Integrated Water and Land Management to Deliver Sustainable Agriculture in Semi-arid Catchments

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ABSTRACT

Arid and semi-arid regions are generally characterized by water scarcity and low per capita water allocation. In such areas, intensive agricultural activities associated with high population growth cause a further exacerbation of this problem. The concept of integrated land and water management has been widely accepted as a practical solution for sustaining both the environment and agricultural production. Integrated catchment management provides an interdisciplinary framework that links physical, social and economical sciences into planning, policy and decision making. Specifically, prioritizing and evaluating different management alternatives using a multi-criteria decision analysis model is essential to achieve a long–term agricultural and natural resources sustainability in agriculture-dominated semi-arid catchments.

The main objective of the research is to develop a framework for a Multi Criteria Decision Support System (MCDSS) that provides planners and decision makers with a tool for planning integrated management of land and water. It also provides a soundly based analysis of agricultural water demand. The data from agriculture-dominated Faria catchment in the West Bank of Palestine was used for the study. The proposed approach integrates a rainfall-runoff model, a groundwater model, statistical analysis of spring discharges, a planning model and a multicriteria decision analysis model. Collectively they form the framework. These models were utilized to determine the optimal cropping pattern that maximizes net income of the catchment that could be sustained by its natural resources. Management alternatives can be introduced by determining the sustainable limits imposed by the limited natural resources. Management alternatives were developed to maximize the net benefit whilst sustaining the available water resources. To evaluate the overall efficiency of the introduced alternatives, decision criteria were developed to account for the economic and environmental consequences and a multi-criteria decision analysis was conducted to rank the land and water management alternatives.

The Kinematic-Wave Geomophological Instantaneous Unit Hydrograph (KW-GIUH) was used to estimate runoff from the catchment in ungauged situations. The model was calibrated and applied to the catchment and the results were compared with observed hydrographs. The simulated and recorded hydrographs were in good agreement. Sensitivity analysis was conducted for all catchment geomorphological parameters. The overland flow roughness

coefficient (n_o) and the channel flow roughness coefficient (n_c) were obtained from tables depending on the catchment cover and channel type. All other model parameters were obtained from the Geographic Information System (GIS). Peak flow values increased by 16% as the n_o decreased by 25% which reflects the land surface condition of the surface hydrologic system. However compared with the n_o, the n_c had a smaller effect on both simulated peak flow and time to peak. The stream order level of each subcatchment indicated that it is necessary to follow the stream network map in developing the KW-GIUH model.

The MODFLOW software package was utilized to estimate the amounts of groundwater that could be safely extracted under different management alternatives and climatic change. Groundwater recharge and pumping rates directly influenced output from MODFLOW. Groundwater recharge reflects the climate variability while groundwater pumping is directly reflective of the possible land area that could be managed. Results showed that, based on 50% allowable limit of drawdown percentage, the current groundwater wells are abstracting water above the safe yield with a total amount of 3200 ML/yr. A statistical analysis of the yield at Faria springs showed a considerable variation in the total annual yield. The reliability of each spring flow was tested and the results showed that the reliability of all the springs exceeded 50%. Hence yield from all the springs was used for planning purposes. Results from this analysis were used to supply the water resource data needed for the planning model as well as to formulate the management alternatives for the catchment.

The planning model (AGricultural Sub Model AGSM) integrates the outputs of the rainfall runoff and groundwater models to determine the total amounts of water available for irrigation. The AGSM computes the net income and the amounts of different qualities of water used to produce the optimal cropping pattern. Application of AGSM to data from the Faria Catchment showed that the model was capable of providing objective evaluation of the changes in management scenarios and water policies. Water demand curve that shows water demand as a function of water price was developed for the Faria catchment. A logarithmic demand curve was developed to derive the optimal water price. This curve approach provides the planners and decision makers with a simple and efficient method to combine the optimal area cropped and obtain the optimal water price that could be charged to farmers. The optimal price and price elasticity of agriculture water demand obtained through the curve enable policy makers to evaluate response to price changes, allow better trading opportunities and optimize agriculture water demand.

Management alternatives were developed for Faria catchment such that the optimal water and land utilization are met to maximize profits. Decision criteria were developed and utilized in a multi-criteria decision analysis. Each management alternative was evaluated in terms of different economic, environmental and social decision criteria. The importance order of criteria (IOC) method was employed in the multi-criteria decision analysis to rank the alternatives. The IOC method relies on the preference of the decision maker in stipulating of the decision criteria. Such an order reflects the importance of these criteria to the decision maker. Combining different management alternatives proved to be an efficient approach for maximizing net benefit and satisfying the yield limits. The latter is a very important issue in a resource constraint of semi-arid area. The ranking of the management alternatives indicates the successfulness of the alternatives for a specific importance order of the criteria. A combined management alternative that includes utilization of Jordan River, changing the cropping pattern by introducing high income crops, building surface water storage (dam) and implementing a groundwater pumping strategy proved to be the best alternative. The optimal management plan obtained from the developed approach addressed the current problems of the study area and met the triple bottom line of land use, governmental policies and water resources protection and development to optimize use of land and water resources. Compared to the "do nothing" alternative the net benefit for the plan is more than double. The irrigated area under the optimal plan exceeded the current irrigated areas by 34%. Under this plan there is no groundwater abstracted above the safe yield. The amounts of surface water and wastewater that could be stored and made available for irrigation under the optimal plan are 6600 ML compared to none stored at present. The MCDSS developed under this study is a very useful tool that can be used by different decision makers and planners in various areas. It can be used to investigate the efficiency of different management alternatives in satisfying the decision criteria that ultimately aim at achieving the policies and strategies envisaged for the area under study.