STRATEGIC DECISION-MAKING IN IRRIGATED AGRICULTURE USING SUSTAINABILITY–RELATED CRITERIA

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ABSTRACT

The use of indicators for sustainability evaluation is an important step towards operationalization of the concepts of sustainability and sustainable development. Many literatures on framework for sustainable water management consider any one dimension of sustainability. In this paper, the sustainability of an irrigation system is assessed from economic and environmental dimension. An optimization model to obtain a trade-off between two conflicting objectives (economy of application and environmental performances) for sustaining irrigated agriculture under water-limited condition through Pressure-State-Impact-Response (P-S-I-R) framework using total water use, soil moisture at the root zone, reservoir level, yield loss and water use efficiency as indicators is developed. Compromise programming is used for the development of indicators. The developed methodology is tested in a water deficit tank irrigation system to evaluate and compare different irrigation polices based on the sustainability indicators and management options.

Keyword: Sustainability, Deficit Irrigation, Compromise programming, P-S-I-R.

INTRODUCTION

Water is already in many parts of the world a scarce commodity and will be of even shorter supply in future. Due to an ever increasing world population, improving standard of living, irregularities caused by global climate change and growing water pollution, the world water problems are aggravating day by day. In many arid or semiarid areas—and seasonally in wetter areas—water is no longer abundant, and the high economic and environmental costs of developing new water resources pose limits to supply expansion. Therefore, new supplies will not be sufficient to meet growing demands**.** *Achieving water savings in existing uses through increases in water use efficiency in agriculture has been suggested as the most readily available path to meet future demands while satisfying both current and future needs* for sustainable water resources management (Cai et al., 2003).

The question of sustainable water resources management then becomes: by what development strategies, management policies, or operational rules, can water uses still maintain long-term stable relationships with the water resources system and not deteriorate the recycling nature and potential sources of the system? On the other hand, facing uncertainties and fluctuations in the future can the water resources system supply water with required quantity and quality at required times to satisfy various water demands? Sustainable water resources management should deal with these two inter-connected questions in an integrated framework (Cai, 1999).

Most literature on framework for sustainable water management considers any one dimension of sustainability. Some recent studies on framework modeling use multi-scale analysis. This paper considers two dimensions of sustainability, economic and environmental, and a methodology to obtain a trade-off between two conflicting objectives (economy of application and environmental performances) for sustaining irrigated agriculture under water-limited condition through Pressure-State-Impact-Response (P-S-I-R) framework using total water use, soil moisture at the root zone, reservoir level, yield loss and water use efficiency as indicators. Compromise programming is used for the development of indicators. The developed framework is applied to evaluate different irrigation policies under water limited condition in a Tank Irrigation System.

LITERATURE REVIEW

An integrated hydrologic-agronomic-economic model combines the management of surface and subsurface reservoir (supply) systems with irrigation and farming, evaluates irrigated crop yields, and derives reservoir operating policies. Recent studies on irrigation planning problems are based on area allocation approach (Paudyal and Gupta, 1990). Ng (1988), Raman et al. (1992), and Onta et al. (1995) assessed the impact of water shortage on crop yield and the risk-related system performance considering surface water. Sundharajan and Thangavadivelu (1994) developed a GA-based decision support system for scheduling crop production operations. Yunalai et al. (1999) developed an optimum irrigation scheduling with stochastic rainfall for rice under limited water supply using SDP; Shangguan et al. (2002) developed a dynamic programming allocation model for optimizing regional water resources for wheat under insufficient irrigation. In spite of numerous models, limited information is available on aspects addressing issues such as; how the decision maker should plan the distribution of water deliveries to obtain the best expected output from the system considering an existing cropping pattern under water limited condition. A few researchers (Ng (1988), Onta et al. (1995), Kumar et al. (1998), Yuanlai et al. (1999) and Shangguan et al. (2002)) attempted to address these issues. Manoliadis (2002) derived a methodology to obtain a trade-off between two conflicting objectives (economy of application and environmental performances) for sustaining irrigated agriculture under water-limited condition through Pressure-State-Impact-Response (P-S-I-R) framework using total water use, soil moisture at the root zone, reservoir level, yield loss and water use efficiency as indicators.

METHODOLOGY

Two primary objectives that conflict in sustainable development are economy of application and environmental performance. The final decision often involves a trade-off between these two objectives. Ecological monitoring and assessment of irrigation system often relies on indicators to evaluate environmental conditions (Manoliadis, 2001). A Pressure-State-Impact-Response approach (P-S-I-R) was used to derive the ecological indicator sets under water-limited condition to consider the various management options.

Total water use, soil water stress, Reservoir storage level, Yield loss and water use efficiency are used as indicators to assess the condition of the system. A Compromise Programming problem is formulated so that indices lead to a trade-off between different management options like water use (Pressure), environmental performance (state) and food production (impact) or cost of crop production (response). Gene Expression Programming (GEP) model is developed using the reported data of Grace (1997) for paddy to estimate the effect of water stress on yield. This module will replace crop growth model in the framework. GA-based optimization model with an objective of maximizing the net benefit by irrigating maximum feasible area through judicious spatial and temporal distribution of the shortages, minimizing loss of yield from water stress, with an aim to get optimum total production by maintaining the spatial and temporal equity for sustaining the irrigated agriculture in a water short irrigation-system is used to generate optimal alternatives. Equal preferences were assumed for all the indicators. The preferred management option is then identified from the candidates by locating the system nearest the ideal point in terms of the compromise distance. The block diagram of the above procedure is shown in Fig. 1.

APPLICATIONS OF THE METHODOLOGY

The developed optimization model was applied to a Minor Tanks / Lakes Irrigation System (MITS) in Tamil Nadu. The Pillaipakkam MITS serves a command area of 440 ha. The tank receives water from a free catchment of 9.89 km^2 with the average elevation above the MSL of 50 m. The existing crop-pattern is semi-dry paddy in the Kharif season and transplanted paddy is practiced as the second crop in the Rabi season. The normal agricultural operations start in the month of July. The optimization of area and decisions on releases at each growth stage makes the objective function nonlinear. The model was applied for three irrigation scenarios viz., extensive, intensive and a typical deficit case, for dry-inflow year conditions and the results are shown in Table 1.

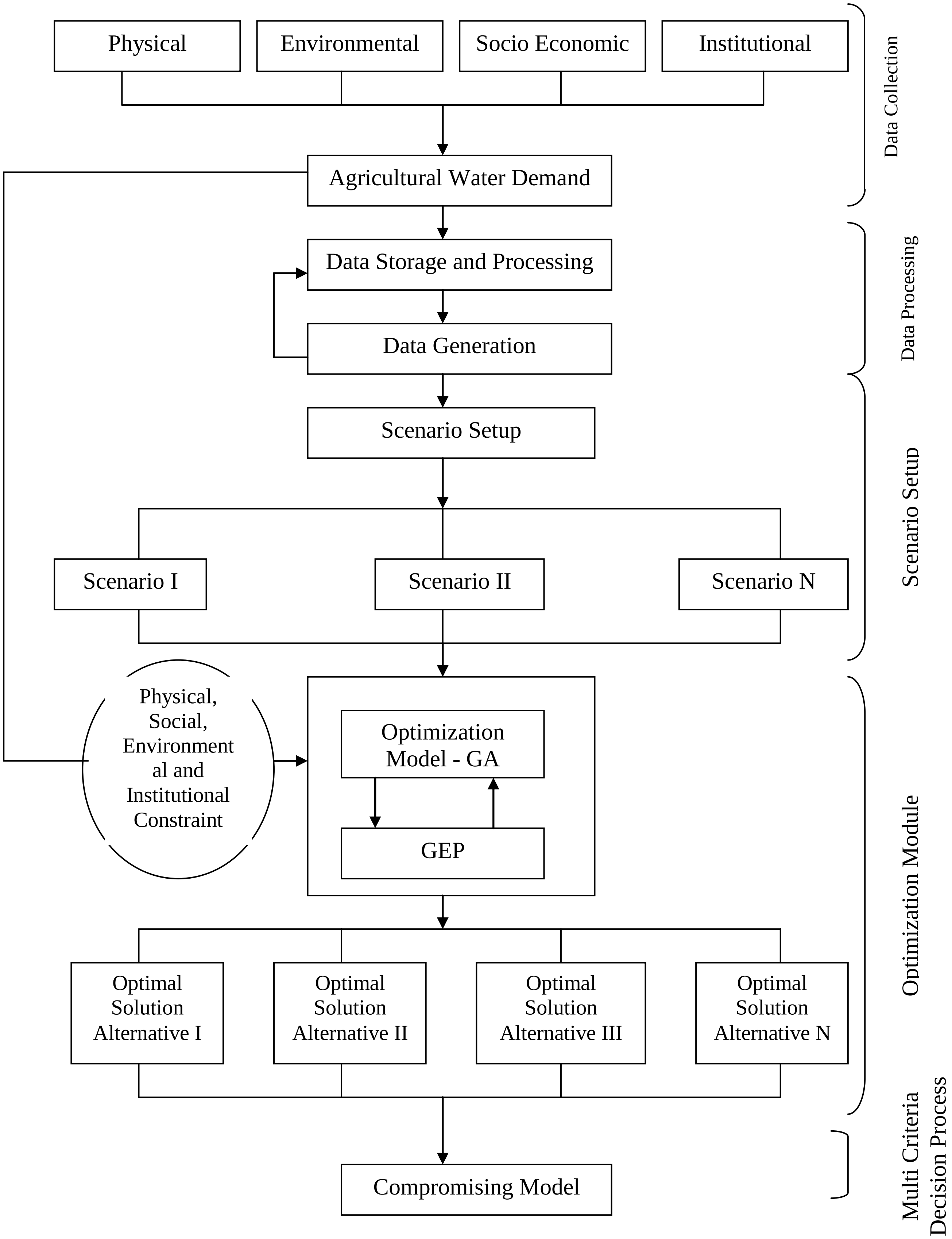

Figure 1. Indicator Based Framework for the Evaluation of Irrigation System

Table 1. Net Return in a Dry- Inflow Year with Different Irrigation Policies (1 x 10^6 million rupees)

Irrigation Scenarios	Net Return	Crop Season – 1					Crop Season – 2				
			Relative Water Supply					Relative Water Supply			
		Area (ha)	Vegetative	Tillering	Flowering	Grain Filling	Area (ha)	Vegetative	Tillering	Flowering	Grain Filling
Extensive	23.7	440	0.79	0.79	1.00	0.99	438	0.98	1.00	0.98	1.00
Intensive	21.9	341	1.00	1.00	1.00	1.00	440	1.00	1.00	1.00	1.00
Deficit	20.8	419	0.90	0.90	0.90	0.90	440	0.90	0.90	0.90	0.90

All the three irrigation scenarios allocate the entire command area during Crop season-II since there happens to be enough water during the season. The more interesting thing is the allocation of area during dry season (Crop season I). For the intensive irrigation, only about 341 ha of command area is irrigated in the first cropping season. About 29% and 23% of excess of command can be seen to be possible under extensive and deficit irrigation respectively.

In case of extensive irrigation, the net monetary return is 8 % and 14% higher than that obtained from intensive and deficit irrigation. Extensive irrigation distributes the water shortage temporally using developed ANN module and maximizes the profit through cultivating more command area with optimal production. The water use efficiency (WUE) under the three irrigation scenarios are shown in Table 2.

The WUE for extensive irrigation is 7 % and 9% higher than those obtained through intensive and deficit irrigation during crop season-I. The sharing of water shortage and reduced yields among users, increases in WUE and command area, and increase in overall monetary return clearly indicates the sustainability of irrigated agriculture under extensive irrigation scenario.

At the same time alternative 1 with a compromise distance of 0.8924 is the worst for the same management option. Like wise the best alternatives can be selected based on the management option.

Table 2. Water Use Efficiency in a Dry-Inflow Year under the three irrigation policies

Irrigation Policies	Water Use Efficiency (kg / ha/ mm)	
	Crop Season – I	Crop Season – II
Extensive	10.6	11.2
Intensive	9.9	11.2
Deficit	9.7	11.0

In all, the alternative 8 with a compromise distance of 0.2999 is best among all the optimal alternatives got from optimization module. Compromise Programming is used to identify the preferred management option from the best alternative optimal candidates generated in optimization module by locating the system nearest the ideal point in terms of the compromise distance. The set of compromise distance is shown in the above table. Alternative 8 with a compromise distance of 0 for Total water use is best alternative to stress the importance of water conservation management option.

Table 3. Indicators and Compromise Distance for various Alternatives

Alternatives	Total Water Use **Pressure**	Environmental Response **State**	Yield Loss **Impact**	Water Use Efficiency **Response**	**Overall Compromise Distance**
Alternative 1	0.8924	0.3459	0.9141	0.6488	0.7003
Alternative 2	0.8781	0.3703	0.9118	0.4280	0.6471
Alternative 3	0.6891	0.4627	0.8365	0.5638	0.6380
Alternative 4	0.8129	0.3604	0.8604	0.4837	0.6294
Alternative 5	0.6960	0.4142	0.8577	0.6474	0.6538
Alternative 6	0.8715	0.3655	0.5289	0.5957	0.5904
Alternative 7	0.8111	0.3361	0.8242	0.8395	0.7027
Alternative 8	0	0.4875	0	0.7120	0.2999
Alternative 9	0.8922	0.3786	0.7633	0.3423	0.5941

CONCLUSIONS

The use of indicators for sustainability evaluation is an important step towards operationalization of the concepts of sustainability and sustainable development. Two primary objectives that often conflict in sustainable development are economy of application and environmental performance. The final decision often involves a trade-off between these two objectives. The developed methodology is applied to demonstrate the use of different objectives combined with compromise programming for solving the problem of allocation of agricultural water within a multi-criteria decision making framework in a tank irrigation system under water limited condition for different irrigation polices.

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