The Economic and Environmental Factors of Water in Arid Regions: Study of the Rural Water Use in Northern Darfur Region, Sudan

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1. Introduction

We develop hypothetical policy scenarios in this part of the paper which are simulated using a product-by-industry economic-ecological model to investigate their impacts on water and other ecological commodities. Results are expected to contribute to the establishment of alternative policy options for water resources management and sustainable economic development in the area. The impact of economic development on the environment is now a global issue and cannot be ignored. However, the extent of these impacts at local and regional levels in less developed countries (LDCs) is not fully understood. Unlike the rich industrialized countries where development is large-scale and the impacts associated with immense consumption of fossil fuels are basically in the form of environmental pollution, development in the LDCs is rather at a small-scale and the nature of impacts is often in the form of severe resource depletion (World Bank, 1992; Lesser, et al., 1997). Therefore, the challenge of sustainable development in these poor countries is an urgent matter of concern (WRI, 1992). This concern can be investigated from two perspectives, economic development and environmental degradation.

Unfortunately, the advancement of environmental economics and its associated discourse on sustainable development have not resolved the links between long-term Sustainable development is considered here to encompass economic, human, environmental, and technological dimensions as defined in WRI (1992) on economic growth and environmental quality. The two schools of thought, that environmental degradation is a necessary outcome of economic growth and that economic growth and environmental quality go together, are still being debated (Antle and Heidebrink, 1995). Thus, one of the strident areas of environmental policy debate continues to be the basic relationship between economic growth and environmental quality (Lesser et al, 1997). According to Ruddle and Rondinelli (1983) a more accurate and increasing conclusion about economic development in relation to conservation of the natural environment is that some development policies are indeed detrimental to environmental quality and natural resources, but others have created opportunities for large numbers of people to improve their levels of living in ways that are compatible with, comparable to, or capable of enhancing the natural resource base. The form development takes, and the way policies are designed and carried out or implemented, determine the effects on a country's natural resource system. Many development policies have neither benefited the rural peasants nor ameliorated the menace of environmental degradation. Therefore, there is the need to introduce better economic development policies that will not only improve the lots of the rural poor but also reduce environmental degradation and ensure sustainability. Economic development policies in the rural areas of LDCs center on agriculture. The agricultural sector is fundamental is central because it still employs more than 75% of the population (Dabi and Anderson, 1998a; 1998b). Consequently, countries like Sudan have emphasized the agricultural sector as a stimulant to rural economic growth over the past four decades. Most of the strategies adopted however, were not very successful. Therefore, present day policymakers are trying to take advantage of the lessons learned from the failures of the past (Eicher and Staatz, 1991).

An analysis of several hypothetical policy approaches is conducted toward local economic development and sustainable water and resource management in drought prone areas with particular reference to agriculture. A case study village in northern Sudan was selected for this study. These policy approaches represent development scenarios drawn from the literature for the area and others with similar environmental and human characteristics as well as empirical results from previous work. Each hypothetical approach is formulated as a scenario and simulated using a product-by-industry economic-ecological model to see the impact associated with such changes. Proposed changes in the structure of production are presented as exogenous final demand. Proposed changes in technology and water conservation are presented reflected by changes in technical coefficients. The results provide a measure of policy impacts as possible. Water use changes and the associated impacts on the economy and the environment are taken into consideration.

2. The Study Area

Our case studies have been centered on a selected drought-inflicted village, Kutum in Northern Darfur State, Sudan. This village is located within the arid zone of Western Sudan. It experiences similar environmental conditions as the rest of the Sahel region of sub-Sahara Africa. Droughts, water scarcity, and the threats of desertification are inherent. Rainfall is limited to four months of the year with annual amounts ranging between 200 and 300 mm. Stream flow and other surface water sources fed by the rainfall are seasonal, suffering from the menace of excessive evaporative demand and siltation. Groundwater are accessed by wells, deep and shallow from the extensive sedimentary Formation which is recharged by the seasonal surface flow and is rather declining. Groundwater serves as the major source of water in the region with its undulating terrain covered mostly by Sudan savanna-type vegetation. That is basically patchy grasses and scrub as well as scattered acacia and baobab tree species upon which the inhabitants derive food, fuel and construction material. The major economic activities in the village as the rest of the region include agriculture, e.g., rain fed, small-scale irrigation, animal husbandry, rural industrial production, e.g., small-scale manufacturing of goods, food processing and handicrafts as well as trade and services transacted mostly within the local economy. The village economy is a combination of subsistence and market activities with limited external linkages. Each household produces agricultural commodities for both intermediate and final demand. The village, as in most rural areas in this region, lacks urban infrastructures and facilities such as piped water and electricity with government policies and assistance rather unfavorable. Therefore, there is heavy dependence on traditional heritage, nature and environmental resources. Water procurement, delivery and processing for economic and domestic activities also depend on traditional initiatives and to a smaller extent, introduced technologies. These often have adverse repercussions on water use and conservation in particular, and the environment at large (Dabi, 1998; Dabi and Anderson, 1998b.)

The main objective here is to assess how alternative development scenarios affect the use of ecological commodities, especially water, in the local economy of Kutum village. In other words, to determine the impacts, on the economy and environment, in terms of production and water use and to develop policy measures aimed at managing the water resources of the area for sustainable agriculture and economic development. This requires a model that can express these scenarios in terms of exogenous changes in final demand - principally representing production of commodities for sale in markets outside the village. Basically, there are three approaches to economic impact analysis for any given region, viz.: the economic base (EB) methodology, input-output (**I-O**) methodology, and Keynesian income expenditure theory (Mulligan, 1994; Hughes, 1997). Both EB and **I-O** methodologies consider the region as consisting of different disaggregate sectors. Interactions between these sectors are analyzed in order to measure the total impact of activity in one or more of these sectors on the region. For the purpose of this study, we have employed the **I-O** methodology because it has sectoral detail and has the ability to show different multipliers for the different industries, through desegregation (Trey z, 1993). This allows us to define accurate coefficients for the use of ecological commodities on a sector-by-sector or industry by-industry bases. **I-O** models are used at the national, regional or local level to identify the effects of changes in deliveries to final demand on aggregate gross output, incomes, and employment. They provide an integrated framework for assessing the impacts of increased final demand from one economic sector or industry on all other sectors or industries. Changes in final demand are treated as exogenous, and their total impacts, direct and indirect are endogenous (Miller and Blair, 1985; Hastings and Brucker, 1993; Sadoulet and de Janvry, 1995).

3. The Application of I-O models

A more exhaustive model for regional impact evaluation requires the inclusion of the environmental sector which takes into account flows of no marketable materials into and out of the economic sector. Such flows, expressed in units of weight, may be treated in much the same manner as economic inputs and outputs in the standard **I-O** model (Johnson and Bennett, 1981). The traditional **I-O** model developed by Leontief (1970) has been extended to accommodate these environmental concerns, linking the environment and the economy.

There are three categories of environmental extensions of the **I-O** model. The first, degradation generation-elimination model was developed by Cumberland (1966). The model was an extension of the rows and columns of the traditional **I-0** accounting framework to include environmental concerns, in the form of an interregional model (IRIO). Daly (1968) led the way with the category, economic-ecological models employing a highly aggregated industry-by-industry characterization of the economic sub-matrix and a classification of ecosystem processes. Isard (1968) also contributed to this category using a product-by-industry accounting scheme in his model which recognizes secondary production and accounts for multiple economic and ecological commodities. The last, environmental product-by-industry model, was first developed by Victor (1972), who limited the scope of his used model to account only for flows of ecological commodities from the environment into the economy and of the waste products from the economy into the environment in two sub-matrices, the Economic and Ecological subsystems. The sets of extensions have their successes and failures and in various applications; most of which have been to analyze the impacts of policy scenarios with particular reference to air and water pollution (Huang et al, 1994).

Huang et al (1994), developed a product-by-industry input-output model for regional solid-waste management. The model improved on the product-by-industry work of Victor (1972) by introducing an environmental policy initiative composing of waste recycling, reuse and reduction activities (3R), reflecting economic and environmental effects. It also improved on the work of Johnson and Bennett (1981) by introducing a regional solid-waste management area to

analyze using hypothetical data, the relationships between economic development and regional solid-waste management alternatives. Such a model is useful for identifying waste sources, their generation rates, as well as their environmental impacts corresponding to the different industries, environmental policies and regional economic development alternatives. More were revealed on the earlier extensions of the **I-O** model (Johnson and Bennett 1981); (Miller and Blair 1985); (Lonergan and Cocklin 1985); (Huang et at 1994); (Dabi and Anderson 1998c). Most applications of these extensions are basically suitable for developed economies characterized with highly integrated industrial complexes accompanied by immense environmental and air pollution, but they are less appropriate for rural areas of less developed countries, where production is done in small-scale local industries with relatively less environmental degradation discharge. The pressing problem in these rural areas is scarcity of environmental resources and associated degradation. Therefore, a more desirable model will be one that captures the use of scarce environmental resources in the economy, properly accounts for the depletion of these resources by the economy or the interdependence between the economy and the environment resources and ascertains impacts associated with such interactions.

If we simulate the impacts of development scenarios and water use on the economy and environment using estimates from a product-by-industry economic-ecological model (PICEEM) applied to the study village (Dabi and Anderson, 1998c). This approach is consistent with Giarratani and Garhart's (1991) observation that computer simulated models can be an appropriate and effective means of evaluating particular aspects of regional **I-O** analysis. This can be done in either of two ways (i) changes to an existing **I-O** model, either deterministically, by substitution or changing certain parameters arbitrarily or (ii) computer generated I-0 model components, either by actual observation or otherwise. We use the first approach by making hypothetical changes to the final demand category and changes in water input as an ecological commodity component of the model as described in the development and water use scenarios below. This will reveal some of the critical commodities that may impact on the village economy and its environment. We are more interested in the applicability and potential insights of the model than its predictive power.

4. Methodology

The categorization of all village activities as a set of interrelated industries producing a larger set of commodities for which input-output relations can be measured to allows us to adopt the product-by-industry economic-ecological model (CMEM). Industries are groups of firms or households, for example, rain fed agriculture and labor that produce goods or services for intermediate or final demand. Commodities are the individual products of the industries, for example sorghum and paid farm labor. Each industry produces one or more commodities. In principle the same commodity can be produced by more than one industry, for example Sorghum can be produced by both rain fed and irrigated agriculture. Economic commodities are traded in the local economy usually in monetary terms. Ecological commodities are no marketable quantities of goods extracted directly from the environment as inputs to an industry production process, for example, water, land and vegetation or as outputs generated by a production process, for example wastewater discharged back to the environment (Miller and Blair, 1985; Dabi and Anderson, 1998b; 1998c). When using the product-by-industry characterization for impact analysis or forecasting the following relationships are used:

$$Q = (I - BD)^{-1} E \qquad (6.1)$$

where Q is a column vector (m x 1) of commodity output (production); I is the m x m identity matrix, $B=[b_{ij}]$ is the matrix (m x n) of economic commodity-by-industry direct requirements, [b_{ij} is the amount of economic commodity i required to produce a unit output of industry j]; $D=[d_{ij}]$ is commodity output proportions (n x m). Therefore, $(I - BD)^{-1}$ is the commodity-by-commodity total requirements matrix (m x m), analogous to the Leontief inverse $(I - A)^{-1}$. Its entries are called the interdependency coefficients that represent the direct and indirect requirements. $E = [E_i]$ is a column vector (m x 1) of commodity deliveries to final demand.

In a similar fashion, output can be defined at the industry level as:

$$X = [(I - DB)^{-1}] Y \qquad (6.2)$$

where X is a vector (n x 1) of industry total outputs, $[(I - DB)^{-1}]$ is the industry-by-industry

Total requirements matrix (n x n); the component D and B are as defined in equation (6.1); and Y is a vector (n x 1) of industry deliveries to final demand, Y = DE (industry final demand is a product of commodity output proportions (D) and commodity final demand (E). We have adopted this relationship for our study by aggregating the changes in commodity production into their respective industries.

Because we were unable to obtain data on quantities of the ecological commodities used for the production of individual economic commodities, especially when more than one commodity is produced, we have based the use of water and other ecological commodities on industry output (Y) instead of commodity output (E). However we expect that this procedure will have little or no impact on the accuracy of our calculations. Thus, the ecological commodity input total requirements are as follows:

$$G^* = [G(I-DB)^{-1}]\ Y \qquad (6.3)$$

where G* is a vector (e x I) of total (direct and indirect) ecological commodity inputs required for the production of economic outputs, G is the matrix (e x n) of ecological commodity input coefficients, e is the number of ecological commodity inputs. The elements of (I-DB)' and Y are as defined in equation (6.2). The ecological commodity output total requirements are given by:

$$F^* = [F(I-DB)^{-1}]\ Y \qquad (6.4)$$

where F* is also a vector (e x 1) the of total (direct and indirect) requirements matrix of ecological commodity outputs produced due to economic commodity production, and F is the matrix (e x n) of ecological commodity direct output coefficients, e also represents the number of ecological commodity outputs. The notations (1-DB)' and Y are as defined in (6.2) above.

To facilitate our simulations, changes were made to either the final demand category of the model equations or the water input requirement components. For changes in the final demand category, the following sets of relationships are used:

$$\Delta X = [(I - DB)^{-1}]\ \Delta Y \qquad (6.5)$$

where ΔX is a vector of new industry output following the change in the final demand category AY used for the simulation. [(I - DB)''] is as defined above;

$$\Delta G^* = [G(I-DB)^{-1}]\ \Delta Y \qquad (6.6)$$

where AG* is a vector of new ecological commodity total (direct and indirect) inputs required`to meet the change in final demand AY used for the simulation. G is as defined in equation (6.3) and [(1- DB)''] as defined earlier in equation (6.2) above.

Then

$$\Delta F^* = [F(I-DB)^{-1}]\ \Delta Y \qquad (6.7)$$

where AF* is a vector of new ecological commodity total (direct and indirect) outputs produced following a change in the final demand Y. F is as defined in equation (6.4), and (l-DB)'' also as defined in equation (6.2) above. Whereas for the change in the water input requirement, we have the following relationship:

$$\Delta G^* = [\Delta G(I-DB)^{-1}]\ Y \qquad (6.8)$$

where AG* is a vector of new ecological commodity total (direct and indirect) inputs required following the change in water input requirement AG, G and [(I-DB)''] are as defined earlier.

The final demand category Y is unchanged, that is, the industry final demand described in equation (6.2).

5. Data and Simulation Procedure

Data used here are based on two field surveys conducted in Kutum Village, e.g., a survey of all households to obtain basic population and activity data and the second a sample survey to obtain more detailed economic and environmental (ecological) information. A complete description of data collection is found in Dabi and Anderson (1998b). Data generated have been used were developed and applied a product-by-industry economic-ecological model (CTEEM) that accounts for the direct and indirect use of water in the village. Data for the simulation is based on the results, with information on local initiatives indigenous knowledge systems and technologies for water use and conservation in the village (Dabi, 1998). The secondary information is based on development policy issues in the region, from relevant literature (for example, Eicher and Staatz, 1990; FA1, Sudan, 1991).

The first set of scenarios is based on changes in the structure of production represented by adjusting the exogenous final demand. The hypothesis here is that an increase in output of certain export commodities will lead to a corresponding increase in the quantity reserved for sale to external (exogenous) markets. It is expected that income generated from such an activity will improve the economic base of the village and consequently, the welfare of its people as they invest further. However, the model will enable us to determine the impact on other sectors of the economy and environment (particularly, water) associated with such changes. A 10 percent increase in final demand for the corresponding commodities is used to establish three sub-scenarios to investigate the resultant changes. The commodities used for these simulations have been reflected as increases in their respective industries to establish the changes in industry output. Scenario (la) uses information given by households to increase the final demand of selected commodities. These are combinations of traditional and introduced agricultural commodities (crops) and handicrafts of which most households indicated willingness to increase their production. Households were asked to list, in order of preference, commodities they are willing to produce more of. The following were identified: groundnuts (pea nuts), cotton, rice, wheat, sheep, goats, calabashes and a variety of handicrafts.

Scenario (1 b) uses information generated from the agriculture and rural development policies in Sudan to increase the final demand on national cash crops (commodities). The national cash crops considered here are those contained in the Sudan agricultural development plans since independence. The production of these crops was promoted by government institutions and agricultural research and extension workers (Eicher and Staatz, 1990). In our study village these crops include groundnuts (peanuts), cotton, rice, wheat and cattle. Scenario (1 c) uses information from our earlier work that established the income generation from commodity production in Kutum village (Dabi and Anderson, I998b) to increase the final demand of 'strategic cash commodities, ' crops that generate more income per head to the farmers engaged in their production. These commodities include groundnuts (peanuts), beans (cow peas), Millet vegetables (irrigated), sheep and goats.

The differences between these sub-scenarios are that scenario (l a) includes sheep, goats, calabashes and handicrafts in addition to major cash crops, groundnuts, cotton, rice and wheat. Scenario (lb) is similar to (1 a) except that it added only cattle, which is absent in (I a), to the major cash crops. Scenario (1 c) is also similar to (la) but the difference between them is that, scenario (I c) excludes all the major cash crops but groundnuts, excludes calabashes and handicrafts, and instead, added three other crops: beans, Millet and irrigated vegetables.

Based on the above scenarios, changes in total output to meet these new final demands were established by multiplying the change in the final demand category with the industry-by-industry inverse matrix (technical coefficients) already calculated. The differences between these 'new' total outputs and the initial (observed) total output were also determined. The corresponding income generated was calculated by multiplying the new total output with the unit price for each commodity and aggregated for each industry. For the ecological input and output categories, the same method was adopted but the changes were established by subtracting the initial total input or output, as the case may be, from the corresponding new total input or output respectively. A simulation of all three scenarios combined (a maximum of 10% increase in any commodity changed in the three scenarios to form a new final demand category) was also done to determine total groundwater use should all the changes be implemented, and the percentage increase from the initial total groundwater withdrawal determined. Finally, ecological commodity inputs and outputs to income ratios were calculated to observe the intensity of ecological commodity use and production. These intensity values are useful for purposes of comparison among the three sub-scenarios.

The second set of policy scenarios relates to water use efficiency based on technology and water conservation strategies drawn in other relevant literature (Eicher and Stutz, 1990) as indicated above. These scenarios are represented as changes in technical coefficients (water requirements for commodity production) as well as in the final demand of the model. Traditionally the model uses coefficients as 'constants' but it is possible to change the ecological commodity coefficients. Income is used here as a measure of `development' and to serve as a common denominator rather than output which was measured in different physical units in this model. We have therefore changed the water input coefficients to enable us to observe the possible effects on production and water demand. A simulation of these changes reveals the possible impacts on the economy and environment. For Kutum village and the rest of the region, water conservation is perhaps feasible through either or a combination of three approaches which have been developed into three other sub-scenarios as follows:

Scenario (2a) is based on water application efficiency by adopting new farming strategies (technologies) that will reduce the quantity of water used for irrigation.'' Although some of' most efficient' (introduced) irrigation water application techniques used have proved to be inappropriate due to their sophistication as well as the high purchase and maintenance cost, the indigenous (traditional) plant-to-plant method is perhaps a better option for this village and others in the region (Dabi, 1998). The use of this traditional technique will reduce the quantity of irrigation water by at least 10% even though it cannot achieve the 30% efficiency claimed for the introduced types. However, labor requirements will be affected, but income generation may remain the same since the same quantities of commodities are produced. Therefore, a l0% reduction in the groundwater requirement per kg in the irrigated is made, but there is no change in the final demand and all other input requirements are expected to remain the same. The total groundwater saved will be determined by the model.

Scenario (2b) represents elimination or transfer of hydrophytes (water-loving) crops. Earlier studies have indicated that water application efficiencies, using especially subsurface irrigation methods, can reduce the quantity of water used by between 30-90% with an average of less than 50%. Water application efficiency refers to the quantity of water required to grow a plant to maturity (Criddle and Haise, 1957; Bertrand, 1965).

That uses more groundwater per unit of output, from the irrigation industry. For example, rice and wheat consume about 13% of the irrigation water in the village (Dabi and Anderson, 1998b). Irrigated rice can be conveniently cultivated as a rain fed crop. Such an adjustment will take advantage of the rainfall but will require additional labor during the rainy season which can be met through communal effort. However, it will reduce the demand for groundwater and labor by the irrigated agriculture during the dry season. Therefore, the final demand category of rice and wheat are eliminated from irrigated agriculture industry and cultivation of rain fed rice increased to meet the same final demand. It is expected that some percentage of groundwater use for irrigation will be conserved in the process and all other inputs will be affected as revealed by the model.

Scenario (2c) represents shifting or rescheduling of rural industry activities (especially, building, brick making and pottery) to depend on rainwater harvested from rooftops and mini-catchments areas or surface water and stream flow collection into surface or groundwater dams (see Pacey and Cullis, 1986). With this adjustment, water and other input requirements as well as income will remain basically the same. However, labor input requirements will increase during the rainy season but groundwater will be conserved and the labor problem can be solved through communal effort (Dabi, 1998). Therefore, there will be an elimination of groundwater requirement in the rural industry, there will be no change in the final demand, all other input requirements will remain the same, and the total quantity of groundwater conserved in the process will be determined by the model. This will be represented by a change in groundwater input requirement in the respective industries to zero. The analysis of these new scenarios is based on changes in the values of the groundwater input requirements for commodity production for scenarios (2a) and (2c). For scenario (2b), there was a change in final demand in addition to the change in groundwater input The new values are multiplied by the corresponding commodity or industry output to determine the new direct and total groundwater requirements and the new industry output for scenario (2b). A simulation of all three scenarios combined (a summation of all three changes, since there are no repetitions in the different scenarios) was also done to determine the total groundwater used should all the changes be implemented, and the percentage decrease from the initial total groundwater withdrawal determined.

Finally, ecological commodity use and production intensities were also calculated to facilitate the comparison among the three sub-scenarios. Both sets of policy scenarios are based on possible options available for the sustainable development of this rural village as well as others in the region. Results will enhance our understanding of these economy-environment relationships.

6. Results and Discussions

The model we have used here allows calculations in physical units making it suitable for application in this village where some of the commodities, especially ecological commodities, do not have monetary values. However, this leaves us with the problem of interpreting the results, especially making comparisons between the different scenarios. It is even worse or probably impossible to compare items measured in different physical units. It is also very unclear how to compare scenarios of different magnitudes developed for this economy. The ecological commodity use and production intensity measures (ratios) described earlier, however, prove useful for making direct comparisons between scenarios.

Simulation results from the two sets of scenarios gave `new' commodity and industry outputs which were subtracted from the corresponding initial (observed) values to establish the implied changes (differences). These changes and the intensity values have been tabulated for easier assessment. Table 6.1 shows the changes in industry production and income generation for first set of scenarios. Comparing among the sub-scenarios for raided agriculture, as an example, scenario (lc) has the highest increase in industry output to meet the new final demand. This is followed by scenario (l a) then (1 b). Correspondingly, scenario (l c) indicated the highest increase in income generated, again followed by scenario (la) and scenario (lb) as the lowest. Similar trends are observed for irrigated agriculture and animal husbandry. The labor requirements for the three sub-scenarios tend to follow the same pattern. However, looking at calabash carving, for instance, the trend is fairly different. Scenario (1a) leads the way with the highest increase in industry output followed by scenarios (1c) then (lb). The same order is reflected in the increase in income generation.

Similar trends are shown in the table for the respective industries in their requirements for ecological commodity inputs. The total values also exhibit the same trend, for example, scenario (lc) requires, significantly, the highest quantity of groundwater, land and vegetation, followed by (la) then (lb). Table 6.3 which shows ecological commodity (production) outputs exhibits some variation. Scenario (1a) leads with wastewater production followed by (1 c) and lastly (1b). However, for solid wastes production, the former trend is repeated, with scenario (1 c) as

the highest producer, the next being (la), and then (lb).
These trends may be attributed to the variation in changes made to generate the hypothetical data. However, taking these figures at face value can obscure some valid information which makes comparisons difficult. Therefore, we have established percentages of the increase in groundwater use required to meet the new final demand and ecological commodity use and production intensities to facilitate our comparisons as suggested earlier. Table 6.4 gives a summary of percentage increases in groundwater use as well as ecological commodity use and production intensities for each scenario. The following percentage increases are observed: scenario (la), 0.13%; (lb) 0.09%; and (1 c) 1.11%. From these, it is evident that scenario (1 b), increasing the production of national cash crops (commodities), will require less groundwater input to meet the new final demand. This will be more appropriate toward meeting our objective, water conservation. But a simulation of all three scenarios combined, will lead to a 1.1 7% increase in groundwater requirements. That is, an increase of nearly one hundred and forty thousand liters of groundwater.
The ecological commodity use and production intensities which show the quantities of commodities used or produced for every Pounds generated, present a better base for comparison and perhaps the determining factor for selection of scenarios. Pounds are the Sudanese currency, pegged at to US$1560.00 in 2001 when most of the data were collected. Interestingly, only the intensity values for groundwater follow the trends demonstrated by the analytical (simulation) figures in which scenario (1 c) dominated in its use and production of ecological commodities followed by (1 a) and (lb). For land use intensity, the trend is reversed with scenario (lb) as the highest followed by (la) and then (1c) as the lowest. But for vegetation input, wastewater and solid wastes intensities, an entirely different trend is observed where scenario (la) leads, followed by (lc) and then (1 b).
The initial trends observed for groundwater intensity may be attributed, for example, to the fact that the strategic cash commodities reflected in scenario (lc) only generate more income per head but excluded the major cash crops which generate more total income. Therefore, scenario (l c) generates less total income than scenarios (1a and b) and is bound to be more water intensive, even though irrigated crops like Millet and vegetables are included in scenario (lc), the more water demanding crops like irrigated rice and wheat are excluded.. Scenario (I a) that follows with the water intensity, generates less total income than scenario (lb) because it had only sheep and goats instead of cattle (a bigger income earner than sheep and goats) reflected in (1 b), consequently, the differences in the respective intensities.
In the second trend in which (lb) leads followed by (l a) and then (l c) as exhibited by land intensity may be attributed, in part, to the transfer of irrigated rice to rain fed agriculture which requires more farmland (usually, rain fed agriculture is more land intensive than irrigated agriculture, see Dabi and Anderson, 1998b) and to the fact that the other scenarios do not involve any change in production per se. The third trend exhibited by vegetation, wastewater and solid wastes where the order is scenario (la), (l c) and (lb) as the lowest may be attributed, in part, to the quantity of vegetation required for wood carving and the corresponding wastes generated and the combination of commodities suggested for scenario (la).
Most probably, the trends described above are a reflection of the total quantities of the different commodities as the income values per commodity are the same in each case. By and large, it is clear that scenario (1c) will be the least preferable because it requires the most groundwater and vegetation per Pounds. It also generates the most waste water and solid waste per Pounds. Ideally, scenario (lb) will be the most preferable but requires the most land per Pounds. Scenario (la) which shows, generally, the lowest intensities across all other ecological commodities and conform with the villagers' willingness to increase the production of a number

of commodities, would have been the most preferred, but requires more groundwater per Pounds than (lb).

Results of the second set of our policy scenarios (water use efficiency) on Table 6.5, indicate that production in scenarios (2a) and (2c) remained the same but scenario (2b) showed some changes (increase or decrease). This is attributable to the fact that no change in the final demand category of the former two scenarios was made for the simulation. Literally, scenario (2b) shows a decline in total production in the irrigated industry as well as animal husbandry, milling and vegetation. Other changes were rather insignificant. Surprisingly, there was also a decline in paid labor, perhaps because irrigated agriculture requires more paid labor than rain fed. There was a decrease in income accruing to the industries indicated above. The most significant decrease was in the animal husbandry industry followed by the irrigation industry. But as expected, there was an increase in income in the rain fed industry, because of the transfer of irrigated rice to the industry.

Table 6.6 shows the analytical results for changes in ecological commodity inputs. All industries but rain fed agriculture that had some amount of change showed a decrease in groundwater use. The increase in groundwater use for rain fed agriculture in scenario (2b) is because of the shift of irrigated rice to that industry. The same trend is observed for land and vegetation inputs owing to the same reason as in groundwater use. But in general, all scenarios (2a, b, and c) recorded a decrease in groundwater input. Scenario (2c) recorded a decrease of more than nine hundred thousand liters of water, scenario (2a) about two hundred and fifty thousand liters, and scenario (2b) a little more than fifty thousand liters. For other ecological commodity inputs, land and vegetation, only scenario (2b) was affected. This was between the irrigated and rain fed industries where the transfer of rice was made. There was a general increase in land input due to the significant increase for rain fed agriculture. Rainfed agriculture uses more land, in total, than irrigated. The decrease in irrigated agriculture was low. Similarly, for vegetation input, there was a small increase into rain fed agriculture but a decrease into irrigated system. However, for ecological commodity outputs, waste water and solid wastes, on only scenario (2b) show some rather insignificant changes. Rainfed agriculture shows an increase in both cases while irrigated, a decrease. The total figures show a general decrease even though rain fed showed some increase. In general, these analytical values for ecological commodity inputs and outputs are a reflection of the changes made to establish the hypothetical data.

To understand the extent of water conservation, the three sub-scenarios were compared with the initial groundwater input to establish the percentage decrease in water use. Ecological commodity use and production intensities were also established. Table 6.8 gives a summary of these values according to the three sub-scenarios. The following percentage changes are observed: scenario (2a), 2.12%; (2b) 0.4%; and (2c) 7.95%. This suggests that scenario (2c), rescheduling of rural industry activities to take advantage of water harvesting will conserve more groundwater. A simulation of all three scenarios combined yielded up to 10.47% savings of groundwater. That is, a conservation of more than one million liters of groundwater.

Ecological commodity use and production intensities could be calculated only for scenario (2b). Scenarios (2a) and (2c) did not show any changes because their final demand categories were not altered in the simulation as indicated earlier. Hence, changes observed in scenario (2b) cannot be compared with the others. However, some deductions can be made with regards to conservation. Mathematically, the positive (+) values in this case indicate a decrease and the negative (-) ones, an increase. This is because income generation generally declined, showing negative values. When used to divide corresponding negative values reflecting decreases in ecological commodity use or production will yield positive (+) results and vice versa. Therefore, only land input appreciated, that is, for every Pound generated, more land will be required. But for the groundwater intensity, there is a higher amount of conservation. For example, for every Pounds generated there will be a reduction or conservation of about two liters of groundwater. Vegetation input, and waste water and solid waste outputs are also low, but gradually decrease.

7. Summary and Conclusions

The paper uses a product-by-industry economic-ecological model (PICEEM) to simulate the economic and environmental impacts associated with a number of development scenarios. In the process, we did a simulation of changes in production and groundwater use to investigate their impacts on the economy and environment. Our simulations are based on two sets of policy scenarios: increase in production of goods aimed at improving the economy of Kutum village and water use efficiency to conserve groundwater and maintain the environment. Our results show that while an increase in production will be met by an increase in groundwater input, changes in the production process and water application efficiency will ensure a reduction in groundwater input as well as other environmental commodities.

The model employed for this analysis has been useful in illuminating economy-environment relationships that would not have been evident without it. We have been able to demonstrate from our first set of policy scenarios that, increasing the production of strategic cash commodities. Those that earn farmers more income per output (scenario lc) will generate more income per head but require more groundwater. The production of national cash crops, scenario (lb), is perhaps a better option because it requires less water in the process, although less income is generated. However, the ecological commodity use and production intensities further clarified the nature of the relationship. For example, the groundwater intensity shows that scenario (I c) requires more water per Pounds and is therefore the least preferable option.

We also elucidate from the second set of our policy scenarios that it is possible to conserve large quantities of groundwater through realistic improvements in water application methods and better choice of irrigated crops or transfer of say irrigated rice to rain fed agriculture. Even more groundwater will be conserved if activities are rescheduled to take advantage of rainwater harvesting. Better still is a combination of all strategies whereby huge sums of groundwater can be conserved. These strategies can serve as policy options for sustainable development in this water-scarce village. They can also be applied to other areas with similar economic and environmental conditions.

However, achieving this dual advantage, increasing production and at the same time reducing the use of or impacts on environmental commodities (especially water), may only be feasible with some tradeoffs.

Such an investigation will require the use of other tools like social cost-benefit analysis. This is because other socio-cultural and political factors not considered in the model may be important. It would also be interesting to introduce time-series data to investigate the possible impacts over time using a dynamic approach. This will allow us to observe rather than just simulate changes in water use associated with changes in agricultural practice. Another useful extension would be to investigate the problem from a regional setting to observe possible linkages with and feed back effects from the rest of the region, using interregional input-output or multiregional input-output (MRIO) approaches.

The purpose of this study was to investigate the nature of water use a drought-inflicted region of Darfur. Economic development in this area is constrained due to the occurrence of intermittent droughts, desertification and water scarcity. The aim of this research therefore, was to develop an analytical framework for assessing alternative economic development scenarios in the village and to advance policy measures for a sustainable economy without endangering the environment. The paper introduced the problem of study, outlined the aims and objectives, and discussed the conceptual framework. The problem was analyzed in context of sustainable agriculture and economic development, identified broad strategies toward solving it, and indicated the need for an analytical approach. The case study was the village of Kutum. Base data on water use and commodity production were generated. An analytical model, a product-by-industry economic-ecological model was developed. It is an environmental extension of the input-output model and useful for determining direct and total direct and indirect input requirements. Because it does not include human responses, an indigenous knowledge systems and technology local initiatives is preferred. The established scenarios were simulated using the model to determine the impacts associated with each development approach. The findings are expected to be applicable not only to the village but to the rest of the region. The major findings of the study are summarized in the next section.

8. Conclusions

The major concern in this study was that of water scarcity. Aridity, droughts, land desiccation, water stress and inaccessibility to water are the environmental and economic interrelated conditions responsible for water scarcity in the region. These have contributed to unsustainable agricultural development and environmental degradation in the area. Therefore, there is relative decline in per capita food production, continued poverty and food insecurity within the economy. There are also endemic environmental problems such as deforestation, overgrazing, soil erosion, ecological degradation, and threats of desertification. The study identified steps toward ameliorating the problem one of which was conducting micro-scale interdisciplinary researches such as the one undertaken and reported here.

Results from the field research reported and indicate that groundwater is a critical resource for the rural villages in the semi-arid zone of northern Sudan, as in the rest of the region. Irrigated cultivation of vegetables and grains on a small proportion of the agricultural land accounted for more than half of all groundwater consumed in Kutum Village. It is practiced by a relatively small proportion of households and generates relatively little income in aggrega, although a significant contribution to the income of the households involved. Animals also consume a significant amount of groundwater, but often benefit from other sources of water while pasturing at locations outside the village area. These results deal only with the direct water requirements of the various commodities produced in the village. To facilitate the estimation of the total (direct and indirect) water requirements or impacts associated with a change in production in any one activity, a better estimation procedure was needed. A product-by-industry economic-ecological model (PICEEM) was used to establish the technical coefficients of the inter-industry transactions of economic and ecological commodity inputs and outputs. Direct, total and indirect effects of commodity production were discussed. The village economy exhibited sparse sectoral interdependence within the economy but a heavy dependence on ecological commodities, particularly water, a scarce ecological commodity in this semi-arid environment. The major users of water (liters per unit output) based on the direct effects include animal husbandry, building and irrigated agriculture; and based on total effects are catering, building and animal husbandry, in descending order. The ability to estimate impacts associated with these effects and changes in water use will contribute to the development of better water management strategies for the area. However, a more sustainable strategy will require an understanding of local initiatives for mitigating the problem of water scarcity. Consequently, some technologies for water management used by the villagers were investigated. Observations show that activities requiring larger quantities of water are concentrated during the dry season, even though local technologies for water procurement, delivery and processing are unsophisticated. The villagers tend to depend on introduced forms of technology such as water pumping machines and storage tanks. Although these are useful in facilitating water supply, they have proved unsustainable due to purchase and maintenance costs, and do not necessarily conserve water. Other issues are the inadequacy in annual scheduling of activities in relation to timing of water availability and absence of specialized skills for rainwater harvesting and farming to take advantage of excess water during the rainy season. However, there are locally fabricated tools and facilities, based on indigenous initiatives, used for water procurement, delivery and processing. Although these tools are manually operated and labor intensive, they require less capital investment, conserve water, and perhaps sustainable. The villagers' willingness to accept new innovation and/or technologies and their effort in wastewater reuse are indications of indigenous knowledge systems geared toward reducing the impact of water scarcity. Despite these efforts, the water scarcity problems have been persistent. Concerted Is for assistance by the people also indicate the need for alternative approaches to water conservation in the area. Hence, the strategy of adopting appropriate technologies for water use is suggested. Prominent among these are rainwater harvesting and farming, utilization of water ponds, construction of groundwater dams, rescheduling of activities to take advantage of water availability and communal participation, e.g., work, planning and implementation of projects. These require education, empowerment and encouragement of the people to enable them exploit their own technologies and knowledge systems. Ideas generated from this study were also used to develop policy scenarios for water use efficiency. The established scenarios were simulated using the product-by-industry economic-ecological model. The two sets of policy scenarios used in the simulation model were:

1. The increase in production of goods is aimed at improving the economy of Kutum Village,
2. Implementing water use efficiency to conserve groundwater and the environment.

Results from our first set of policy scenarios show that increasing the production of the number strategic cash commodities, those that endow farmers with more income (scenario 1 c) will be worthwhile because they actually generate more income per head but require more groundwater. But the production of national cash crops (scenario lb) is perhaps a better option because it requires less water in the process, although less income is generated. However, the ecological commodity-income ratios further clarified the controversy in which the groundwater-income ratio shows that scenario (1c) requires more water per Pounds and therefore, the least preferable option. The second set of our policy scenarios indicate the possibility of conserving large quantities of groundwater through better water application methods and better choice of irrigated crops. Moreover, the transfer of irrigated sorghum is important to rain fed agriculture. More groundwater will be conserved if activities are rescheduled to take advantage of rainwater harvesting. A combination of all strategies will conserve even larger quantities of groundwater. Achieving this dual advantage, increasing production and at the same time reducing the use of or impacts on environmental commodities (especially water), involves some tradeoffs. Either irrigation farmers, who are usually the land owners, sacrifice the cash flow and conserve water for the benefit of the rest of the community or insist on making money to the detriment of the rest of the community and the environment.

Conflicts may also emanate from the strategies suggested in this study, but with education and a better approach that involves the participation of the people, some amount of success can be achieved. These issues are only identified and outlined here, determining the credibility of these tradeoffs is however, not within the scope of this research.

The results of this study summarized a great deal of knowledge on the nature of the problem, actual and potential, of water scarcity and water use in this drought-prone village. The associated impact on the economy and environment as well as strategies geared toward a sustainable economy and environmental rehabilitation were identified and discussed. The model employed in this study produced results and a more comprehensive measure of economic and environmental policy impacts than would be possible otherwise. Having estimated the possible economic and environmental effects in this village, it will be interesting to introduce time-series data to investigate the possible impacts over time using a dynamic approach. A dynamic input-output (DUO) model facilitates the description of the relationships and impacts over time. This association can also be investigated over space using either an interregional input-output (TRIO) model for example between Kutum and the rest of the region or a multiregional input-output (MRIO) model among the different districts or village areas within the region including Kutum. The problem with these approaches will be data requirements. For information on the structure of these possibilities, see for example, Isard (1951); Leontief et al (1953); Richardson (1972); Polenske (1980); Hewings (1985); Miller and Blair (1985); Johnson (1986). It will perhaps be more interesting and rewarding to investigate further the tradeoffs inherent in the implementation of policy options identified in this study. The input-output-type model employed here is useful for describing the type of relationship and the impacts of proposed development policies, economic and environmental. However, it does not incorporate criteria for decision making such as project selection or rejection (Lonergan and Cocklin, 1985). Such an investigation will require the use of other tools, for example social) cost-benefit analysis, the formal procedure for comparing the costs and benefits or assessing the consequences of alternative public policies (Peskin and Seskin, 1975; Haveman and Weisbrod, 1975; van Kooten, 1993; Munashinge, 1993; Lutz and Munashinge, 1994; Schulze, 1994). The social accounting matrix (SAM) in which socio-cultural and political factors (for example, van Kooten, 1993) not considered in this study are included can also be used. However, the use of these analytical techniques at this stage of the study will obscure the inherent environmental implications illuminated by the PICEEM used. Other areas worth study include labor availability and annual rescheduling of activities. The study suggested rescheduling of activities to take advantage of the abundant water during and immediately after the short rainy season. However, more labor input will be required to make the changes. Although communal effort based on field observations and interviews discussed in Dabi (1998) have been suggested. It will be interesting to investigate further how such an arrangement can be made and success will be achieved.

9. References

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