

A Bilevel Fuzzy Goal Programming Approach for Two-Stage Production Planning Problems

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Abstract

Water is an important ingredient for both agricultural and processing industries to transform agricultural products for domestic consumption. Due to competitions for fresh water among the three sectors, the tradeoff analysis to satisfy much of the consumption demands with little stress on the already aggravated water conflicts is highly desirable. To serve the purpose, the problem is modeled as a two-stage production (TSP) problem in which dynamic inventory control operation (DICO) is introduced as mass balance equation and solved using bilevel fuzzy goal programming (BL-FGP) approach. In TSP, a first stage decision is undertaken before values of random variables are known and then, a second-stage decision using recourse action is made after the random events have happened and their values are known, in order to minimize penalties that may appear due to any infeasibility. By decomposing the multi-stage production planning (MSPP) into a sequence of finite number of TSP, a search for the optimal decision is made while the optimal solutions in the previous steps are used as inputs to the current stage and are updated progressively.

This process continues to sequentially solve the problem until the final two-stage sub-problem is optimized. The model is tested with data from agro-processing industry zones in Gidabo watershed of Central Rift Valley Basin (Ethiopia).

Keywords: *Agro-processing, Bilevel fuzzy goal programming, Dynamic inventory control, Optimal water allocation, Two-stage production.*

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1 Introduction

The value of water is long recognized from early human civilization. Early human settlements are closely linked with water bodies and they contribute to the modern settlements [1]. Most developed nations are due to their proximity to water resources or their capacity to utilize the available resources for sustainable development. The greatest challenge of 21st century in water resource management is hydro solidarity and sustainable development. Naturally this is the "paradox of commons": In any collectively managed resources users demand high out of the resource and contribute less to its preservation.

Due to increasing human population and competition for water resources, often too many people depend on the same water resource and societies become unable to share the water resources in a traditional First- Come -First -Served (FCFS) basis. In such cases alternative allocation mechanisms are highly demanded. Due to the critical importance of water for human existence and its multitude of uses for drinking and domestic purposes, irrigation, fishing, tourism, recreation and navigation, hydropower generation, flood management and preservation of ecosystem, too much pressure is being exerted on natural resources and these uses are often in conflict with one another and the satisfaction of one obstructs the fulfillment of the others [2].

Water resources allocation under conflicting demand and supply was studied in [3, 4, 5] for hydropower production and agricultural production in Nile River Basin, in Africa. It is an adaptive problem that calls for designing allocation mechanisms fit according to changing physical, social, institutional and political settings [6]. The root cause of the problem is related to population increase, growing resources consumption, non-equitable distribution of resources and inefficient management [5]. Conflicts also arise from selfish behaviors of stakeholders and partly due to complexity of system dynamics.

Water allocation has received considerable attention in the recent past by the scientific community due to its potential to avoid and resolve the present as well as future treats to conflicts between competing uses and users by developing optimization tools and techniques for improved management of the water resources [7, 8]. Contemporary water resources management approaches

are based on the principle of sharing water in an equitable way and resolving conflicts among stakeholders without affecting the environment. To establish a balance between water resource demand and supply within a basin, mathematical models have been built to optimize water resource allocation. Many optimal water allocation models have been developed in different basins and varieties of optimization techniques with different levels of sophistication have been employed for water allocation using linear programming [9], dynamic programming [3, 4], multi-objective programming [10, 11, 12], genetic programming [5], and goal programming [13].

Water resources systems analysis is an approach by which the components of such a system and their interactions are described by means of mathematical or logical functions [14]. A physical water resources system is a collection of various elements that interact in a logical manner and are designed in response to various social need in the development and improvement of existing water resources for the benefit of human use. The effective use of computer models require an adopted model to be commensurate with the nature of problems being studied; the available data; accuracy requirement; and computer environment [15]. This necessitates the development and use of hard computing numerical techniques applied to water resource planning. The capacity of multi-objective programming [16] to handle conflicting objectives makes it particularly preferable for water conflict management.

Conventional bilevel programming problem (BLPP) is a special case of multilevel decision making process with two decision makers (DMs) in two levels or hierarchical organization often with conflicting goals [17, 18]. Distinguishing characteristic of bilevel systems is that the decision maker (DM) at one level may be able to influence the behavior of the DM at another level but can not completely control. In addition, the objective functions of each DM may, in part, be determined by variables controlled by other DMs operating at parallel or subordinate levels.

The drawback of this model is that it has unclear definition of the objective function values of each DM while both have control over only partial variables. In particular if the optimal solutions of the follower are not unique for each choice of the leader's decision vector, the problem has no unique optimum value [17]. In the standard formulation, the leader's problem is defined in terms of the follower's problem which itself was defined in terms of the leader's unknown decision vector. The lower level optimization problem is a constraint to the upper level optimization problem, such that, only those members are considered feasible that are lower level optimal and also satisfy the upper level constraints. This formulation of bilevel programming leads to circular definition and incomplete information about the context of optimization.

Due to the above unclear formulation, solution methods [19, 20] to the problem are complicated and not straight forward. As cited in Bard [18], the linear

BLPP with the above formulation was first shown to be NP-hard by Jeroslow [21] using satisfiability arguments and Bard [17] also provided an alternative proof by constructively reducing the problem of maximizing a strictly convex quadratic function over a polyhedron to a linear max-min problem. The vast majority of research on bilevel programming has centered on the linear version of the problem, bilevel linear programming problem (BLPP), alternatively known as the linear Stackelberg game is a combination of the two approaches of optimization and game theory.

The methodology known as goal programming was originally introduced by Charnes and Cooper [22] for a linear model [23]. Other texts on goal programming have been anchored by Lee [24], Ignizio [25], and Romero [26]. Goal programming relies on prior articulation of allocation preferences based on concrete goals. The DM specifies a target for each objective function and a preferred solution is then defined as the one that minimizes the sum of the deviations from the prescribed set of target values [27]. That is GP yields only an efficient and satisfactory result rather than optimum solution to the problem. The overall purpose of goal programming is to minimize the deviations between the achievement of the goals and their aspiration levels. GP is advantageous over classical optimization techniques in that it attempts to find one or more feasible solutions which satisfy a number of designed goals to the extent possible. Due to the complexity of water resources GP helps to take selective action pertinent to the problem based on expertise judgment.

In an interactive BLPP, both DMs are expected to cooperate with each other and they try to optimize their individual problem, paying serious attention to the interest of the other. The solution procedure of the fuzzy mathematical programming is to satisfy the fuzzy objectives where a decision in a fuzzy environment is thus defined as the intersection of those membership functions corresponding to fuzzy objectives [28, 29]. In these approaches each DM solves his/her own individual best and worst solutions subject to the same system constraints and designate the best solution as their aspiration level, assign it the highest membership value (unity) and designate the worst solution as their dissatisfaction level and assign lowest membership value (zero) to their fuzzy goals. For any fuzzy decision a feasible membership goal is constructed by introducing under- and over- deviational variables and fuzzy transformation constraints are introduced within weighted goal programming formulation [30].

Narasimhan [31] incorporated fuzzy set theory within goal formulation in 1980, in the methodology known as bilevel fuzzy goal programming (BL-FGP). Several other works on fuzzy goal programming (FGP) procedure were proposed [32, 33, 34] for decision making problems. This methodology is used in [11, 30] within the general framework of GP. Fang et al. [30] used BL-FGP approach for the water allocation problem in Wuwei basin of China. Two

methodologies were used to set target values and aspiration level: subjective choice and choice based on detail analysis of water demand and water supply. The main problem of water allocation is however, to understand the complex link between hydrology, water consumption, crop-water-yield interdependence. In the decision process, the fuzzy goal membership functions for all the DMs variables are considered and the fuzzy programming problem is solved using a constraint on the overall satisfactory degree [35].

2 Problem Formulations

2.1 Background of two stage agro-processing

Many of the agricultural products are not directly consumed but rather processed as food, drink, cloth, chemical or pharmaceutical before they are consumed by end users [36]. Agro-processing industries take an intermediate role in between agricultural production and human consumption. Some intermediate processes remove unwanted parts of agricultural inputs and clean them from unwanted odor, smell or taste. Processing industries use water as an ingredient in the final output in addition to its use to assist the intermediate processes. Agro-processing industries like coffee wet processing involve a series of cleansing, fermentation, transportation, etc. in the process that take long periods, consume large quantity of water and release waste. Wet processing is generally regarded as producing a higher quality coffee and commands a significant premium over unwashed coffee at the export level-20% higher [37]. The process involves a series of technical, human and managerial considerations but the premium money paid for the product compensates all its costs.

However, even when there are seemingly significant price premiums for washed coffee, only about 30% of Ethiopia's coffee export is washed and the country and coffee processors are missing out on the opportunity of higher production [37]. Thus, water plays a significant role in agro-processing industries. The agro-processed products are highly advocated for the immense value they add to agricultural products. However, these industries are not expanding in budget deficit countries like Ethiopia because of shortage of capital, technology, expertise and other constraints. These countries export their agricultural outputs at a cheaper price and import processed outputs at higher costs. Agro-processing in Ethiopia is advantageous because of relative abundances of land and water resources in addition to cheaper labour force.

Agro-processing industry, understood here broadly as post-harvest activities involved in the transformation, preservation and preparation of agricultural production for intermediary or final consumption, typically increases in importance with regard to agriculture [38]. Agricultural products could be used in combination to produce a number of agro-processed outputs that con-

sume water in the mean processes or as an ingredient in the final product. Agro-processing decisions depend on agricultural supply of raw materials, the permanent and seasonal availability of work force, expertise, chemicals, machinery, availability of facilities and storage for raw materials, intermediates and finished products. In addition, availability of reliable water supply and water storage facilities, the market demand and the cost and benefit of the production and other goals of economic and environment concern determine the size and timing of the production while keeping the technology parameters constant.

The common characteristics of agricultural production and processing industries is that both are multi-stage production planning problems with uncertainties. We consider the case where the agricultural production stage takes the form of aggregate production planning (APP). APP determines the intermediate range capacity needed to respond to fluctuating demand [39]. In many production systems a successful and realistic model can be obtained at the expense of adjusting some aggregate level parameters. Given demand forecasts for each period of a finite planning horizon, the APP specifies production levels, work force, inventory levels, subcontracting rates, and other controllable variables for each period that satisfy anticipated demand requirements while minimizing relevant cost over that planning horizon [39].

Two-stage production (TSP) problems [40, 41] and multi-stage production [42, 43] planning problems occur naturally in production planning. In TSP, a first stage decision is undertaken before values of random variables are known and then, a second-stage decision using recourse action is made after the random events have happened and their values are known, in order to minimize penalties that may appear due to any infeasibility. Marques et al. [44] proposed a model of agricultural land and water use decisions using two-stage stochastic quadratic programming (TSQP) to simulate decisions on the mix of perennial and annual crops, water use, irrigation technologies and economic performance considering probabilistic water availability with objective of maximizing the net expected economic benefit of crop production.

To handle uncertainties for optimal allocation of irrigation water, models were developed based on stochastic dynamic programming (SDP). For a single crop situation (for example, Dudley and Burt [45]) and for a multi-crop situation [46] is referred for this study. A Fuzzy Goal Programming (FGP) model was proposed in [47] and compared with goal programming (GP) and linear programming (LP) models to find the optimal cropping pattern, in Bardsir region of Kerman-Iran, which maximizes the crop production and net return, and minimizes the employing of labor, water and machinery inputs.

Li et al. [48] proposed an inexact two-stage water management (ITWM) model for planning agricultural irrigation in the Zhangweinan River Basin, China. The ITWM model is derived from the incorporation of interval-parameter

programming (IPP) within a two-stage stochastic programming (TSSP) not only to reflect uncertainties expressed as probability distributions but also as interval numbers. Bekri et al. [49] proposed optimal water allocation under uncertain system conditions for the Alfeios River Basin (Greece) for hydropower production and irrigated agriculture based on an inexact two-stage stochastic programming methodology developed by Huang and Loucks [50].

Belmokaddem et al. [39] proposed a fuzzy goal programming approach with different importance and priorities (FGPIP) developed by Chen and Tsai [51] to aggregate production planning (APP) for a two-stage production (TSP) planning problem in which dynamic inventory control operation (DICO) constraints introduced as model constraints. The DICO helps to meet the imbalances between customers demand and production levels by storing resources and working force during deficit periods from previous inventories, overtime production or change of contractual levels. The methodology successfully incorporated fuzzy goal programming approach to TSP using DICO. Application of this methodology for multi-stage production planning (MSPP) problems like agro-processing requires to decompose the MSPP into a sequence of finite number of TSP sub-problems. While solving each two-stage sub- problem, a search for the optimal decision is made while the optimal solutions in the previous step are used as inputs to the current stage and are updated progressively. This process continues to sequentially solve the problem until the final two-stage sub-problem is optimized.

Gaglioppa et al. [42] considered the planning and scheduling of production in a multistage batch manufacturing process of typical industries like chemical manufacturing, food processing, and oil refining. The model formulation of the multistage production planning and scheduling problem (MPSP) was a mixed-integer linear program (MILP) in which they considered a system with a single processing unit capable of carrying out several stages, each consuming one or more inputs and producing one or more outputs. Inputs for each stage might consist of raw resources (feeds) or semifinished products (intermediates). Similarly, outputs from each stage may consist of intermediates or finished products. This formulation led to an NP-hard problem with a large integrality gap (gap between the optimal solution of the MILP and the optimal solution of the linear programming relaxation).

Adaptation measures in water allocation are categorized into "supply-side" options and "demand-side" options. "Supply-side" options focus on augmenting water availability by storing water during wet seasons and using it for latter deficit period by reservoir operation [52] and conjunctive uses of surface water, ground water, rain water, recycled water, desalinated water, etc. depending on which alternative best applies to the changing circumstances [53]. "Demand-side" options on the other side aim to reduce water demand mainly through the efficient use of water through decreasing water loss in the form

of conveyance loss or evaporation, using water saving technologies like drip irrigation as well as use of water for more productive purposes.

However, as an adaptation measure the state of art methods for dynamic inventory control [36, 39, 40, 41] optimization approaches are not adequately incorporated into optimal water allocation models in previous studies. In this study of optimal water allocation modeling under conflicting demand and supply, from the decentralized production, consumption and water allocation planning for agricultural, industrial and domestic sectors a new methodology is proposed to coordinate the production and consumption of finished products that would lead to better water management. The problem is modeled as a Two-Stage Production Dynamic Inventory Control Optimization (TSP-DICO) problem that considers the multi-stage decision problem as several subproblems of two-stage model application and in subsequent steps the algorithm modifies the previous solutions by fixing values obtained at current iteration until finally only one two-stage problem remains in the optimization problem. Thus, the proposed Two-Stage Production Dynamic Inventory Control (TSP-DICO) incorporates inventory control models to water allocation planning methodology to develop a better water management decision to avoid conflicts. The methodology eliminates overproduction beyond demand for consumption by domestic sector from both agricultural sector and processing industries and water allocation decision is made to meet as much of the demands with little stress on the already aggravated water conflicts.

2.2 Problem description

We assume finite supply of raw materials and capacitated production at two stages as in [40]. Items are manufactured at stage one (agricultural production), and then held in inventory. Items are transported to stage two (industrial production), where they are again held in intermediate inventory. Additional capacitated production is completed at stage two (that is, value is added to each item), items are held in finished goods inventory after this stage, and this inventory is used to meet final demand. The demand for final products is also time dependent and known in advance. These demands are to be totally or partially satisfied from production within the same period plus previous period inventory. Each stage production s consumes a set of inputs $i \in I(s)$ in fixed proportions, with α_{si} being the proportion of input to stage s production due to input i independently of period t . Each stage s production results in a set of outputs (yield, solid waste, liquid waste, etc.) $i \in O(s)$ also in fixed proportions, with β_{si} being the proportion of output from stage s production independently of period t . The solid waste, liquid waste, etc. will leave the production line and either removed from the system or else they are recycled. The yield at each stage s is used to satisfy the production/consumption

demand in the next stages.

Several goals at the two stages were set to meet as much of the demands as possible from production and inventory at minimum economic and environment costs. Mass balance equation is the constraint of inventory level. The inventory control helps to eliminate wastes by avoiding overproduction in addition to minimization of all the production cost, inventory holding cost and penalty cost for not meeting any of the demands for consumption. Using a TSP-DICO model, the production targets for both agricultural and processing industries were determined before the water allocation decision.

In the sequel the first stage agricultural production decision and supply of agricultural inputs to the processing industries are optimized based on the maximum production capacities at the two stages in the first run of TSP-DICO. Any imbalance between processing demand and agricultural supply during time periods of finite planning horizon are held at stage one buffer of reasonable size. Similarly the second stage decision production from agro-processing industries and supply of agro-processed outputs to the consumption sector are optimized based on the maximum production capacities at the second stages and maximum demand for consumption of final agro-processed products by consumption sector in the second run of TSP-DICO. Any imbalance between consumption demand and supply of agro-processed outputs during time periods of finite planning horizon are held at post-stage two buffer. From the two model runs of TSP-DICO, the final optimal processing and post-stage two inventory decisions are made.

Model parameters

$i =$	Index for resources $i = r_1, r_2, \dots, r_R$
$t =$	Index for periods $t = t_1, t_2, \dots, t_T$
$s =$	Index for production stages $s = s_1, s_2, \dots, s_S$
$I(s) =$	Set of all resources i used as inputs of production at stage s
$O(s) =$	Set of all resources i outputs of production stages s
$K_{st} =$	maximum capacity of stage s production at period t
$D_{it} =$	consumption/production demand for stage s output $i \in O(s)$ within time period t
$h_{it} =$	holding cost per unit for stage s output $i \in O(s)$ within time period t
$c_{st} =$	per unit stage s production cost at time t
$p_{st} =$	per unit penalty cost for unmet demands within time period t

$\alpha_{si} =$	proportion of input of production $i \in I(s)$
$\beta_{si} =$	proportion of output of production $i \in O(s)$
$R_{i0} =$	initial inventory level of resource i at time period 0
$R_{iT} =$	final inventory level of resource i at time period T
$TWA_t =$	Total available water supply for the two stage productions and final stage consumption at time period t
$TSWDG_t =$	Total waste disposal capacity at time period t

2.2.1 Decision variables

$x_{st} =$	production quantity of stage s production i within time period t
$I_{st} =$	inventory level at the stage s buffer at the end of period t
$TPRODG =$	Total production quantity
$TECOG =$	Total economic goal
$TSWDG =$	Total waste production quantity
$TWSG =$	Total water supply quantity
$TH_{it} =$	Total holding cost for stage s production within time period t
$TC_{st} =$	Total stage s production cost at time t
$TP_{st} =$	Total penalty cost for unmet demands within time period t
$I_{sMax} =$	Minimum buffer size for stage s production
$SW_t =$	inventory level for total wastes within time period t
$W_t =$	Reservoir water level within time period t
$W_{Max} =$	Minimum Reservoir size

All water management are multi-objective in nature many of which are conflicting particularly when water resources are scarce-as such, there is no single management option of water for a single purpose. Within a nation these interests include increasing access of water supply, increasing production (yield), decreasing cost of water supply, decreasing investment cost, decreasing treatment cost, decreasing environment hazard, etc any two of which are frequently at odds and the chances of finding mutually acceptable solutions are hardly possible.

In this two-stage production dynamic inventory control model, production maximization goal $TPRODG$ given by equation (1) is the first level goal for each time period t .

2.2.2 Higher level goals

$$\max TPROD G = \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_{S+1}} \sum_{i=i_1}^{I_R} \beta_{si} x_{st} \quad (1)$$

Zimmerman [29] uses individual maxima and minima of the various objective functions to choose the aspiration levels and tolerance limits for each of the fuzzy goals, as if they were optimized individually, in defining the membership functions based on concrete data. Such an approach removes the 'fuzziness' associated with the targets. In general, especially in large scale problems, this can be quite a difficult task for decision makers. Another possibility in applying fuzzy set theory to GP is that decision makers are allowed to specify imprecise aspiration levels. A heuristic method called Greedy Search Heuristic (GSH) for TSP-DICO described in the next subsection maximizes production while minimizing inventory holding cost in isolation. This solution is taken as the aspiration level for the first goal.

With the following three assumptions on cost coefficients, GSH also solves the total economic cost minimization goal (TECOG) given by equation (2) is the second level goal.

2.2.3 Lower level goals

Economic goals

$$\begin{aligned} \min TECOG = & \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_S} \sum_{i=i_1}^{I_R} (h_{it} I_{st} + R_{iMax}) + \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_S} \sum_{i \in I(s)} c_{st} \alpha_{si} x_{st} \\ & + \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_S} \sum_{i \in O(s)} p_{it} (D_{it} - \beta_{si} x_{(S+1)t}) \quad (2) \end{aligned}$$

Assumption 1. Any unmet demand of firm production/consumption in a period t is considered lost and it incurs "penalty" cost p_{it} larger than the production cost c_{st} .

Assumption 2. The production cost $c_{s(t+1)}$ at any time period $t+1$ is less than the production cost c_{st} plus inventory holding cost h_{it} of a previous period t .

Assumption 3. The penalty cost $p_{i(t+1)}$ at any time period $t+1$ is less than the penalty cost p_{it} plus inventory holding cost h_{it} of a previous period t .

Minimizing total economic cost TECOG given by equation (2) for each time period t measured in terms of total production cost and inventory holding costs is the second goal under consideration. Minimizing total environment goal (TSWDG) given by equations (3)-(6) is measured in terms of total volumes of solid and liquid wastes produced $TSWDG_t$ and the total volumes of solid and liquid wastes treated $TSWDK_t$ limited to treatment capacity leading to final inventory of wastes $SW_T = 0$.

Waste control goals

$$TSWDG = \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_{S+1}} \sum_{i=i_1}^{I_R} (\alpha_{si} - \beta_{si}) x_{st} \quad (3)$$

$$TSWDG_t = \sum_{s=s_1}^{s_{S+1}} \sum_{i=i_1}^{I_R} (\alpha_{si} - \beta_{si}) x_{st} \quad (4)$$

$$SW_t = SW_{t-1} + TSWDG_t - TSWDK_t \quad (5)$$

$$SW_T = 0 \quad (6)$$

Water allocation goals

Maximizing total water supply (TWSG) given by equation (7)-(10) measured in terms of total water supply and reservoir operation depending on the total available water TWA_t and previous period storage level for each time period t .

$$\max TWSG = \sum_{t=t_1}^{t_T} \sum_{s=s_1}^{s_{S+1}} \sum_{i=i_1}^{I_R} \alpha_{si} w_{st} x_{st} \quad (7)$$

$$TWSG_t = \sum_{s=s_1}^{s_{S+1}} \sum_{i=i_1}^{I_R} \alpha_{si} w_{si} x_{st} \quad (8)$$

$$W_t = W_{t-1} + TWA_t - TWD_t \quad (9)$$

$$W_t \leq W_{Max} \quad (10)$$

$$W_T = W_{Min} \quad (11)$$

Inventory level constraints

$$I_{st} = I_{s(t-1)} + x_{s(t-1)} - x_{(s+1)t} \quad \forall i \in I(s) \quad (12)$$

$$I_{st} = I_{s(t-1)} + x_{st} - x_{(s+1)t} \quad \forall i \in O(s) \quad (13)$$

$$I_{St} = I_{S(t-1)} + x_{St} - x_{(S+1)t} \quad \forall i \in O(S) \quad (14)$$

$$I_{it} = I_{i(t-1)} + \alpha_{si} I_{st} \quad \forall i \in I(s) \quad (15)$$

$$I_{it} = I_{i(t-1)} + \beta_{si} I_{st} \quad \forall i \in O(s) \quad (16)$$

$$I_{i0} = R_{i0} \quad \forall i \quad (17)$$

$$I_{iT} \leq R_{iT} \quad \forall i \quad (18)$$

$$R_{iMin} \leq I_{it} \leq R_{iMax} \quad \forall i \quad (19)$$

$$I_{it} \geq 0, x_{st} \geq 0, R_{iMax} \geq 0 \quad \forall i, s, t \quad (20)$$

Constraints (11)-(15) are mass balance equations for inventory level constraints for each time period t . Constraints (16)-(17) are initial and final inventory level constraints. Constraints (18) are buffer size constraints. Constraints (19) are

non-negativity constraints.

Production capacity level constraints

$$x_{st} \leq K_{st} \quad \forall s \quad \forall t \quad (21)$$

$$x_{(s+1)t} \leq x_{st} + I_{s(t-1)} \quad \forall s \quad \forall t' \quad (22)$$

The constraints (20) specify that each stage s production x_{st} of product i is bounded above by its maximum capacity limit K_{st} . The constraints (21) specify that each stage $s + 1$ production $x_{(s+1)t}$ of product i is bounded above by the previous stage production x_{st} plus previous period inventory $I_{s(t-1)}$.

Consumption demand level constraints

$$\sum_{i=i_1}^{I_R} \beta_{si} x_{(s+1)t} \leq \sum_{i=i_1}^{I_R} D_{it} \quad \forall i \in O(s) \quad \forall t' \quad (23)$$

The constraints (22) specify that each final stage $S + 1$ consumption $x_{(S+1)t}$ of product i is bounded above by the maximum demand D_{it} for each time period t .

2.3 Greedy search heuristic for two stage production problem

The problem is modeled as residual network $G = (v, A)$ where $v = \{t_1, t_2, \dots, t_T\}$, and $(t_i, t_j) \in A$ if $i \leq j$. This means the production at period t_i is used to meet the production/consumption demand at period t_j . For each period $t = t_1, t_2, \dots, t_T$ suppose stage s can produce a maximum of K_{st} units and stage $s + 1$ can process $D_{(s+1)t}$ units and a buffer of reasonable size has to be installed in between the stages s and $s + 1$ to balance the demand and supply using inventory control.

We illustrate the greedy search heuristic using single item capacitated dynamic inventory control optimization. Let for each time period, the production capacity be K_{st} and demand for the next stage operation/consumption be $D_{(s+1)t}$.

$$D_{st} = K_{st} \quad \text{for } s = s_2, s_3, \dots, s_S \quad (24)$$

$$D_{st} = D_{(S+1)t} \quad \text{for } s = S + 1 \quad (25)$$

The portion of the demand that may not be met from maximum production within the same period was denoted by $d_{st}^-, t = t_1, t_2, \dots, t_T$ and is given by equations (25). This demand may be partly or totally satisfied from previous

period inventory if that inventory level is positive. The previous period inventory depends on the excess productions beyond the demands in early periods that are denoted by d_{st}^+ , $t = t_1, t_2, \dots, t_T$ and are given by equations (26).

$$d_{st}^- = \max\{0, D_{(s+1)t} - K_{st}\} \quad (26)$$

$$d_{st}^+ = \max\{0, K_{st} - D_{(s+1)t}\} \quad (27)$$

For each period $t = t_1, t_2, \dots, t_T$, $d_{st}^+ d_{st}^- = 0$. A period t is stockin if $d_{st}^+ > 0$ and t is stockout if $d_{st}^- > 0$.

At the first phase of planning, to satisfy as much of the unmet demands as possible, it is necessary to produce excess at early periods and to meet early unmet demands from inventory plus production rather than reserving it for latter deficits. This decision is made without any cost-benefit analysis. Such an approach is termed a greedy search method.

Thus, the following schedule given by equations (27)-(30) for each period $t = t_1, t_2, \dots, t_T$ maximizes the number of units at consumption sectors to be satisfied from production plus inventories in stage one.

$$I_{s1} = d_{s1}^+ \quad (28)$$

$$I_{st} = \max\{0, I_{s(t-1)} + d_{st}^+ - d_{st}^-\} \quad (29)$$

$$x_{st} = K_{st} \quad (30)$$

$$x_{(s+1)t} = \min\{x_{st} + I_{s(t-1)}, D_{(s+1)t}\} \quad (31)$$

With this schedule there is an unmet demand at stage $s + 1$ at time period t' if $D_{(s+1)t'} > x_{st'} + I_{s(t'-1)}$. This means it is not possible to decrease any of the production levels $x_{st} = K_{st}$ for $t = t_1, t_2, \dots, t'$ in order to meet as much of the demands from production plus inventory. To supply one more unmet demand at period t' another one unit deficit should be created for any of the periods $t = t_1, t_2, \dots, t'_t - 1$. This is not possible if $t' = 1$. Even if $t' > 1$, this decision will have an additional inventory holding cost $\sum_{t=t''}^{t'-1} h_{st}$ where t'' is the time period for which an additional one unit deficit is created in order to satisfy one unit of unmet demand at period t' . It also has an additional penalty cost $p_{(s+1)t''} - p_{(s+1)t'}$ where $p_{(s+1)t''}$ and $p_{(s+1)t'}$ are the penalty costs for one unit deficits at periods t'' and t' respectively. It depends on whether the value $\sum_{t=t''}^{t'-1} h_{st} + p_{(s+1)t''} - p_{(s+1)t'}$ is positive or not the decision that an additional one unit deficit is created at periods t'' in order to satisfy one additional unit of unmet demand at period t' is preferable for the optimal decision. If an assumption is made that at any period, $h_{s(t-1)} + p_{s(t-1)} - p_{(s+1)t} > 0, \forall t = t_1, t_2, \dots, t_T$, it is not necessary to supply one more unmet demand at period t' by creating another one unit deficit at a previous period. In this case the above schedule not only optimizes the number of units of stage two demand satisfied from production plus inventories in stage one but also the total cost of supply.

However, with the above schedule if there exists a period t' for which there are no unmet demands for $t = t', t' + 1, t' + 2, \dots, T$, it may be necessary to decrease some of stage one production without decreasing any of stage two supplies in order to lead the final inventory to zero. With the above schedule, if $I_{sT} \leq R_{sT}$ then the schedule given by equations (27)-(30) also optimizes stage two consumption and the corresponding inventory that optimize the production and inventory holding costs. Otherwise, it is necessary to decrease the inventory level using the following backward recursion formula for each period $t = t_1, t_2, \dots, t_T$ from I_{sT} so that $I_{sT}^* = R_{sT}$.

$$I_{sT}^* = R_{sT} \quad (32)$$

$$I_{s(T-1)}^* = \min\{I_{s(T-1)}, R_{sT} + d_{sT}^-\} \quad (33)$$

$$I_{s(t-1)}^* = \min\{I_{s(t-1)}, I_{st}^* + d_{st}^- - d_{st}^+\} \quad (34)$$

$$B_s^* = \max_{t=t_1}^{t_T} \{I_{st}^*\} \quad (35)$$

Equations (31)-(33) eliminate any of the excess inventories in stage one that are beyond the demands afterwards. The corresponding stage two allocation and stage one production are given by equations (35)-(36) for each period $t = t_1, t_2, \dots, t_T$.

$$x_{(s+1)t}^* = x_{(s+1)t} \quad (36)$$

$$x_{st}^* = \min\{x_{st}, x_{(s+1)t}^* + I_{st}^* - I_{s(t-1)}^*\} \quad (37)$$

Equations (31)-(36) solve the two stage dynamic inventory control optimization problem and we refer it TSP-DICO model solution. With repeated applications of TSP-DICO it was possible to solve the multi- stage production dynamic inventory control problem.

$$I_{it}^* = I_{st}^* \alpha_{si} \quad \forall i \in I(s) \quad (38)$$

$$I_{it}^* = I_{st}^* \beta_{si} \quad \forall i \in O(s) \quad (39)$$

Equations (37)-(38) give the quantity of item i in inputs and outputs of stage s production.

First stage decision

$$D_{st} = K_{st} \text{ for } s = s_2, s_3, \dots, s_S$$

$$D_{st} = D_{(S+1)t} \text{ for } s = S + 1$$

$$d_{st}^- = \max\{0, D_{(s+1)t} - K_{st}\}$$

$$d_{st}^+ = \max\{0, K_{st} - D_{(s+1)t}\}$$

$$I_{s1} = d_{s1}^+$$

$$I_{st} = \max\{0, I_{s(t-1)} + d_{st}^+ - d_{st}^-\}$$

$$x_{st} = K_{st}$$

$$x_{(s+1)t} = \min\{x_{st} + I_{s(t-1)}, D_{(s+1)t}\}$$

if $I_{sT} \leq R_{sT}$ Stop

Second stage decision

$$I_{sT}^* = R_{sT}$$

$$I_{s(T-1)}^* = \min\{I_{s(T-1)}, R_{sT} + d_{sT}^-\}$$

$$I_{s(t-1)}^* = \min\{I_{s(t-1)}, I_{st}^* + d_{st}^- - d_{st}^+\}$$

$$B_s^* = \max_{t=t_1}^{t_T} \{I_{st}^*\} x_{(s+1)t}^* = x_{(s+1)t}$$

$$x_{st}^* = \min\{x_{st}, x_{(s+1)t}^* + I_{st}^* - I_{s(t-1)}^*\}$$

$$I_{it}^* = I_{st}^* \alpha_{si} \text{ for all } i \in I(s)$$

$$I_{it}^* = I_{st}^* \beta_{si} \text{ for all } i \in O(s)$$

The illustration of the application of the greedy search heuristic (GSH) for single item capacitated dynamic inventory control optimization for multi-stage agro-processing production is as follows. Let there be only three stages 1, 2, 3.

Step 1: Take the production capacity at stage 1 $K_{st} = K_{1t}$ and demand for the next stage operation/consumption to be industrial production capacity $D_{(s+1)t} = K_{2t}$ and solve the problem using the proposed solution procedure (GSH) for TSP-DICO discussed in section 2.3 to determine the decentralized optimal stage one schedule for inventory I_{1t} , agricultural production x_{1t} and industrial production x_{2t}

Step 2: Take the production capacity at processing industry production $K_{st} = K_{2t}$ and demand for the next stage operation/consumption to be domestic consumption demand $D_{(s+1)t} = D_{3t}$ and solve the problem using the proposed solution procedure (GSH) for TSP-DICO discussed in section 2.3 to determine the decentralized processing industry production schedule for inventory I_{3t} , industrial production x'_{2t} and final stage consumption x_{3t} .

Step 3: Take the production capacity at processing industry production $K_{st} = x_{2t}$ and demand for the next stage operation/consumption be $D_{(s+1)t} = x'_{2t}$ and solve the problem using the proposed solution procedure (GSH) for TSP-DICO given in section 2.3 to determine the centralized optimal pre-stage two production schedule for inventory I_{2t}^* and aspiration level processing industrial production x_{2t}^* .

Step 4: Take the production capacity at agricultural production $K_{st} = K_{1t}$ and demand for the next stage operation/consumption be $D_{(s+1)t} = x_{2t}^*$ and solve the problem using the proposed solution procedure (GSH) for TSP-DICO given in section 2.3 to determine the centralized optimal stage one schedule for I_{1t}^* , and aspiration level for agricultural production x_{1t}^* .

Step 5: Take the production capacity at industrial production $K_{st} = x_{2t}^*$

and demand for the final stage operation/consumption be $D_{(s+1)t} = D_{3t}$ and solve the problem using the proposed solution procedure (GSH) for TSP-DICO given in section 2.3 to determine the centralized optimal final stage schedule for inventory I_{3t}^* industrial production x_{2t}^* and aspiration level for final stage consumption x_{3t}^* .

2.4 Bilevel fuzzy goal programming

Water allocation decisions are compounded by a number of uncertainties. The watershed is a useful unit for water resources management, since institutions representing the watershed can bring together and consider the goals of all interconnected parties and balance the costs and benefits of interventions [54]. Because of these great complications, it is not possible to describe all the physical characteristics within the watershed with exact physical laws, instead, using the GP concept the effort is directed to the construction of a model representing the most important processes, and their interaction within the total system. The reason for this is that models are the easier means of gaining insight into the planning, operation and policy formulation of systems that have some degree of complexity. Water allocation decisions not only require consideration and understanding of the hydrological cycle of the watershed and the associated pattern of interconnection between agents, but also the evaluation of demands in a coherent and objective manner so as to balance demand and supply and meet social welfare goals. Therefore, the GP approach becomes a more flexible method to handle such complications. The advantage of GP is it enables to take selective actions on affected sectors or parts of the ecosystem rather than optimizing the whole watershed. There is no single optimum solution for these problems but rather a set of alternative efficient solutions which are called Pareto optimal solutions (non-inferior or non-dominated solutions). GP plays an important role in solving real world problems with multiple conflicting goals.

Lack of control mechanism between allocated water and actually consumed by users, the uncertainties in each DM's goal and insufficient knowledge of available resources make the decision making environment fuzzy. To handle these uncertainties fuzzy logic and fuzzy goal programming (FGP) approaches are proposed. In fuzzy programming, some of the model parameters, decision variables or goals may be expressed in terms of imprecise measurements, language or logic and in these cases fuzzy numbers, fuzzy arithmetic and fuzzy logic are incorporated into the mathematical modeling application. These uncertain measurements are expressed in terms of aspiration levels and their tolerance limits [55]. An aspiration level is the most preferred decision that we assign the highest membership value (unity) while tolerances are the extents

to which deviations from the aspiration level are admissible. A solution of a fuzzy goal programming problem depends on how the aspiration levels and tolerance limits are chosen. Tolerance limits may be lower tolerance limits, upper tolerance limits or both.

To solve the model TSP-DICO, the problem is reformulated as a bilevel fuzzy goal programming problem in which the first level goal of production maximization is represented by f_u and the remaining goals at the lower level are represented by $f_k, k = 1, 2, \dots, L$ where L is the number of goals to be optimized at the lower level.

For $x \in X \subset \mathfrak{R}^n, y \in Y \subset \mathfrak{R}^m, f_u : X \times Y \rightarrow \mathfrak{R}$, and $f_k : X \times Y \rightarrow \mathfrak{R}$, the linear bilevel programming problem (BLPP) can be written as follows:

$$(P_u) \min_{x \in X} f_u(x, y) = c_u x + d_u y \quad (40)$$

$$\text{subject to } (P_k) \min_{y \in Y} f_k(x, y) = c_k x + d_k y \quad \text{for } k = 1, 2, \dots, L \quad (41)$$

$$\text{subject to } Ax + By \leq b \quad (42)$$

$$x = x_u \quad (43)$$

where $c_u, c_k \in \mathfrak{R}^n; d_u, d_k \in \mathfrak{R}^m; A \in \mathfrak{R}^{n \times p}; B \in \mathfrak{R}^{m \times p}; b \in \mathfrak{R}^p$. In this model there are more than one objective functions at the lower level, the problem is one-leader, multi-follower problem also known as bilevel multi-objective linear programming problem (BLMOLPP).

2.4.1 Construction of membership functions

For minimization problems P_u and P_k with objective functions f_u and f_k respectively, let (x_u^b, y_u^b) and (x_u^w, y_u^w) be the best and worst solutions of the leader's goals and (x_k^b, y_k^b) and (x_k^w, y_k^w) be the best and worst solutions of the respective goals in the lower level $k = 1, 2, \dots, L$. So the respective fuzzy tolerance values of leader and follower appear as $f_u(x_u^b, y_u^b) \preceq f_u(x, y)$ and $f_k(x_k^b, y_k^b) \preceq f_k(x, y)$ where the symbol $\preceq$ stands for the fuzzy comparison of essentially less than relation.

In FGP procedure the highest aspiration levels of the defined membership functions is considered as unity. This value is assigned to the most preferred decision and the lowest aspiration level, zero is assigned to the worst decision. Other decisions take values in between 0 and 1. Linear membership functions like triangular fuzzy numbers (TFN) and trapezoidal fuzzy numbers (TRFN) are commonly used in decision making problems due to their simplicity. Therefore, if the goals, the constraints and the membership functions are linear, then the problem can be solved using the readily available linear programming packages. The triangular membership functions of the defined fuzzy goals can be

formulated as follows:

$$\mu_u(f_u(x, y)) = \begin{cases} 1 & \text{if } f_u(x, y) \leq f_u(x_u^b, y_u^b) \\ \frac{f_k(x_u^w, y_u^w) - f_u(x, y)}{f_u(x_u^w, y_u^w) - f_u(x_u^b, y_u^b)} & \text{if } f_u(x_u^b, y_u^b) \leq f_u(x, y) \leq f_u(x_u^w, y_u^w), \\ 0 & \text{if } f_u(x_u^w, y_u^w) \leq f_u(x, y) \end{cases} \quad (44)$$

$$\mu_k(f_k(x, y)) = \begin{cases} 1 & \text{if } f_k(x, y) \leq f_k(x_k^b, y_k^b) \\ \frac{f_k(x_k^w, y_k^w) - f_k(x, y)}{f_k(x_k^w, y_k^w) - f_k(x_k^b, y_k^b)} & \text{if } f_k(x_k^b, y_k^b) \leq f_k(x, y) \leq f_k(x_k^w, y_k^w), \\ 0 & \text{if } f_k(x_k^w, y_k^w) \leq f_k(x, y) \end{cases} \quad (45)$$

for $k = 1, 2, \dots, L$

According to [56], the respective tolerance ranges of the decision vectors x and y , are considered as $x^b = \min\{x_u^b, x_k^b, x_u^w, x_k^w\}$, $x^w = \max\{x_u^b, x_k^b, x_u^w, x_k^w\}$, $y^b = \min\{y_u^b, y_k^b, y_u^w, y_k^w\}$, $y^w = \max\{y_u^b, y_k^b, y_u^w, y_k^w\}$ and the membership functions of the defined fuzzy goals can be formulated as in (45) - (46).

$$\mu_{x_u^b}(x) = \begin{cases} \frac{x - (x_u^b - x^b)}{x^b} & \text{if } x_u^b - x^b \leq x \leq x_u^b \\ \frac{(x_u^b + x^w - x)}{x^w} & \text{if } x_u^b \leq x \leq x_u^b + x^w \\ 0 & \text{Otherwise} \end{cases} \quad (46)$$

$$\mu_{y_k^b}(y) = \begin{cases} \frac{y - (y_k^b - y^b)}{y^b} & \text{if } y_k^b - y^b \leq y \leq y_k^b \\ \frac{(y_k^b + y^w - y)}{y^w} & \text{if } y_k^b \leq y \leq y_k^b + y^w \\ 0 & \text{Otherwise} \end{cases} \quad (47)$$

2.4.2 Formulation of membership goals

According to [30], for the defined membership functions in (43) - (46), by introducing the under-and over-deviational variables $\tilde{\delta}_{ju}^-$, $\tilde{\delta}_{ju}^+$, $j \in \{f, b, w\}$ and $\tilde{\delta}_{jk}^-$ and $\tilde{\delta}_{jk}^+$, $j \in \{f, b, w\}$, the membership functions are converted into fuzzy goals with the upper and lower level as (47) - (52). In [57], only $\tilde{\delta}_{fu}^-$ and $\tilde{\delta}_{fk}^-$ are proposed for the highest aspired level 1 of the fuzzy goal in (43) and (44) but for the fuzzy goal in (45) - (46) both deviation variables are required.

$$\frac{f_u(x_u^w, y_u^w) - f_u(x, y)}{f_u(x_u^w, y_u^w) - f_u(x_u^b, y_u^b)} + \tilde{\delta}_{fu}^- = 1 \quad (48)$$

$$\frac{x - (x_u^b - x^b)}{x^b} + \tilde{\delta}_{bu}^- - \tilde{\delta}_{bu}^+ = 1 \quad (49)$$

$$\frac{(x_u^b + x^w - x)}{x^w} + \tilde{\delta}_{wu}^- - \tilde{\delta}_{wu}^+ = 1 \quad (50)$$

$$\frac{f_k(x_k^w, y_k^w) - f_k(x, y)}{f_k(x_k^w, y_k^w) - f_k(x_k^b, y_k^b)} + \tilde{\delta}_{fk}^- = 1 \quad (51)$$

for $k = 1, 2, \dots, L$

$$\frac{y - (y_k^b - y^b)}{y^b} + \tilde{\delta}_{bk}^- - \tilde{\delta}_{bk}^+ = 1 \quad (52)$$

$$\frac{(y_k^b + y^w - y)}{y^w} + \tilde{\delta}_{wk}^- - \tilde{\delta}_{wk}^+ = 1 \quad (53)$$

To assess the relative importance of the fuzzy goals properly, the weighting scheme suggested by Mohamed [32] that decision makers can rank the different objectives according to their priority in [30] to assign the values to w_{ju}, w_{jk} for $j \in \{f, b, w\}$ and are given by equations (53) - (54).

$$w_{fu} = \frac{1}{f_u(x_u^w, y_u^w) - f_u(x_u^b, y_u^b)}, w_{bu} = \frac{1}{x^b}, w_{wu} = \frac{1}{x^w}, \quad (54)$$

$$w_{fk} = \frac{1}{f_k(x_k^w, y_k^w) - f_k(x_k^b, y_k^b)}, w_{bk} = \frac{1}{y^b}, w_{wk} = \frac{1}{y^w} \quad (55)$$

for $k = 1, 2, \dots, L$

Substituting equations (53) - (54) in (47) - (52) we get the linear constraints (56) - (61).

2.4.3 Formulation of linear model

Hence, we use linearization strategies [57] to transform the BFGP into the standard version of FGP. The standard version of FGP is then solved using common linear programming packages.

$$\max w_{fu} \tilde{\delta}_{fu}^- + \sum_{k=1}^L w_{fk} \tilde{\delta}_{fk}^- + \sum_{j \in \{b, w\}} w_{ju} (\tilde{\delta}_{ju}^- + \tilde{\delta}_{ju}^+) + \sum_{j \in \{b, w\}} \sum_{k=1}^L w_{jk} (\tilde{\delta}_{jk}^- + \tilde{\delta}_{jk}^+) \quad (56)$$

Subject to

$$w_{fu}(f_u(x_u^w, y_u^w) - f_u(x, y)) + \tilde{\delta}_{fu}^- = 1 \quad (57)$$

$$w_{bu}(x - (x_u^b - x^b)) + \tilde{\delta}_{bu}^- - \tilde{\delta}_{bu}^+ = 1 \quad (58)$$

$$w_{wu}(x_u^b + x^w - x) + \tilde{\delta}_{wu}^- - \tilde{\delta}_{wu}^+ = 1 \quad (59)$$

$$w_{fk}(f_k(x_k^w, y_k^w) - f_k(x, y)) + \tilde{\delta}_{fk}^- = 1 \quad \text{for } k = 1, 2, \dots, L \quad (60)$$

$$w_{bk}(y - (y_k^b - y^b)) + \tilde{\delta}_{bk}^- - \tilde{\delta}_{bk}^+ = 1 \quad \text{for } k = 1, 2, \dots, L \quad (61)$$

$$w_{wk}(y_k^b + y^w - y) + \tilde{\delta}_{wk}^- - \tilde{\delta}_{wk}^+ = 1 \quad \text{for } k = 1, 2, \dots, L \quad (62)$$

$$Ax + By \leq b \quad (63)$$

$$x \in X \quad (64)$$

$$y \in Y \quad (65)$$

$$\tilde{\delta}_{fu}^- \tilde{\delta}_{fu}^+ = 0, \tilde{\delta}_{bu}^- \tilde{\delta}_{bu}^+ = 0, \tilde{\delta}_{wu}^- \tilde{\delta}_{wu}^+ = 0, \quad (66)$$

$$\tilde{\delta}_{fk}^- \tilde{\delta}_{fk}^+ = 0, \tilde{\delta}_{bk}^- \tilde{\delta}_{bk}^+ = 0, \tilde{\delta}_{wk}^- \tilde{\delta}_{wk}^+ = 0 \quad \text{for } k = 1, 2, \dots, L \quad (67)$$

$$\tilde{\delta}_{ju}^- \geq 0, \tilde{\delta}_{ju}^+ \geq 0 \quad \text{for } j \in \{f, b, w\} \quad (68)$$

$$\tilde{\delta}_{jk}^- \geq 0, \tilde{\delta}_{jk}^+ \geq 0 \quad \text{for } j \in \{f, b, w\}, k = 1, 2, \dots, L \quad (69)$$

3 Model Application

3.1 Description of the study area

The Gidabo River Basin is located in the south-eastern Main Ethiopian Rift (MER) (Fig. 1). Gidabo watershed is one of resourceful and economically active regions in Ethiopia where surplus production and consumption of agricultural and agro-processed outputs are supplied to the national and international market. It comprises of economically important zones and woredas alongside the main Hawasa-Moyale asphalt road stretching from North East to South West a distance of around 120 km a catchment area of about 3440km². It consists of Sidama and Gedeo zones of Southern Nations Nationalities and People's Regional State (SNNPRS) and W. Guji zone of Oromia Regional State. The river is one of the main flow contributors to Lake Abaya.

The flow of main river Gidabo is being measured at Aposto where the river has 646km² catchments with mean annual runoff 216 mm and mean annual discharge 140 Million Cubic Meter (MCM). Two of its tributaries namely Kolla (catchment 206km²) near Aleta Wondo (1975-2005) also measured for flow at Aleta Wondo since 1980 with mean annual runoff 523 mm and mean annual discharge 107.77 MCM and Bedessa (catchment 80km²) near Dilla with mean annual runoff 701.90 mm and mean annual discharge 63.87 MCM. A new station at Meissa (near the dam site) was set up in 1997 on Main River where its

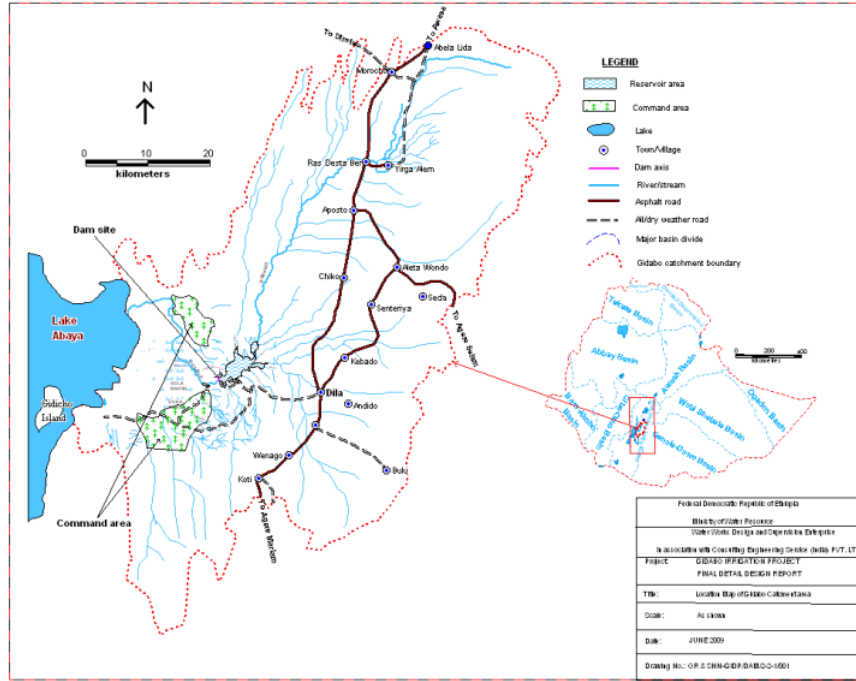


Figure 1: The Gidabo Watershed

catchments area is 2575km^2 with mean annual runoff 238.85 mm and mean annual discharge 615.05 MCM. The Gidabo River has many perennial tributaries originating from the Sidama mountain peaks. The left bank area can be accessed by a dry weather road from Dila, while the right bank can be reached by a dry weather road from Antate town.

The watershed is best known for its high coffee production and coffee marketing center. Two varieties of export standard Specialty Coffee (Sidama Coffee and Yirga Chefe Coffee) are grown and they have highest standards in the export market. Wet coffee processing is becoming very popular for the high value it adds to the export market. Coffee is one of the world's largest agricultural products and it is one of the most popular beverages, which is consumed by millions of people every day. It is the second largest traded commodity in the world next to petroleum, and generates huge amount of coffee byproducts during processing [58]. Coffee processing refers to the methods used to transform a picked coffee cherry into a green coffee bean that is ready to be roasted and then being brewed. It includes the steps used to remove the different layers surrounding a coffee bean, the cherry, mucilage and parchment. Almost all wet coffee processing plants in Ethiopia are located close to water bodies due to the fact that it requires a lot of water (on average 15 liters of water/kg of coffee bean) is needed for washing the beans, removing the pulp and the

mucilage, but also in order to use the water bodies for direct disposal of the waste water released from the wet coffee processing plants. In Ethiopia almost all, wet coffee processing industries are not reusing the water that is once used for depulping and fermentation.

Wet coffee processing step yields coffee pulp, mucilage, enormous quantities of high strength waste water on the one hand, and coffee beans with hulls on the other. The separated pulp which is used for varieties of purposes can be discarded as waste material after which the grains are transported to fermentation reservoirs. In the fermentation reservoirs the grains remain between 12 and 36 hours, depending on the temperature, the thickness of the mucilage layer and the concentration of enzymes. Then, mucilage layer is fermented through a combination of microbial activity and the work of endogenous enzymes contained within the mucilage. The process is finished after the grains are washed to eliminate the last remnants of decomposed mucilage. Finally, coffee brought to this mill is to be sun-dried or by using electrical dryer. When it is dried the parchment is manually or mechanically removed. Then, green coffee is stored in silos and is ready to be used and exported [58].

Pollution of water is commonly defined as any physical, chemical or biological change in water quality which adversely impact the living organisms in the environment or which makes a water resource unsuitable for one or more of its beneficial uses. The reason for its high level of pollution is that, water is indeed a wonderful chemical medium which has unique properties of dissolving and carrying in suspension huge varieties of chemicals. Coffee processing plants are one of the major agro- industries which are contributors for water pollution. However, even when there are seemingly significant price premiums for washed coffee, only about 30% of Ethiopia's coffee export is washed and the country and coffee processors are missing out on the opportunity of higher production [37].

3.2 Input data for two-stage production problem

The data in Table 1 indicating the maximum production capacities at the two levels, maximum demand for consumption, holding costs, production costs, penalty costs, water demand at each level were collected from 121 private and 57 cooperatives coffee processing plants in Sidama and Gedeo zones within Gidabo watershed.

Table 1: Input data for two-stage production model for an agro-processing industry.

Factors	Periods (Months)												
	1	2	3	4	5	6	7	8	9	10	11	12	
Production Capacity (Volumes of industrial products 10^3Tones)													Total
Agri	39	34	31	20	32	26	39	14	31	20	32	26	344
Indu	38	40	30	17	25	26	38	40	30	17	25	26	352
Consumption Demand (Volumes of industrial products 10^3Tones)													Total
Domestic	18	27	16	36	29	38	18	27	16	36	29	38	328
Unit Minimum Water Demand (m^3/Tone)													Total
Agri	56	72	64	56	60	64	72	64	56	60	64	60	
Indu	28	24	24	32	24	24	24	24	32	24	24	32	
Domestic	32	32	28	28	24	32	32	28	28	24	32	24	
Scenario	Maximum Available Water ($10^5 m^3$)												Total
v. high	35	44	29	66	52	24	20	36	36	38	25	25	430
low	25	33	19	54	40	14	10	26	26	28	15	15	305
low (reuse)	25	33	19	54	40	14	10	26	26	28	15	15	305
normal	30	38	24	62	48	19	15	31	31	33	20	20	371
Unit Production Cost (<i>Birr/Quintal</i>)													
Agri	49	63	56	49	53	56	63	56	49	53	56	53	
Indu	35	31	31	38	31	31	31	31	38	31	31	38	
Unit Penalty Cost (<i>Birr/Quintal</i>)													
Domestic	72	83	72	72	65	76	83	72	72	65	76	72	
Unit Inventory holding cost (<i>Birr/Quintal/month</i>)													
Stage 1	40	40	40	40	40	40	40	40	40	40	40	40	
Stage 2	60	60	60	60	60	60	60	60	60	60	60	60	

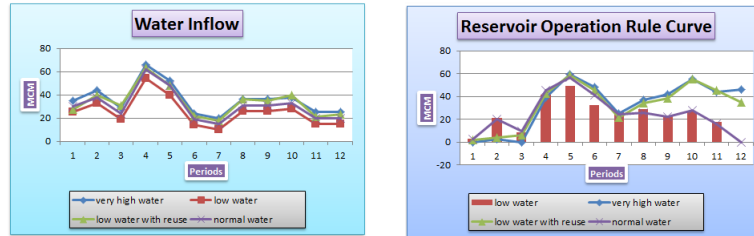


Figure 2: Available Water and Optimal reservoir operation for different scenarios of water availability.

Figure 3: Optimal production, water allocation and unmet production at agricultural stage for different scenarios of water availability.

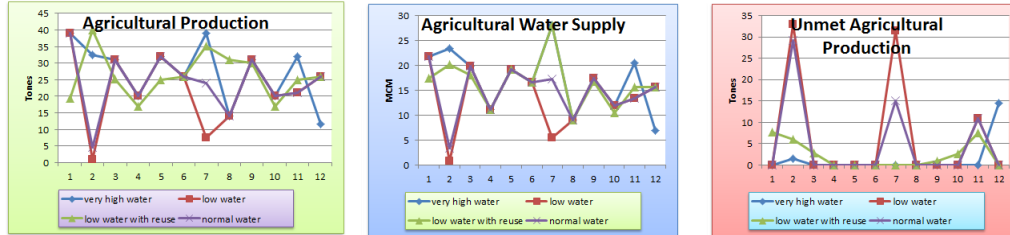


Figure 4: Optimal production, water allocation and unmet production at industrial stage for different scenarios of water availability.

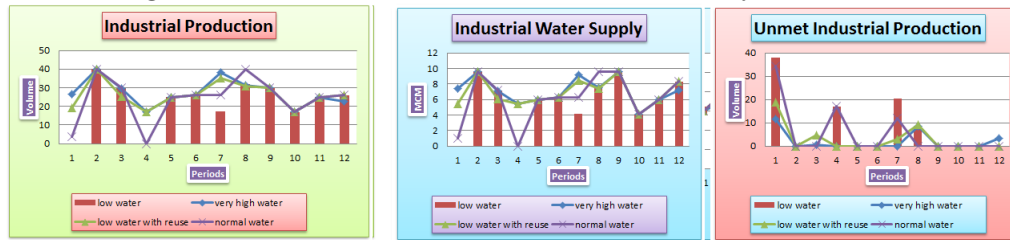


Figure 5: Optimal supply of production, water allocation and unmet demand at domestic consumption for different scenarios of water availability.

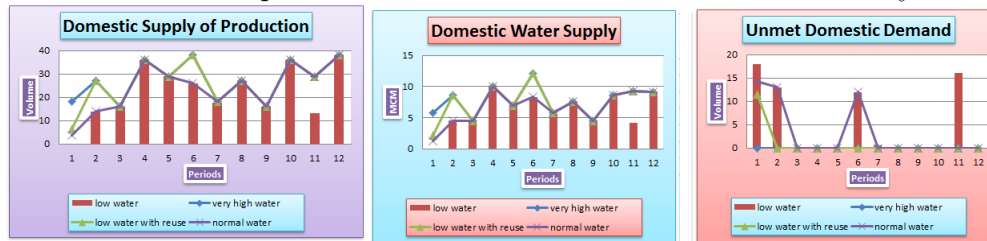


Figure 6: Optimal inventory levels and reservoir operation for different scenarios of water availability.



3.3 Results and discussions

3.3.1 Scenario 1: Very high water availability without reuse

Table 2: Optimal Production and Reservoir Operation for Scenario 1

Factors	Periods (Months)												
	1	2	3	4	5	6	7	8	9	10	11	12	
Water Allocated ($10^5 m^3$)													Total
Agri	22	23	20	11	19	17	28	9	17	12	20	7	206
Industry	7	10	7	5	6	6	9	8	10	4	6	7	85
Domestic	6	9	4	10	7	12	6	8	4	9	9	9	93
Total	35	42	31	27	32	35	43	24	31	25	36	23	384
Total Available Water ($10^5 m^3$)													Total
Inflow	35	44	29	66	52	24	20	36	36	38	25	25	430
Reservoir Operation ($10^5 m^3$)													Max
	0	2	0	39	59	48	25	37	42	55	44	46	59
Production ($10^3 Tones$)													Total
Agri	39	32	31	20	32	26	39	14	31	20	32	12	328
Industry	26	40	30	17	25	26	38	31	30	17	25	23	328
Consumption ($10^3 Tones$)													Total
Domestic	18	27	16	36	29	38	18	27	16	36	29	38	328
Inventory levels ($10^3 Tones$)													Max
Stage 1	13	5	6	9	16	16	17	0	1	4	11	0	17
Stage 2	8	21	35	16	12	0	20	24	38	19	15	0	38
Unmet Production ($10^3 Tones$)													Total
Agri	0	2	0	0	0	0	0	0	0	0	0	14	16
Industry	12	0	0	0	0	0	0	9	0	0	0	3	24
Unmet Consumption ($10^3 Tones$)													Total
Domestic	0	0	0	0	0	0	0	0	0	0	0	0	0

In this scenario (see Table 2) the model TSP-DICO is used to solve the problem and all the consumption demands are fully satisfied from production and inventory at the two production stages. Thus there is no unmet demand for domestic consumption. Consequently, there is no penalty cost incurred due to infeasibility. However, the productions at the two stages were limited by the consumption demand even if there was excess water in the reservoir at the end of the planning period. This solution also agrees with the greedy search heuristic (GSH) solution and it has the highest aspiration level (unity) for the fuzzy goal of the leader's problem. The water supply target in this case was not fully satisfied and the aspiration level attained for the fuzzy goal of the water supply target was 0.893.

3.3.2 Scenario 2: Low water availability without reuse

Table 3: Optimal Production and Reservoir Operation for Scenario 2

Factors	Periods (Months)												
	1	2	3	4	5	6	7	8	9	10	11	12	
Water Allocated ($10^5 m^3$)													Total
Agri	22	1	20	11	19	17	5	9	17	12	13	16	162
Industry	0	10	7	0	6	6	4	8	10	4	6	8	69
Domestic	0	4	4	10	7	8	6	8	4	9	4	9	74
Total	22	15	32	21	32	31	15	24	31	25	24	33	305
Total Available Water ($10^5 m^3$)													Total
Inflow	25	33	19	54	40	14	10	26	26	28	15	15	305
Reservoir Operation ($10^5 m^3$)													Max
	3	21	9	42	49	32	27	29	23	27	18	0	49
Production ($10^3 Tones$)													Total
Agri	39	1	31	20	32	26	8	14	31	20	21	26	269
Industry	0	40	30	0	25	26	17	32	30	17	25	26	269
Consumption ($10^3 Tones$)													Total
Domestic	0	14	16	36	29	26	17	27	16	36	13	38	269
Inventory levels ($10^3 Tones$)													Max
Stage 1	39	0	1	21	28	28	18	0	1	4	0	0	39
Stage 2	0	26	40	4	0	0	0	5	19	0	12	0	40
Unmet Production ($10^3 Tones$)													Total
Agri	0	33	0	0	0	0	31	0	0	0	11	0	75
Industry	38	0	0	17	0	0	21	8	0	0	0	0	84
Unmet Consumption ($10^3 Tones$)													Total
Domestic	18	13	0	0	0	12	1	0	0	0	16	0	60

In this scenario (see Table 3) the model TSP-DICO is used to solve the problem and 269 units of consumption demands are fully satisfied from production and inventory at the two production stages. Thus there are 59 units of unmet demand for domestic consumption. Consequently, there is equivalent penalty cost incurred due to infeasibility. The aspiration level attained for the fuzzy goal of the production target was 0.82. However, the productions at the two stages were limited by the available water even if there were unmet demands for domestic consumption at the end of the planning period. The water supply target in this case was fully satisfied and the aspiration level attained for the fuzzy goal of the water supply target was 1.

3.3.3 Scenario 3: Normal water availability without reuse

Table 4: Optimal Production and Reservoir Operation for Scenario 3

Factors	Periods (Months)												
	1	2	3	4	5	6	7	8	9	10	11	12	
Water Allocated ($10^5 m^3$)													Total
Agri	22	3	20	11	19	17	17	9	17	12	13	16	177
Industry	1	10	7	0	6	6	6	10	10	4	6	8	74
Domestic	1	4	4	10	7	8	6	8	4	9	9	9	80
Total	24	17	32	21	32	31	29	26	31	25	29	33	331
Total Available Water ($10^5 m^3$)													Total
Inflow	27	35	21	57	43	16	12	28	28	30	17	17	331
Reservoir Operation ($10^5 m^3$)													Max
	3	20	10	46	57	41	24	26	22	28	16	0	57
Production ($10^3 Tones$)													Total
Agri	39	5	31	20	32	26	24	14	31	20	21	26	289
Industry	4	40	30	0	25	26	26	40	30	17	25	26	289
Consumption ($10^3 Tones$)													Total
Domestic	4	14	16	36	29	26	18	27	16	36	29	38	289
Inventory levels ($10^3 Tones$)													Max
Stage 1	35	0	1	21	28	28	26	0	1	4	0	0	35
Stage 2	0	26	40	4	0	0	8	21	35	16	12	0	40
Unmet Production ($10^3 Tones$)													Total
Agri	0	29	0	0	0	0	15	0	0	0	11	0	55
Industry	34	0	0	17	0	0	12	0	0	0	0	0	63
Unmet Consumption ($10^3 Tones$)													Total
Domestic	14	13	0	0	0	12	0	0	0	0	0	0	39

In this scenario (see Table 4) the model TSP-DICO is used to solve the problem and 289 units of consumption demands are fully satisfied from production and inventory at the two production stages. Thus there are 39 units of unmet demand for domestic consumption. Consequently, there is equivalent penalty cost incurred due to infeasibility. The aspiration level attained for the fuzzy goal of the production target was 0.881. However, the productions at the two stages were limited by the available water even if there was unmet demand for domestic consumption at the end of the planning period. The water supply target in this case was fully satisfied and the aspiration level attained for the fuzzy goal of the water supply target was 1.

3.3.4 Scenario 4: Low water availability with reuse

Table 5: Optimal Production and Reservoir Operation for Scenario 4

Factors	Periods (Months)												
	1	2	3	4	5	6	7	8	9	10	11	12	
Water Allocated ($10^5 m^3$)													Total
Agri	18	20	18	11	19	17	17	9	17	10	16	16	198
Industry	5	10	6	5	6	6	17	7	10	4	6	8	83
Domestic	2	9	4	10	7	12	28	8	4	9	9	9	89
Total	25	38	29	27	32	35	8	24	31	23	31	33	370
Total Available Water ($10^5 m^3$)													Total
Inflow	25	33	19	54	40	14	0	26	26	28	15	15	305
Reused	0	5	10	6	5	6	3	8	7	10	4	6	74
Total Available	25	38	29	60	45	20	6	34	33	38	19	21	379
Reservoir Operation ($10^5 m^3$)													Max
Level	0	0	0	33	47	32	42	16	19	33	21	9	47
Production ($10^3 Tones$)													Total
Agri	31	28	28	20	32	26	0	14	30	17	25	26	317
Industry	19	40	25	17	25	26	7	31	30	17	25	26	317
Consumption ($10^3 Tones$)													Total
Domestic	7	27	16	36	29	38	39	27	16	36	29	38	317
Inventory levels ($10^3 Tones$)													Max
Stage 1	12	0	3	6	13	13	35	0	0	0	0	0	35
Stage 2	13	26	35	16	12	0	18	21	35	16	12	0	35
Unmet Production ($10^3 Tones$)													Total
Agri	8	6	3	0	0	0	16	0	1	3	7	0	27
Industry	19	0	5	0	0	0	6	9	0	0	0	0	35
Unmet Consumption ($10^3 Tones$)													Total
Domestic	11	0	0	0	0	0	0	0	0	0	0	0	11

In this scenario (see Table 5) the model TSP-DICO is used to solve the problem and 318 units of consumption demands are fully satisfied from production and inventory at the two production stages. Thus there are 10 units of unmet demand for domestic consumption. Consequently, there is equivalent penalty cost incurred due to infeasibility. In comparison with scenario 2 water reuse helped to increase production and consumption target with 49 units at each stage. In comparison with scenario 3, the production target with water reuse is larger than the production target with normal water availability by 29 units at each stage. The aspiration level attained for the fuzzy goal of the production target was 0.97. However, the productions at the two stages were increased due to reused water from industry thus the water supply target was overachieved at the end of the planning period and the aspiration level attained for the fuzzy goal of the water supply target was 1.

4 Conclusion

The proposed TSP-DICO model and the associated Bilevel Fuzzy Goal Programming (BL-FGP) approach incorporated the state-of-art methods for inventory control optimization into water allocation planning methodology to develop a better water management decision so as to avoid conflicts between competing agricultural, industrial and domestic sectors. The multi-stage decision problem is decomposed as several subproblems of two-stage model application and in subsequent steps the algorithm modifies the previous solutions by fixing values obtained at current iteration until finally only one two-stage problem remains in the optimization problem which could be solved using the proposed BL-FGP. The methodology sufficiently eliminates overproduction beyond demand for consumption by domestic sector from both agricultural sector and processing industries and water allocation decision was made to meet as much of the demands with little stress on the already aggravated water conflicts. It also eliminates wastes beyond the capacity of waste disposal from all the three sectors of agriculture, processing industry production and domestic consumption. In this, FGP is advantageous over classical optimization techniques in that it attempts to find one or more feasible solutions which satisfy a number of designed goals to the extent possible and helps to take selective actions pertinent to the problem based on expertise judgment. The FGP formulation may be difficult to solve in general. However if the goals, the constraints and the membership functions are linear, then the problem can be solved using the readily available linear programming packages. There are several alternative for optimal water allocation under conflicting demand and supply and using FGP efficient solutions are generated to help the management select the most preferred solution (set of solutions).

5 Open Problem

In many areas of the world, international agreements have created amenable conditions for upstream-downstream cooperation. However there are loops in these agreements that open up room for any conflict and negotiation. It is an open problem for any upstream and downstream users to agree on mechanisms to allocate the water resources from their shared water basin. Solving FGP with nonlinear membership functions can be viewed as an open problem and developing software packages for solving such problems could be a challenging task.

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