an irrigation resource as it contributes towards crop productivity and water value, at market or shadow prices, represents the benefit of wastewater as an irrigant. But, a portion of the wastewater applied to the land for crop irrigation also serves as a source of groundwater recharge. If the groundwater recharge value is also enumerated, it will be an instance of double counting unless water value is evaluated in terms of consumptive use of crop instead of total wastewater applied to the crop.

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[11] The social discount rate can be assumed to the difference between commercial bank lending rate and inflation rate.

Valuation of Impacts on Public Health

Wastewater irrigation has the potential to cause the disease as discussed earlier though the degree of risk is higher with untreated wastewater irrigation than treated wastewater irrigation. In order to characterize extreme circumstances, both the morbidity and mortality potential of wastewater pathogens should be economically evaluated.

The morbidity or illness caused by wastewater pathogens may result in:

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

The loss of potential earnings can be evaluated using *human capital approach* to which medical or healthcare costs and inconvenience costs can be added (opportunity cost principle). The approach assumes that earnings represent the value of marginal product of labor and medical and other costs are well defined.

Productivity or earnings loss 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 off-work called restricted activity days in literature), daily wage rate and incidence of disease. 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 ex-post) 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.

The sickness related leisure and sleep disturbances may 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 may attach to such losses in developing countries (costs are not well defined). Nevertheless, as leisure and sleep disturbances has the potential to impact labor productivity, they should not be dropped out of the analysis because of technical difficulties.

Using estimates of consumers willingness pay to avert any inconvenience, such as the one caused due to sickness, or appropriately deflated wage rate (say 25%), to work out the opportunity cost, may be one alternative to put monetary values on time lost through leisure and sleep disturbances (also see Frame 1).

As schooling and education manifest human capital formation universally, schooling loss due to absenteeism, caused by wastewater borne illness, can be used as a measure of productivity loss for schooling class. Amortized per pupil expenditure can be used as a 'shadow price' for monetary monetization of sickness related schooling loss.

Since a large proportion of children drop out of schools and engage in work in developing countries, the loss of children productivity should also be valued in economic terms. The opportunity value of children labour can be evaluated by using appropriately deflated market wage rate (say 25%, 50% and 75% depending upon age) to reflect the fact that marginal product of child labor is less than adult labor (alternatively, social cost of child labor is much higher than the actual value added in developing countries).

The productivity loss and inconvenience cost of unemployed and underemployed sick individuals can be estimated using the above methodology though the wage rate may require some adjustment.

Frame 1: Estimates of Willingness to Pay

The averting expenditure approach has been used by Dickie *et. al*. (1991) to estimate the benefits of reduced morbidity such as skin cancer. The stated willingness to pay for an imaginary product that would reduce life time cancer risk by one percent ranges between $4.44 to $2.70 per head- a WTP value considered very small by any conservative estimate. The willingness to pay for the supply of safe drinking water, that would reduce the risk of waterborne disease, in Faisalabad city ranges between US$ 2-3 per month (Hanjra and Hanjra, 1995).

The economic value of mortality (deaths), if any, caused by wastewater irrigation can be evaluated in terms of net productivity of an individual over the expected life span. The mortality related productivity loss is thus net present value of difference between production and consumption of an individual over the remaining period of life (in case of premature deaths).

For adults, the net present value of productivity lost by the society is the difference between adult earnings and adult consumption. Where as, for children, the net present value of productivity lost by the society is the difference between child's future production and household expenditure per capita (assuming that child is future head of family unit). The value of life estimates[12] along with the estimated

[12] Although considerable controversy exists over the value of life estimates, one commonly used value in the US studies is UDS300 for 0.0001 reduction in death risk. Thus, the reduction in risk equals USD3 million per death avoided. Some UK studies, e.g., Meng and Smith (1990) estimate the value of life at 3.84 million pounds. However, as the value of life estimates are country specific, a regional estimate would be more appropriate to use.

change in mortality[13] for each population cohort, attributable to wastewater pathogens, can be used to generate population wide measures of economic cost of mortality[14] .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.

Valuation of Impacts on Crops

The wastewater is a rich source of plant food nutrients. Empirical studies, presented in last section of this report, show that a number of crops such as cereals, forage crops, fruits and vegetables, and horticultural crops etc can be successfully grown by using appropriately treated wastewater as a source of irrigation. Infact, wastewater irrigation can give yields at least equal to or higher than the yields achievable by the use of inorganic fertilizers. The impact of wastewater irrigation on yield however, varies from crop to crop. If the crops are undersupplied with essential plant food nutrients, wastewater irrigation will act as a supplemental source of fertilizer thus increasing crop yields. Alternatively, if plant food nutrients delivered through wastewater irrigation result in nutrients over supply, yields may be negatively affected. In the absence of any chemical fertilizer application, wastewater nutrients will act as a sole source of fertilizer delivering fertilizer cost savings. Thus, from an economic standpoint wastewater irrigation may have a three fold effect on crops: (1) higher yields, (2) source of irrigation water, and (3) fertilizer value.

The economic approaches that may be used to evaluate the yield effects of wastewater irrigation are: traditional models, optimization models, and econometric models (Hanley and Spash, 1993).

The *traditional model* uses a biological approach to evaluate monetary value of yield changes. The dollar value estimates can be generated by using information on crop yield changes, acreage, and current prices. This is static type basic model which assumes that resource use or crop response function, prices, and consumer surplus remain constant. As the information requirements for the estimation of

[13] Change in mortality (persons per year) = mortality coefficient x crude mortality x population exposed. The value of mortality coefficient estimated by empirical epidemiological studies on wastewater pathogen risk can be used. For example, based on the available empirical evidence, WHO guidelines assume a risk factor of 10^{-6}.

[14] Shuval *et. al*. (1997) use a risk assessment model to evaluate additional cost of wastewater treatment from WHO standards to USEPA standards.

traditional model are relatively small and quantitative measurements can be performed quickly and inexpensively, the model results may provide quick insight into the effects of policy changes such as wastewater irrigation.

This simple model may be useful if we assume that yield increases lead to a small change in supply relative to regional market, crop is not regionally concentrated (unlike sugarcane acreage in Faisalabad), and major benefits of wastewater irrigation accrue in the from of fertilizer cost savings. Nevertheless, constant price assumption may be easily violated in practice, say if the crop in question is regionally concentrated, as is the case with sugarcane production in Faisalabad. Moreover, as price effects and their distributional consequences are very well documented in economic literature, constant prices assumption is an unrealistic abstraction from reality.

Thus, as the traditional model assumes prices to remain constant, it is unable to quantify changes in regional welfare due to changes in input use (fertilizer and water economy), output(s), employment, secondary benefits of increase in income, and distributional impacts of income changes. These disadvantages can be overcome by the use of optimization models as they can model complex inter-relationships of an agricultural system and predict direct, indirect and distributional effects of yield changes.

The mathematical optimization models include Linear Programming Models and Quadratic Programming Models.

For the estimation of benefits of wastewater irrigation, a linear programming model can be specified as a profit maximization model with constraints on inputs such as crop acreage and NPK use per crop. Along with the standard assumptions, this linear programming model will assume a perfectly elastic supply and constant returns to scale. As profit maximization is the objective function, prices will be exogenously fixed. The linear programming model can be transformed into a quadratic programming model by relaxing the assumption of exogenously determined prices and making both prices and quantities as being endogenously determined.

By changing the biological relationships between inputs and output, the quantities of output produced can be estimated. The linear programming model can be very helpful tool in crop selection subject to the land and variable resource constraints, when profit maximization is the over riding objective.

Not only the optimization models are complex and data requirements are high, they are poor predictive tools.

Among the *econometric models*, neoclassical production function models can be used for evaluation of yield effects of wastewater irrigation. These model require the specification of the functional form of the model for each crop output. In agriculture sector, Cobb Douglas production is the most commonly used functional form. However, as the prior specification of production function imposes unrealistic assumptions on crop supply and input demand functions, the 'dual approach' offers a better alternative. The dual approach uses a production function, to quantify the maximum output as a function of inputs, and a transformation function, to quantify the maximum net output vector (Varian, 1992). The transformation function describes the production possibilities and measures the technical inefficiency of farm with multiple outputs. The duality approach can be set as a profit function with wastewater quality as an input so that it directly determines the loss in farmer profits and how other inputs are adjusted in response to a change in wastewater quality. A dose-response function is unable to provide latter type of information.

The dual approaches can be modeled as cost function and profit function for the estimation of effect of wastewater irrigation on crops. The use of dual approach is advantageous as it will allow the estimation of cost, revenue, and profit functions in a systematic and theoretically consistent manner (see Mjelde et. al., 1984 for an application of duality).

Whatever the model used, the empirical valuation of the effects of wastewater irrigation on crops should include both direct and indirect effects estimated in a dynamic framework.

Valuation of Impacts on Aquaculture

As wastewater is a rich source f nutrients, the use of wastewater for aquaculture can deliver economic benefits like: (1) saving fresh water resources; (2) nutrient recycling value; (3) higher than normal fish yields and protein supplies; and (4) treatment cost savings.

The fresh water savings and nutrients recycling can be valued in dollar terms by using the opportunity cost approach described earlier. Alternatively, aquaculture can be modeled as a crop in farmers output mix and the economic benefit can be evaluated using models described under the effects on crops.

Valuation of Impacts on Soil Resources

In addition to plant food nutrients, wastewater contains high concentrations of dissolved salts and some heavy metals and trace elements. Some of these dissolved salts may accumulate in the plant root zone with possible harmful impacts on soil health and crop yields and the leaching of these salts may cause soil and groundwater pollution. The long term use of saline and sodium rich water may erode soil structure , and hence productivity, permanently there by making the land use non-sustainable in the long run.

Though the problem of soil salinity and sodicity can be resolved by the use of organic or inorganic soil amendments, the soil reclamation measures have costs which are in addition to the income foregone through crop productivity loss. Moreover, it may not be possible to restore full health, and hence productivity, of the soil using these soil amendments. Hence, wastewater irrigation may have long term economic impacts on the soil which in turn may affect market prices and land values of saline and waterlogged soils. In short, salinity related economic impacts of wastewater irrigation on soil resources are: (1) potential yield and income loss; (2) loss of soil productivity; (3) depreciation in market value of land; (4) cost of soil reclamation measures

The potential yield loss, due to salinity, constitutes the loss of potential income for the farmers practicing wastewater irrigation. The yield losses can be evaluated in economic terms by using productivity loss approach as described earlier. However, as yield loss may be affected by several factors simultaneously, the yield loss due to salinity alone may be difficult to isolate and quantity in absolute terms. Moreover, to the extent agricultural markets perform poorly, crop prices may be distorted. Hence, potential yield loss as a measure of income foregone may at best be a gross approximation of the actual impact of wastewater induced salinity on soil resources. Expert opinion regarding salinity related crop yield loss can serve as a proxy for estimating such income loss.

Similarly, the economic value of soil productivity, ability to produce crops, loss may be difficult to quantify and evaluate in economic terms as the general measure of soil productivity is land price (more fertile and productive land command higher prices). But, land prices for similar parcels may differ significantly due to a variety of reasons, say proximity to canal or residential area. Unless, a full blown hedonic price analysis is conducted, the true price of land productivity differential attributable to salinity parameter may be difficult to quantify and evaluate in economic terms.

The depreciation in market value of land has two dimensions: decline in sale value of land (investment depreciation), that is market price per acre, and land rent, that is, annual lease revenue per acre under lease hold arrangement[15].

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[15] Even under share cropping, the tenant may require soft terms for salinity affected land there by reducing the annual return to landlord.

The net present value of differential in market price or annual lease per acre over a common period, say 20 years, may be used as a measure of opportunity cost of wastewater induced salinity. To the extent resource and commodity markets perform perfectly, the use of sale value or annual lease differential should yield same results if discount period is based on actual time required for reclamation. However, for all practical purposes, sale value differential may be used as a proxy if the impact of salinity is long term and severe (irreversible). Alternatively, annual lease differential may be used as a proxy if the impact of salinity is moderate.

A more consistent and practical measure of the opportunity cost of wastewater induced salinity is cost of soil reclamation measures such as gypsum application or green manuring. The underlying premise is that the use of wastewater irrigation induces salinity and in order to control the salinity farmer has to undertake control measures such as the application of inorganic soil amendments and/or green manuring. As the application of gypsum or green manuring is a recurring and ongoing expenditure, it represents a better proxy for evaluating the cost of wastewater irrigation induced salinity. Moreover, it does not require the selection of discount period based on level of salinity because wastewater irrigation project or policy period itself sets the discount period. However, to the extent the effect of salinity is not significant or damage to the soil productivity is minor, cost of soil reclamation measure is a good proxy for all economic valuation purposes (though some upward adjustments would be required as gypsum prices are highly subsidized in Pakistan). Ideally, soil sodium absorptive ratio, a measure of salinity, and corresponding cost of reclamation measures, if supported by available empirical literature, should be should for the valuation of wastewater irrigation induced salinity.

In summary, as the impact of salinity varies from severe to moderate to minor, the appropriate proxies for the valuation of wastewater induced salinity damage are sale value differential, annual lease differential, and cost of soil reclamation measures respectively[16].

Valuation of Impacts on Groundwater Resources

Two principle effects of wastewater irrigation that deserve economic valuation are: (1) groundwater recharge (a benefit item), and nitrate contamination of groundwater resources (a cost item) through leaching and drainage.

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[16] Two other proxies for economic valuation of salinity are: (1) cost of desalinization or removal of saline content per acre inch of wastewater, (2) cost of regulation and community based initiatives to reduce salt enrichment of domestic sewage.

Wastewater irrigation may serve as a source of groundwater recharge because not all water applied to the soil is consumed by the crops rather a significant proportion percolates through the crop root zone and into the aquifer. Based on the amount of wastewater applied and leaching fraction, the annual contribution of wastewater irrigation towards groundwater recharge, say in terms of mega liters or acre inches, can be estimated. The recharge volume can be converted into economic terms by using market prices of water. Since, water resources are not priced at their true opportunity cost in Pakistan, appropriate proxies can be used to generate dollar value estimated of benefits of groundwater recharge. The suggested proxies are:

- cost of domestic water supply per capita
- cost of irrigation water supply per acre inch.

The economic rationale behind using these proxies is that the groundwater is a major source of domestic and agricultural water supplies and the depletion of groundwater resources, in the absence of recharge, may have serious economic, social, and ecological consequences. Hence, the relevant measures of economic value of water is the cost of domestic water supply per capita, say if water is to be supplied by installation of a pipeline from river Chenab located some 30km away from Faisalabad.

Literature has cited two health problems associated with excess nitrate levels in drinking water. The first, methaemoglobinaemia caused in bottle feeding infants due to oxygen starvation. And, second stomach cancer caused due to the formation of N-nitroso compounds considered to be carcinogenic. While the evidence on stomach cancer is inconclusive, cases of methaemoglobinaemia have been reported in UK and elsewhere (Hanley and Spash, 1993). Health concerns associated with excess nitrate levels have therefore, prompted WHO to recommend an upper limit of 50 mg/l in drinking water.

If the groundwater survey reveals excess nitrate levels in drinking water in Faisalabad, the nitrate risk to human health should be evaluated and incorporated into economic analysis of wastewater irrigation.

The evaluation of risk from contaminants migrating by groundwater, say nitrates, however is a complex and impossible task. Andricevic and Cvetkovic Valdimir (1996) suggest that the general evaluation of nitrate pollution risk would involve the identification of risk agent, its fate and transport through soil, estimation of human exposure, and conversion of this exposure into the risk level. The risk level can be quantified on the basis of risk factor (risk per unit of intake) and total potential intake . In view of the uncertainty in consuming nitrate polluted water and dose response functions, the total risk level can be expressed as a distribution rather than a single estimate from which mean risk factor affecting a population cohort can be estimated

Alternatively, wastewater nitrogen application rates, nitrogen leaching fraction and base level nitrate concentrations in groundwater can be used to estimate the amount of nitrates added to groundwater, say in terms of kg per acre inch per year. Leaching fraction can be calculated as the concentration of available nitrogen minus nitrogen required by the crop. If nutrients are undersupplied than crop requirements, leaching fraction can be assumed as a fraction of supplemental fertilizer dose (say, 30%, though it will be advisable to use the estimate developed by regional irrigation and drainage studies).

The nitrate related risk to human health can be evaluated using human capital approach and opportunity cost principle as described under the valuation of health impacts earlier. Assuming that nitrate pollution already exists in the study area, an alternate approach would be to use contingent valuation method[17] to question households to state their maximum willingness to pay per annum to reduce nitrate concentrations in drinking (ground) water to WHO limit of 50 mg/l. In a follow up questionnaire, respondents can be given additional information that high nitrate levels can lead to a higher cancer risk to see if their risk valuation and willingness to pay changes. The mean bids, with full information, can be aggregated over the entire population of Faisalabad to estimate regional benefit (or alternatively cost) of averting nitrate pollution of groundwater resources.

Valuation of Impacts on Property Values

Wastewater irrigation has the potential to negatively affect property values because of the potential to affect groundwater quality, public health risk, and disamenity associated with odour, nuisance, and poor hygiene. Hedonic pricing studies show that people discount the risk of proximity to polluted streams and waterfront while placing values on properties. Moreover, there is documented evidence in literature that depreciation of property values may sometimes be solely due to belief that risk persists. Thus, both actual or potential risk to property values due to wastewater irrigation should be evaluated in economic terms.

Hedonic price models can be used to place monetary values on property attributes such as the size and location, proximity to road, market and major population centre, productivity and fertility index or land rent and annual lease revenue, availability of canal/groundwater, agro forestry, earthwork investments, and more

[17] For an application of this technique, see Edwards, (1988) and Hanley (1989).

importantly proximity to wastewater irrigation sites. Holding the effect of income and other demographic variables constant, the proximity risk premium for properties located near sources of wastewater related pollution can be estimated. Since, empirical data on real estate sales are recorded by Revenue Department, Punjab, Pakistan on a regular basis, the paucity of data in itself should not be a problem (notwithstanding the difficulty in accessing these data).

Valuation of Ecological Impacts

The ultimate destination of excess nitrates in wastewater is either rivers and streams or groundwater. The addition of nutrient rich waters to water bodies can cause eutrophication which can result in algal blooms and subsequent decay and consequent depletion of dissolved oxygen. Ingestion or even contact with blue green algae has been reported to cause fish kills in streams and deaths in sheep and dogs. Fish contaminated with blue green algae can be fatal if eaten by human beings. Not only commercial aquaculture operations can be adversely affected (income loss) due to eutrophication, the disappearance of popular fish species can result in recreation to general public (welfare loss). The loss of potential income to commercial fish farms and loss of welfare to recreational fisherman can be evaluated using contingent valuation method. For this purpose, the respondents can be divided into: (1) those who go fishing and (2) those who do not go fishing. A willingness to pay (and willingness to accept) question can be asked to solicit bids for management programs for controlling wastewater related eutrophication problems so as to maintain current levels of fish in the ecosystems. A positive willingness to pay, even for even for nonfishing population, indicated that people discount the risk of eutrophication related fish kills.

The bids for fishing and nonfishing populations can be used to generate estimates of welfare loss to general public and this estimate in turn can be added to income loss to aquaculture and commercial fishing to generate an aggregate eutrophication economic loss to regional fisheries.

In the terrestrial ecosystems, such as Faisalabad, eutrophication can result in an increase in population of vascular plants, a change plant, microbial, and animal community structure. These changes alongwith the monoculture effect of wastewater irrigation can result in an imbalance of the existing ecosystem with a consequent loss of biodiversity.

The development of a biodiversity index would be the first step to facilitate the analysis of environmental impacts of wastewater irrigation. In the absence of detailed quantification of species, a probability based biodiversity index can be used. In simple terms, biodiversity index can be defined as the hectares of ecosystem of a particular habitat type on a specific location and the relative biodiversity value of each habitat. Munasinghe (1993) develop a biodiversity index by ranking different ecosystems in the order of their importance and assign a weight to each ecosystem, on a scale of one to zero, to indicate relative biodiversity value of each habitat. The habitats are valued in relative terms by considering the 'value of the area lost as a function of the proportion of the habitat that is lost'. This system would assign an infinite value of the last hectare of habitat (endangered species) and a lower value if the habitat is not at risk.

The debt for nature swaps and carbon offset programs indicate that individuals and nations are willing to pay for the protection of ecological biodiversity (Dixon, et. al., 1994). Moreover, some aspects of biodiversity such as ecotourism are marketable, again positive WTP, and can therefore be valued using techniques such as travel cost method and contingent valuation method.

In order to incorporate non-marketable aspects, such as bequest and existence values, measures of total economic value of biodiversity can be developed by using willingness to pay for the protection and enhancement of biodiversity.

In a recent application, Montogomery et. al. (1999) use economic analysis to demonstrate the concept of biodiversity management, its pricing, and the derivation of marginal cost curves for biodiversity. A similar framework can be used for evaluating the biodiversity effects of wastewater use practices.

Valuation of Social Impacts

The social concerns about the potential risk of wastewater irrigation originate from general concerns about the effect on environmental quality, social concerns about public health and safety, and concerns about the non sustainability of natural resource. These concerns can be addressed by appropriately targeted education and public awareness programs. 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. These cost estimates can be developed by using adult learning and education models.

The agribusiness risk and potential liability concerns can be addressed by seeking insurance against these potential risk. The insurance premium to cover the risk of wastewater irrigation can be used as a 'near proxy'. The underlying premise is that insurance providers are profit seeking commercial firms who would set the premium over and above the true cost of risk involved in wastewater irrigation. Hence, the risk premium should be adjusted downwards before using it as a proxy for the cost of wastewater irrigation risk to agribusiness. In summary: the cost of public education programs plus insurance premium can be regarded as an opportunity cost of addressing social and agribusiness business concerns about the potential risk of wastewater irrigation

Valuation of indirect impacts

The secondary impacts of wastewater irrigation can occur at a regional and national level. The wastewater irrigation may have major effects on particular regions; say peri-urban areas using wastewater for producing crops for immediate or on-site market can become employment centers for labor, or particular groups; say landless farmers leasing agricultural properties to grow horticultural nurseries can afford higher standard of living for their families, or communities; say those using wastewater and garden compost for urban agriculture and ornamental production may enjoy better nutrition and life styles. Thus the indirect effects of wastewater irrigation such as effects on employment, income levels and its distribution, and social effects such as equity implications should be assessed.

Assessment of distributional effects can be accomplished by incidence analysis. However, the secondary effects of wastewater irrigation can be assessed by using input output model or applied general equilibrium analysis. Welfare estimates can also be developed via a micro-macro model using farm models to derive effects of regional production changes on national market. However, given the high data requirements and complexity of these models, for the purpose of this study, the secondary effects of wastewater irrigation can be evaluated by a comparison of income levels (a function of employment or resource rents), and using measures of income distribution such as Lorenz curve and Theil entropy change index. Educational attainment index of communities practicing wastewater irrigation and those not utilizing wastewater resources can be compared to assess relative human capital formation.

Integrated Valuation Framework

The economic valuation techniques evaluate costs and benefits of wastewater irrigation in economic terms but units of measurement may differ, say dollar per head vs. dollars per acre. Using appropriate conversions, the costs and benefits of wastewater irrigation, as described and estimated above, can be converted to a common measure such as dollar per acre inch of wastewater used to facilitate additivity and subtraction.

The studies suggest that the risk of wastewater irrigation related impacts exists both within and outside the irrigation zone. Hence, the costs and benefits of wastewater irrigation should be aggregated over the entire population of Faisalabad unless otherwise advisable (such as property value impacts). A sensitivity analysis can be conducted by using different discount rate over a common period, say statistical life expectancy (±60 years)[18].

It is important to emphasize that the major issue in the cost benefit analysis of wastewater irrigation is that how to conceptualize and estimate the total economic value of impacts in a consistent manner and how to integrate various economic value measures to generate a single representative measure, such as net present value, that may be used for policy analysis. A framework for analyzing the effects of wastewater irrigation and their valuation is given in Annex Figure 1.

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[18] Sixty years period is a reasonable approximation because most wastewater treatment, utilization, and reuse projects and general irrigation projects have life span falling well within that period. Moreover, this period is sufficient to cover most impacts of wastewater, including nitrate pollution of groundwater which take longest time (≥ 40 years) to express itself.

5. THE MODEL

Valuation Framework and Scenarios

The framework used for the economic valuation of wastewater irrigation impacts is an environmental cost-benefit analysis. The term environmental impacts refers to social, economic, and ecological impacts of wastewater use in agriculture. The approach uses an analytical framework that would normally be utilized to conduct an environmental impact assessment of wastewater irrigation program but it specifically considers the economic effects and their valuations. The agricultural effects of wastewater irrigation considered are: the effects on crop production and aquaculture and economic aspects of other effects such as health effects, groundwater effects, soil resource effects, property values effects, ecological effects, and social effects. The overall objective is to evaluate the costs and benefits of wastewater use in agriculture from a holistic peri-urban life support system perspective.

The model can be estimated for two basic scenarios viz: with program scenario and without program scenario, that is, with wastewater irrigation scenario and without wastewater irrigation scenario. Various combinations of these basic scenarios can later be used to construct various sub-scenarios such as:

- Communities using wastewater irrigation only
- Using treated vs. untreated vs. both wastewater vs.
- Using wastewater plus freshwater vs.
- Fresh water only vs.
- Rainfed agriculture.

The effects of wastewater irrigation for the above sub-scenarios can be evaluated in the context of:

- ♦ *Location*: peri urban vs. suburban vs. rural communities
- ♦ *Activity*: agricultural vs. nonagricultural vs. mixed populations
- ♦ *Gender*: male vs. female vs. children vs. adult
- ♦ *Education*: primary vs. secondary vs. higher vs. no education
- ♦ *Employment*: on farm vs. off farm vs. mixed employment vs. unemployed

- *Income*: various income groups

Sustainability of Wastewater Irrigation

Wastewater reuse in peri-urban agriculture should be evaluated from economic, social, and ecological sustainability perspective. The economic sustainability of wastewater irrigation implies that wastewater irrigation should lead to maximum flow of income while at least maintaining the stock of production assets intact. Thus, economic sustainability emphasizes optimality and economic efficiency. The ecological sustainability of wastewater irrigation refers to the stability of biological and physical systems while socio-cultural sustainability refers to the stability of social and cultural systems. Thus, the sustainability of wastewater irrigation implies the use of wastewater in crop production with a profit maximizing and cost minimizing perspective in the context of holistic ecosystem impacts.

Affected Parties

These include:

Plant operators, farmers, laborers, and their families

Crop consumers, handlers, processors and service providers

General community: personal welfare concerns, and environmental, and ecological concerns

Agribusiness

Analyzing Farm Level Impacts

Let us assume that both wastewater and canal water is used by the farmer for the irrigation of different crops. Since water supply during the year is variable, let us divide the growing season into 12 months (*m*) in each year (*t*). Also, let us assume that the objective function of the farmer is to maximize his net return (*NR*), that is total revenue (*TR*) less total variable cost (*TC*). Farmers net return function from different cropping activities, including aquaculture, at a given year therefore, is:

Maximize $$NR_t = \sum_{k=1}^{K} (TR_{kt} - TC_{kt})$$

Maximize $$NR_t = \sum_{k=1}^{K} A_{kt}(Y_{kt}\, P_{kt} - C_{tk})$$

Where: A_{kt} is area allocated to k^{th} crop in time *t* (in acres)

Y_k is yield per acre of k^{th} crop in time *t*

P_{kt} is price of k^{th} crop in time *t*

C_{kt} is variable cost per acre of k^{th} crop in time *t*

Model Equation

In order to be consistent with the notation used in our worksheet, the optimization function can be written as:

Max $$NR_t = \sum_{k=1}^{K} GR_{kt}\, A_{kt}(WWS_{tm}, CWS_{tm}) - \sum_{k}^{K} TCV_{kt}\, A_{kt}$$

Where:

NR_t is net returns to farmer from various crops in year t

GR_{kt} is gross revenue for k^{th} crop per acre in year t

A_{kt} is area allocated to k^{th} crop in time t (in acres)

WWS_{tm} is wastewater supply during month m in year t

CWS_{tm} is canal water supply during month m in year t

TCV_{kt} is total cost that vary for k^{th} crop per acre in time t

k is particular crop grown during month m such that $k_{max}=K$

K is thus all crops grown during the planning horizon.

Model Statement

The above model states that net returns from producing different crops is a function of gross returns and variable cost of production. The production levels and number of acres of crops grown depend on the annual wastewater supply and canal water supply applied to different crops. The annual wastewater effluent applied to different crops depends upon monthly flow, as farmer has no storage facility, and canal water supply depends upon monthly allocation (no of turns).

Model Constraints

The optimization model is subject to following constraints.

1. Land availability constraint

$$\sum_{k=1}^{K} A_{ktm} \leq FS_t$$

Land availability constraint implies that total area under all crops in a particular month[19] should not exceed farm size (*FS*). The cropland constraint equation thus bounds cropland availability.

2. Nutrient constraint

$$\sum_{k=1}^{K} N_{kt} A_{kt} \geq \sum_{m=1}^{12} NS_t$$

[19] Though total area under all crops in a particular year may exceed farm size due to multiple cropping.

Nitrogen availability constraint implies that total available nitrogen or nitrogen supply (*NS*) per year should not exceed the annual nitrogen uptake (*N*) per acre of crop *k*. That is, selected crops and their associated acreage should remove all the nitrogen (and phosphorous[20]) supplied during a particular year. If:

RHS > LHS, nitrogen supply should be supplemented

RHS < LHS, implies nitrogen over supply which may lead to excessive leaching.

3. Wastewater availability constraint

$$\sum_{k=1}^{K} Inch_{ktm} A_{ktm} \leq WWS_{tm}$$

That is, acre inches of water required for crop *k* should not should not exceed monthly wastewater supply (*WWS*). It implies that, without supplementary irrigation monthly crop water requirements should be equal to or less than total amount of wastewater available in any month.

4. Water requirement constraint

$$\sum_{k=1}^{K} Inch_{ktm} A_{ktm} - WWS_{tm} = CWS_{tm}$$

Total amount of water available in a particular month *m* equals to wastewater supply (*WSS*) and canal (and tubewell) water supply (*CWS*). If water crop water requirements fall short of total water supply in a particular month, surplus canal water may be sold to other farmers

5. Non negativity constraints

$A_{kt} > 0$, and

$WWS_t > 0$

Form an intertemporal perspective, the objective function of farmer would be to maximize net present value of returns over the planning horizon (say 5-10 years, depending upon cropping pattern). Thus, the optimization model becomes:

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[20] With wastewater irrigation, it is often recommended that crop phosphorous requirements should be satisfied frits.

$$Max\ z = \sum_{t=1}^{T} NR_t \ (1+i)^{-t}$$

Where:

z represents present value of net returns at farm level

i is social discount rate (varies from 5 to 10 percent for agricultural development projects).

Analyzing Externality Effects

The wastewater irrigation has externality benefits and costs as explained elsewhere in this report. After incorporating total externality benefits (*TEB*) and total externality costs (*TEC*) the above model becomes:

Max

$$Z = \sum_{t=1}^{T} NR_t \ (1+i)^{-t} + \sum_{t}^{all} TEB_t \ (WWS_t) \ (1+i)^{-t} + \sum_{t}^{all} TEC_t (WWS_t) \ (1+i)^{-t}$$

Where

t refers to time period and its upper limit *all* refers to all future periods over which externality benefits and costs of wastewater irrigation can be exacted. The upper limit is unspecified as it varies for every cost and benefit item.

The intemporal holistic model states that discounted over all benefit (Z) is determined by the level of on-farm net returns and off-farm external benefits and costs. And total external benefits are a function of wastewater supply used for crop irrigation.

The major externality benefit of wastewater irrigation is groundwater recharge and its associated ecosystem services. The groundwater recharge benefit can be estimated using information on wastewater supply, leaching fraction (*LF*) and shadow price of water (*SP*) per acre inch such that:

$$\sum_{t}^{all} TEB_t = \sum_{t}^{all} WSS_t \, LF_t \, SP_t$$

The taxonomy of externality costs and their estimation is given in Table 2 below.

Table 3:

Taxonomy of External Costs of Wastewater Irrigation and Their Valuation

Cost item	Proxy	Model	Description
Regional Impacts			
Wastewater diseases Morbidity	WTP	$\sum_{nt}^{popT} Ploss_t + \sum_{n}^{popT} WTP_t$	Morbidity related cost is a function of productivity loss and willingness to pay for avoiding inconvenience (sleep and leisure loss etc) for n^{th} person estimated over entire population (*pop*) size
Mortality	Value of life	$\sum_{nt}^{popT} VL_t R_t$	Mortality related cost is defined by the value of life (*VL*) and risk of death from wastewater borne illness ®
Salinity etc	Cost of soil reclamation	$\sum_{t}^{all} C\,\mathrm{Re}\,c_t\, A_t (WSS_t)$	Salinity related damage is determined by cost of soil reclamation measures (*CRec*) and area irrigated with wastewater supply (*WSS*)
Property values	Property value differential	$\sum_{tn}^{allN} Dif_{tn}\, Mpp_{tn}$	Property value loss is equal to the differential in the value of n^{th} property (*Dif*) and median property value (*MPP*) for affected properties (*N*) over *all* future periods
Social impacts	Cost of adult education and insurance premium	$\sum_{t}^{all} Edu_t (pop) + \sum_{tn}^{allN} Ipr_t$	The cost of social impacts is equal to the cost of adult education programs, as a function of population size, plus the cost of insurance premium (*Ipr*) paid to avert agribusiness risk
Nitrate pollution	Value of life and loss of earnings approach	$\sum_{nt}^{popT} VL_t\, Cmr_t\, Rn_t (LFn)$	Nitrate pollution related health cost can be approximated by using value of life, child mortality rate (*Cmr*) and nitrate pollution related mortality risk factor (*Rn*) as function of nitrate leaching fraction (*LFn*)
Ecosystem Impacts			
Fisheries loss	Productivity loss approach	$\sum_{t}^{all} Flos_t (LFn_t, (WWn$	Fisheries loss (*Flos*) is affected by nitrogen leaching fraction and wastewater nitrogen (*WWn*) and wastewater nitrogen is an implicit function of wastewater supply (*WSS*) A damage function extrapolated over the size of fisheries may be an alternative approach
Biodiversity loss	WTP	$\sum_{nt}^{N,all} WTP_t\, (BI_t)$	Biodiversity loss can be estimated from willingness to pay (WTP) which is implicitly determined by predicted change in biodiversity index (*BI*)

Among the externality benefits, groundwater recharge can be considered as a regional impact as well as ecosystem impact. Similarly, the effects of nitrate pollution are manifolds and affect various parties simultaneously. As the fine line between effects of wastewater irrigation does not exist, their classification into regional impacts and ecosystem impacts is arbitrary only. However, above taxonomy is useful as it facilitates economic valuation.

Other Decision Tools

Recently researchers have used physically conservation models (Crane, 1996) and entropy change models (Fernandezzed, 1997) to evaluate the impacts of environmental change, however, time and resource constraints do not permit their inclusion in this report.

6. DATA REQUIREMENTS AND PROBLEMS AREAS

Using Benefit Transfer Protocol

There are two main approaches to deriving the environmental values for a given program or policy such as wastewater irrigation. These approaches are: (1) benefit transfer, (2) site specific valuation study. As a detailed site specific environmental valuation using market based or non market based valuation techniques can be expensive and time consuming, benefit transfer method can be used as an alternative.

Box 1

Some site specific and relevant studies are:

- Chaudhary and Hanjra (1992) analyzing monthly healthcare expenditure on treatment of waterborne diseases in urban Faisalabad;
- Altaf (1993) focusing on consumers willingness to pay for water supply in rural areas of Faisalabad;
- Hanjra and Hanjra (1995) reporting willingness to pay for safe drinking water in Faisalabad city;
- Hanjra and Hanjra (1994) measuring human productivity loss due to waterborne diseases in Faisalabad city; and
- Hanjra (1996) reporting leisure and sleep disturbances and schooling loss due to waterborne sickness in Faisalabad.

Studies specifically focusing on wastewater pollution are:

- Hussain and Hanjra and Hussain (1993) reporting the compliance of industrial discharges to national environmental quality standards and their impact on groundwater quality in Faisalabad city; and
- Hanjra (1999) the only supply side study, presenting a cost benefit analysis of treatment of textile effluents to agricultural reuse standards and its policy implications, for Pakistan.

Under benefit transfer protocol, values derived from site specific studies are transposed to other site or situations exhibiting similar attributes. As there is no paucity of site specific studies (though there is a paucity of content specific studies (see Box 2)., two alternatives for our environmental valuation to proceed are:

1. to develop a framework based on existing data to help generate crude indicators of economic value

2. to conduct a range of site specific and content specific studies to fill the gaps in existing data and thus to allow a comprehensive valuation of holistic impacts of wastewater irrigation.

With these options in mind, the existing and required data resources are identified below.

Data Resources

Existing Data Resources

Site specific existing data resources are:

- WTP for water supply (Altaf, 1993, Hanjra and Hanjra, 1995)

- Wastewater treatment costs data (Hanjra, 1999), and

- Secondary data resources such as: Population Census, Health statistics, Agricultural Statistics, Economic Survey, Faisalabad Municipal Corporation, Local EPA data set on industrial effluents quality, Revenue Department, and Canal Department etc.

- ***UAF Data Base***: Department of Farm Management, University of Agriculture, Faisalabad has a Pakistan vide extensive data set on yields, inputs, and outputs of agricultural and livestock products.

Required Data Resources

Further site specific data can be collected through a specially commissioned survey and opinion pools.

Survey Data

- the specifics of the variables to be included in the survey are given Appendix 2.

Opinion Pools

- Expert opinion regarding the extent of salinity and water logging and its effect on land values and crop yields

- Survey of risk screening for exposure to wastewater

- Expert consultations with agri. scientists, health specialists, and opinion leaders to facilitate the estimation of off-farm effects and their costs

Data Analysis and Policy Results

The data can be analyzed within the valuation framework described above. Some *additional* estimations may include (suggestion only):

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

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

- *Input demand changes*: fertilizer, farmyard manure, green manure, other fertility enhancement measures such as EM technology, traditional and high yielding verities, water, mechanization, agricultural credit, on farm and off farm labor, extension services etc.

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

- *Degree of structural change*: endowment of capital, labor, and material, farm size, operational size holding (leasing in and out), plot size, mechanization, labor input, crop varieties, capital deepening or labor deepening change, agri credit, water use efficiency

- *Income changes*: on farm and off farm employment, resource rents, savings, investments, and credits

- *Welfare changes*: consumption pattern, lifestyle, human capital formation, income levels, income distribution, social standing, community welfare roles, institutional changes,

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

Problem Areas

In addition to the general issues in the use of valuation measures, additional problems may arise in wastewater epidemiology, mortality, and morbidity risk assessment. The use of human capital approach may be problematic where the cause and effect relationship between the disease and wastewater irrigation in not known or sickness is of long duration.

Market imperfections may affect resource prices (water; fertilizer, green manure, animal dung), wages (disguised and open unemployment, value of life), capital costs (market rate and inflation). Unstable legal and institutional framework may reinforce these effects.

The simulation of environmental and ecological impacts may be another area of potential difficulty. Additional valuation difficulties may include treatment of risk and uncertainty (population size, selection of social discount rate (low WTP, high market rates and inflation implying high discount rates and hence very high time preference rates due to erodability of incomes), and the selection of a common discount period.

Despite all these difficulties and shortcomings the utility of this methodological 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 measured with a common monetary yardstick.

A question arises, would an alternative methodology be more helpful for decision making? Certainly, given the time constraint (this methodology was developed in less than four weeks!) the development of a significantly superior valuation methodology seems an impossible task. However, the experience gained in the development of this methodology and its subsequent implementation will pave the way for a more sophisticated and super valuation methodology in near future.

APPENDIX 1

Demand Revealing Mechanism

Continuing with our model on *discrete public good*, suppose that G is either 1 or zero, r_i is agent i's reservation price and s_i is his cost share. If public good costs c to provide, then $s_i c$ is the total amount of money that agent i must pay if the public good is provided. Agent *i's* net value for the public good is: $v_i = r_i - s_i c$ and it is efficient to provide the public good if:

$$\sum_i v_i = \sum_i (r_i - s_i c) > 0$$

Rule: Ask each agent to report his net value and provide the public good if the sum of these reported values is non negative.

However, a scheme like this lacks incentive for the agents to reveal their true WTP. The agent might report (false) as large as possible value to enjoy the public good since it does not commit him to any payment. In order to induce each agent to truthfully reveal his true value, let:

- each agent report a bid b_i, (may or may not be his true bid);
- don't provide the public good if $\sum_i b_i < 0$;
- provide public good if $\sum_i b_i > 0$;
- make side payment equal to the sum of other bids ($\sum_{j \neq i} b_j$). If this sum is negative agent pays this amount, but if the sum is positive he receives it (incentive).

Truth telling is dominant strategy i.e., reporting $b_i = v_i$ regardless of what the other agents report.

Payoff to agent i= $\begin{matrix} \left\{ v_i + \sum_{j \neq i} b_j \text{ if } b_i + \sum_{j \neq i} b_j \geq 0 \right\} \\ \left\{ 0 \text{ if } \; b_i + \sum_{j \neq i} b_j < 0 \right\} \end{matrix}$

Suppose that $\sum_{j \neq i} b_j > 0$, then agent i can ensure that public good is provided by reporting his true bid. If $\sum_{j \neq i} b_j < 0$, agent i can ensure that public good is not provided by reporting $b_i = v_i$ As the information gathering mechanism had been modified the agent faces the social decision problem, rather than individual decision problem, and thus each agent has an incentive to reveal his preferences correctly. As with such preference revelation mechanisms the side payments to be made are very large, it is useful to design a mechanism where the sidepayments are non positive such that the agent is required to pay a tax for misreporting but never subsidized. The tax

that agent *i* must pay to change the amount of the public good equals to the harm (pollution) he imposes on the other agents (society).

In case of a *continuous supply of public good*, if *G* units are to be provided then agent *i*'s utility function is:

$$v_i(G) = U_i(G) - s_i G$$

Where $v_i(G)$ is quasilinear utility function (asked to reveal) for the public good and $s_i G$ is the cost share. The Government undertakes to provide a level of public good, G^*, that maximizes the sum of reported functions b_i. Each agent gets a side payment of $\sum_{j \neq i} b_j(G^*)$. Thus agent attempts to maximizes $v_i(G\ ) + \sum_{j \neq i} b_j(G\ )$, while the Government will maximize $\sum_{j \neq i} b_j(G^*)$.

Thus by reporting the true values i.e., $b_i\ (G) = v_i\ (G)$, the agent ensures that the Government will choose a G^* that maximizes agent's utility. However, sidepayments are very large. These can be reduced by choosing a side payment of negative $\max_G \sum_{j \neq i} b_j(G^*)$. This gives the agent a net utility of

$v_i(G) \sum_{j \neq i} b_i(G) - \max_G \sum_{j \neq i} b_j(G\ )$. Again the agent *i* is taxed by the amount it changes social welfare.

Appendix 2

Variables to be Included in Survey Instruments for the Valuation of Environmental Impacts of Wastewater Irrigation in Faisalabad Division, Pakistan

***Village level data*:**

On variables such as health care, schools, post office, bank, community education, water rates, labor rates, land rent and lease, systems of land tenure and arrangements, government rates and charges, and other levy

***Farm level data*:**

- Demographic information: (family size, ages, gender, education, dwellings, entertainment)

- Access to water supply (hand pump, well, canal, piped water)

- Source of irrigation water (canal, tubewell, wastewater)

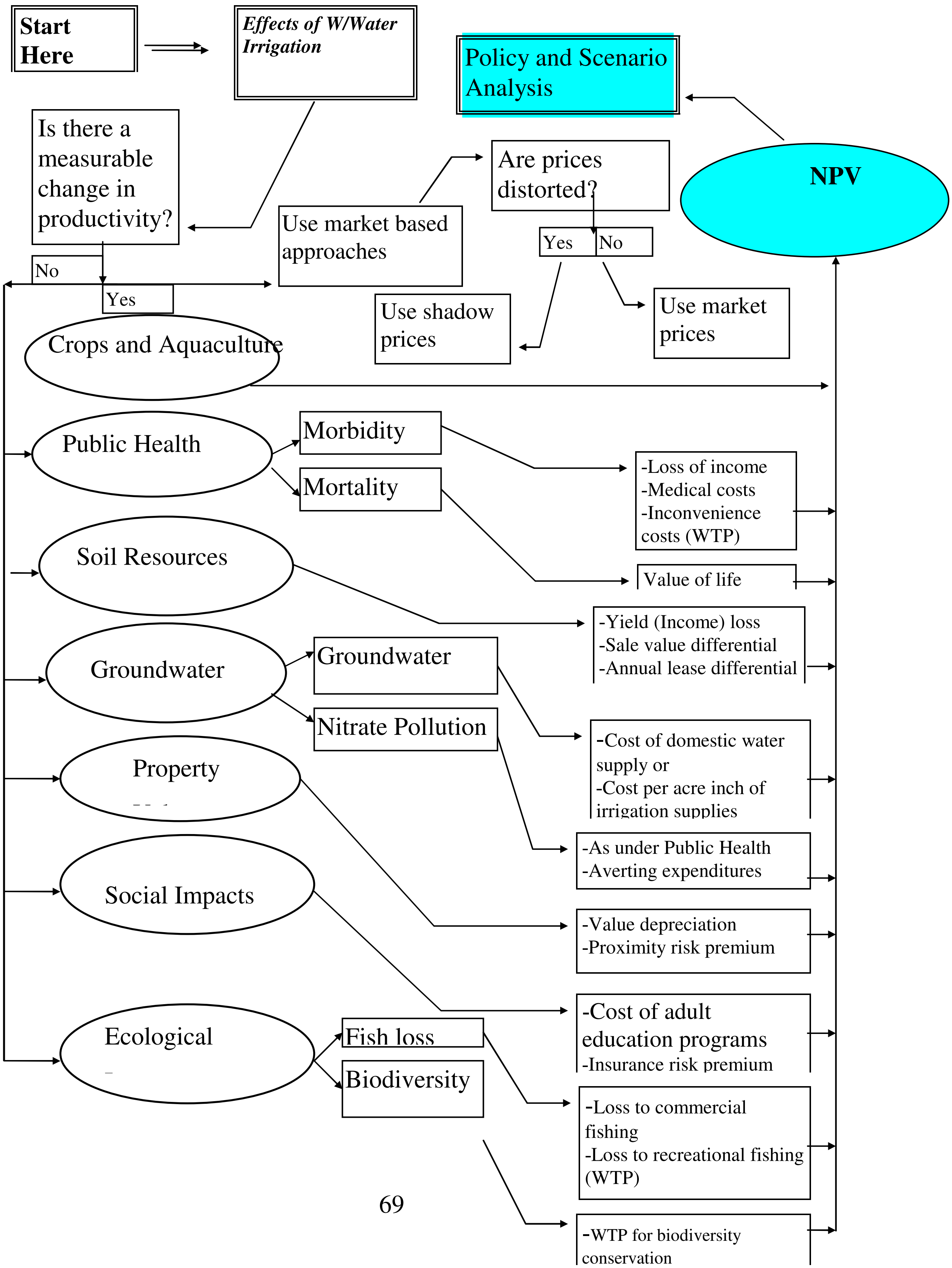
- Health statistics (age groups, morbidity, treatment cost (doctor visits, transportation cost, medication), preventive expenditure, work (and schooling) days lost, inconvenience cost (leisure and sleep disturbances)

- Employment, land tenure and land use, farm location (main population center, input market, output markets, civic facilities -school, hospital, mosque, post office, bank, chemist, doctor)

- Resource endowments (tubewell, tractor, bullocks, cart, livestock, agro forestry), farm finance, crops, area allocation, seed rate,

- Water use and types, fertilizer and manure use, chemical use, yield, farming operations (land preparation: seed bed preparation; and sowing (poughings, plankings), interculture, harvest, processing, transportation, rates and prices, agri machinery stock, payment to artisans, water rates etc

Appendix Figure 1: A Framework for Analyzing the Environmental Impacts of Wastewater Irrigation and their Valuation



Literature Cited

To be sorted/finalized later depending on the final format.

For an extended list of bibliographical references, please see:

Hanjra, M. A. (2000) *Socio-Economic Aspects of Wastewater Use in Agriculture: A Bibliography*. Unpublished report. International Water Management Institute, Colombo, Sri Lanka

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