IMPACTS OF ALTERNATIVE WATER POLICY SCENARIOS ON SUSTAINABILITY OF IRRIGATION DEVELOPMENT IN LAKE TANA BASIN, ETHIOPIA: A POSITIVE MATHEMATICAL PROGRAMMING APPROACH

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Abstract

Although the achievements of irrigation in ensuring food security and improving rural welfare have been impressive, the practice had encountered a number of problems and failures of irrigated agriculture in relation to its high water consumption and other environmental concerns. This study has investigated the impacts of alternative water policy scenarios on sustainability of irrigation developmentby applying a PMP simulation model in two modern irrigation schemes of Lake Tana Basin, Ethiopia. According to the simulation model, implementation of each alternative water policy scenario may result in reduction of total cultivated land in both irrigation schemes. In general, implementation of alternative water policy scenarios may lead to deterioration of the economic (i.e. reduction of private income) and social (i.e. reduction of rural labor demand) roles of irrigated agriculture in the study area, while, at the same time, it will improve the environmental sustainability of irrigated agriculture (a reduction of negative externalities such as consumption of irrigation water and release of agrochemicals such as fertilizers and pesticides).Although measuring the overall impacts of alternative policies requires composite indicators of sustainability, the results of this study suggested that, in general, relatively lower water price levels are conducive to meet the environmental requirements with less economic and social impacts, and will result in a more sustainable irrigation development if they are complementarily applied with restricted water supply levels. Furthermore, the results suggested that water policies should be designed in such a way that they are able to address a specific objective(s) of water resource management. The results of this study can be useful as they will enable policy makers to reflect on the design and implementation of policies that affect the sustainability of irrigated agriculture. The results of this analysis may also be relevant in improving the existing water policy at national level

Key words: sustainability, irrigation development, PMP, water policy scenarios, Lake Tana Basin

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1. Introduction

Although the achievements of irrigation in ensuring food security and improving rural welfare have been impressive, past experience indicates problems and failures of irrigated agriculture inrelation to its high water consumption andother environmental concerns(Kampas*et al.;* 2010, Ward, 2007). The marked reduction in annual discharge of some of the major rivers has been attributed, in part, to the large water depletion caused by irrigated agriculture. In some basins, excessive diversion of river water for irrigation has brought environmental and ecological disasters to downstream areas (Cai*et al.*, 2001). Furthermore, many of the water quality problems have also been attributed to excessive use of agrochemicals in irrigated agriculture.

There is no question that the demand for water resource will increase significantly in the years to come mainly due to population growth, economic growth and climate change and hence, water scarcity is expected to be a major concern worldwide as we progress into the 21st century (Zugravu and Turek, 2010; ADB/ADF, 2000). The growing scarcity and competition for water, in quantity, quality and location threatens the sustainability of economic development in many developing countries and thus, poverty will remain persistent problem in such countries.

The agricultural sector in Ethiopia is highly dependent on unreliable and erratic distribution of rainfall which has persistently affected agricultural production and economic growth. The country is, however, endowed with comparatively huge water resource potential having 12 major river basins with an annual runoff volume of 122 billion m^3 of water and an estimated 2.6 billion $m^3$of ground water potential (Awulachew*et al.*, 2010 and World

Bank, 2006).The country has an estimated 3.6 million ha of irrigable land out of which very small proportion is developed (MOFED, 2006).As a result, irrigation development has been identified as one of the core strategies aimed to de-link economic performance from the existing nature of erratic rainfall and bring sustainable development.

Owing to its huge water resource potential for irrigation development, Lake Tana Basin is identified as a region of agricultural development toenhance commercialization and diversification of agricultural production (Heide, 2012). However, an important challenge in water management is to satisfy growing human demands for water while protecting the aquatic ecosystems upon which economies and life depend.

Despite, its huge economic, social and environmental importance with a rich biodiversity, the lake and its surrounding area are facing very serious threats of environmental and social crises as a result of irrigation and hydropower developments around the lake area. The increased demand for water resource resulted in huge impacts on the river flows, water quality, fish populations, livelihoods in the downstream areas and aquatic plant communities.

Effective water resources development is widely recognized as crucial for sustainable economic growth and poverty reduction in developing countries (World Bank, 2004). Maintaining current irrigation practices will, therefore, put Lake Tana basin and the Lake itself at tremendous risk. Environmental problems associated with irrigation development are creeping with slow-onset, low-grade, but cumulative (Glantz, 1999), and it will take longer to reverse the changes if not impossible.Therefore, the present status of poor water resource management in LTB is in need of urgent solution which relies on theprovision of appropriate water policy. This in turn requires a better understanding of the possible impacts of alternative water policy scenarios on the sustainability of irrigated agriculture.However, there is lack of research in Ethiopia and many other developing countries onthis issue. This study is,therefore, aimed at investigating the impacts of alternative water policy scenarios on sustainability of irrigation development in Lake Tana Basin, Ethiopia.

2. Methodology

2.1. Study Area

The study was conducted in Lake Tana Basin irrigated agriculture in Northwestern part of Ethiopia. The basin is geographically located between 10°58`–12°47`N latitudes and 36°45`-38°14`E longitudes. The climate of Lake Tana basin is 'tropical highland monsoon' with mean annual rainfall of the catchmentarea is about 1280 mm of which about 70% to 90% occurs in the rainy season from June to September (Setegn*et al.,* 2008).

The total area of the basin is 15,319 square kilometers, of which 3150 (about 20%) is the lake area (Conway, 2000). The lake is fed nearly by 60 water sources and only four major perennial rivers namelyGilgelAbay, Gumara, Rib, and Megech contribute 93% of the inflow. About 51.3%, of the Lake Tana Basin is used for agriculture, 29% is agropastoral area (Setegn*et al*., 2008).

This basin is of critical national significance owing to the huge water resource potentials for irrigation, hydroelectric power, high value crops and livestock production, ecotourism and others. There is an increasing demand for irrigation In Lake Tana Basin to cope with the recurrent drought and increasing food demand of an increasing population.Accordingly,the basin is selected as a region for agricultural development in the country and hence,irrigation developments become the focus of water resource management (Awulachew*et al.*, 2009).

2.2. Data

The data used in this study were collected from two modern irrigation schemes of Lake Tana Basin namely Koga large scale and Guanta-Lomidur small scale irrigation schemes with total command area of 7,000 ha, and 133 ha, respectively. Both primary data and secondary data were used for this study. Secondary data concerning irrigation activities, number of irrigation user households, yield data, input use, variable costs of crop production and local crop prices were obtained from official records of local agricultural offices. A household level survey was carried out in May, 2013 in order to verify the validity of the secondary data and support the results.Time series climate data were collected from local meteorology stations to calculate the location based crop-water requirement data based on FAO (2009) using CROPWAT8.0 Software.

2.3. Water Policy Impact Assessment on Sustainability of Irrigated Agriculture: PMP Model

The link between farm and policies is becoming increasingly important in the general framework of model-based policy impact analysis. That is why farm-level mathematical programming models which represent the farmers' behaviour towards changes in policy have become an important and widely used tool for analyses in agricultural economics(Cortignani andSeverini, 2010). The basic motivation for using programming models in agricultural economic analysis is that these models are based on neoclassical economic theory which perceives economic agents as optimizers (Buysse*et al.*, 2007).Mathematical programming provides a tool to evaluate simultaneous policy interventions (Kampas*et al.*, 2010).

Among mathematical programming models, Positive Mathematical Programming (PMP), developed by Howitt (1995), has been widely accepted by many economists as a way of analyzing the *ex-ante* impacts of potential scenarios and policy instruments that affect the agricultural sector (Gallego-Ayala and Gómez-Limón, 2011). PMP is a method to calibrate mathematical programming models to observed behaviours during a reference period by using the information provided by the dual variables of the calibration constraints (Howitt, 1995).The PMP methodology provides the recovery of additional information from observed activity levels in order to specify a non-linear objective function (Cortignani andSeverini, 2010).

The term "positive" that qualifies this method implies that, like in econometrics, the parameters of the non-linear objective function are derived from an economic behaviour assumed to be rational given all the observed and non-observed conditions that generates the observed activity levels. The main difference with econometrics is that PMP does not require a series of observations to reveal the economic behaviour (Henry de Frahan, 2005).

In recent years, PMP has been increasingly used in farm-level economic analyses. The main advantages of this programming approach compared with its counterparts (such as linear programming) are an exact representation of the base situation, lower data requirements and a smoother model response to continuous changes in exogenous parameters when the model is used for impact analysis (Cortignani and Severini, 2011).

One of the main shortcomings of positive mathematical programming (PMP) is its limited capability to simulate activities non-observed in the base situation but that could be adopted if the policy scenario changes. To overcome this difficulty many developments have been made in recent years as an extension of the standard PMP model(e.g. Henry de Frahan, 2005; Rohm and Dabbert, 2003,Heckelei and Britz, 2005, Cortignani and Severini, 2011). However, these extensions of PMP model require more information beyond estimates of prices, yields, input levels and variable costs and hence, are more valid in the context of agriculture in advanced countries.

In this study, we applied the standard PMP model (Howitt, 1995) to investigate water policy impactson sustainability of irrigated agriculture in Lake Tana Basin, since it is suitable for use with the baseline dataset we already have for the study area. On the top that new irrigation technologies are less expected in response to implementation of water policies in the study area due to high cost of installations. The PMP model represents irrigators decision processes and evaluates how they react to alternative water policy scenarios. This standard PMP model is still in use by many scholars (e.g., Dagnino and Ward, 2012).

The analysis begins by building mathematical programming model that maximize net farm income by allocating land and irrigation water across the different crops in both Koga and Guanta-Lomidur irrigation schemes. The model was specified taking into account relevant data thatinclude: (i) the objective function describing the farmers’ behavior as a maximization of net irrigation farm income; and (ii) the set of explicit constraints related to resource availability (land and water) and non-negativity constraints.

This mathematical modeling technique can be established by either a non-linear revenue or non-linear cost function that reproduce the same crop-mix distribution as that observed in the real world. Both are equally valid as means of calibrating mathematical models (Gallego-Ayala andGómez-Limón, 2011). Due to its simplicity and convenience for our dataset, we used non-linear revenue function for calibrating the mathematical programming model.In this way, maximization of a quadratic farm income function is considered, and the parameters of a decreasing yield function are used in the non-linear terms of the total revenue function and reproduce exactly the reference or observed situation. This method is also very useful in assessing policies as it provides reliable outputs.

The central insight of PMP is that observed land allocations are the result of optimizing behavior by farmers. The approach begins by assuming that crop water production is a linear function of land, with observed land and water allocations as constraints. Water and land inputs are assumed to be used in fixed proportions in the production functions for all crops. The resulting shadow prices on these constraints are then used to parameterize production and cost functions that will reproduce observed production and input levels, even without land and water allocation constraints given objective function is income maximization. The PMP modeling approach as applied in this study is outlined as follows.

I. Calibration

Our application of PMP model uses information on conditions required for maximization of farm income to identify parameters of a non-linear function for which unconstrained optimization reproduces observed data. One important source of non-linearity in the farmer's production function is heterogeneity in land quality, resulting in declining yields as the total amount of land increases for a given crop planted (Dagnino and Ward, 2012). The declining land quality at the level of irrigation scheme with an expanded scale of production for any given crop simplifies the many sources of declining yields and captures much of the farm behavioral response.

The crop production function applied in this study assumes that each crop's yield is falling as more land is planted to that crop due to the fact that each crop's best lands are used first, then yields fall off as less-suitable land enters into production. The declining yield function with expanded scale of production is modeled following the methodological framework applied by Dagnino and Ward (2012).

The PMP approach used here begins by assuming that yield is a linear function of land and then total crop production is equal to the product of yield and area of land used in the production.

$$yield = B_o + B_1 Land \qquad (1.1)$$

Where B_o is the crop yield for the first unit of land brought into production, and B_1 is the marginal impact of additional unit of land on yield.For any given crop, the water use rate per unit land is assumed to be constant and the functional relationship canbe expressed as:

$$Land = \frac{water}{B_w}$$

(1.2)

Where B_w is crop-water requirement per unit of land in production, and substituting Equation (1.2) into Equation (1.1) gives yield as a function of total water applied.

$$Yield = B_o + \left(\frac{B_1}{B_w} \right) * water$$

(1.3)

Based on this yield function, total profitability function is expressed as:

$$\pi = (P * Yield - C) * land - P_w * water$$

(1.4)

Where P is crop price, P_w is the price of water and C is non-water production cost per unit land. Yield multiplied by land planted to the crop is the crop production function. Then, total farm profitability over all water applied in the irrigation scheme for each crop can be expressed as:

$$\pi = \frac{\left[P * \left(B_o + \frac{B_1 * water}{B_w} \right) - C \right] * water}{B_w} - P_w * watrer$$

(1.5)

Equation (1.5) expresses total profitability for irrigation schemes in terms of water required for all farms and all variables are observable except the terms B_o and B_1.

Maximizing total irrigation farm profitability for any crop in the irrigation area requires expanding water and associated land use for each crop as long as additional crop values exceed additional costs. Where there is a fixed water requirement per unit land for any crop in a given irrigation area, actions that maximize farm profits can be discovered by differentiating the farm profitability in Equation (1.5) with respect to additional water used or additional unit of land in production.

$$\frac{\partial \pi}{\partial water} = \frac{2(P * B_1 * water) + (B_w * B_o * P - (B_w * C)}{B_w^2} - P_w = 0$$

(1.6)

Note that Equation (1.6) presents a classic result from microeconomic theory. That is, for a given irrigation scheme, farm income maximization requires that irrigation water use be expanded to the point where the price of water equals the value of the marginal product of the additional water used. This condition thus, predicts irrigators' behavior that will be observed in reality and hence, a higher water price or water scarcity may result in water conservation.Equation (1.6) can be solved first for the coefficient B_1 as:

$$B_1 = \frac{B_W * P_w - P * Yield + C}{P * water} = \frac{- Average\ Income\ per\ unit\ of\ Land}{P * Land}$$

(1.7)

The term B_1 in this equation is the reduction in crop yield for each additional unit of land brought into production. So the marginal yield reduction on new lands is twice the size of B_1. Then, crop yield for the first unit of land brought into production, B_o, can be immediately solved by

$$B_o = Yield - B_1 * Land$$

(1.8)

Now, using information on both B_o and B_1, a range of yields can be calculated for each crop under the whole irrigation income optimizations that would occur under future policy scenarios.When the two estimated parameters B_o and B_1 are substituted back into the yield function, equation (1.1), the net income defined by equation (1.4) becomes a quadratic function. Using that quadratic function, a simple unconstrained maximization of the income objective produces behavioral results that could match the observed net revenue, crop yield, and land in production by crop, cost, etc. Thus, the crop yield function developed in such a way reproduces observed behavior for each crop in each irrigation scheme in the baseline situation.

This model is based on combining observed facts with an underlying theory that could have generated them. It is implemented first by estimating the parameters Bo and B_1 and then solves the unconstrained optimization of the model using these parameters to produce the observed data. Once the PMP model is calibrated, it allows the productive pattern behavior of farmers to be simulated when they face new economic conditions such as water policies that affect irrigated agriculture.

The farm income optimization model described above is applied to explain the amount of total water required for crop production and the associated total land use in the two modern irrigation schemes of Lake Tana Basin. For both irrigation schemes, data regarding production activity levels, input use per activity, variable costs per activity and crop prices and yields were obtained from district level agricultural offices and were also validated using primary data collected from household survey. An important concern wasto find valid data, particularly in the key variables such as irrigation water requirement (water use per irrigation unit for each crop). To overcome this problem, for each crop,we calculated the water requirement based on time series climate and location data for the study area using CROPWAT8.0 software (FAO, 2009). This application software is developed by FAO for water resources development and management services.

II. Modeling

Irrigators in LTB produce for both household consumption and market. As a result, irrigation water users in Lake Tana Basin can be modeled as income-maximizing producers where agricultural production is described using a production function and output is a function of basic factor input level. The irrigation user is then assumed to optimize with the goal of income maximization subject to input constraints.

Although each irrigation areas may consist of many independent private farms, each of the two irrigation schemes is treated as a single profit-maximizing entity for the purpose of this analysis. Consequently, net farm income is maximized in both irrigation schemes using non-linear programming with baseline land and water allocations as constraints.The objective function and constraints are given below.

$$Max \sum_i X_{ij} \left(P_i Yield_{ij} - VC_{ij} - t_w WR_{ij} \right)$$

$$s.t$$

$$\sum_i X_{ij} < \sum_i X_{ij}^o$$

$$\sum_i W_{ij} < \sum_i W_{ij}^o$$

Where X_{ij} *is* the optimal level of land area allocated to crop *i* in irrigation scheme *j* under each water policy scenario , X_{ij}^o is the observed land area allocated to crop *i* in irrigation scheme *j*, $Yield_{ij}$ is the crop production function for crop *i* in irrigation scheme *j*, P_i *is* price of crop *i* per 100kg, $VC_{ij}$is the sum of all variable costs of production for crop *i*, in irrigation scheme j, $t_w$is volumetric irrigation water tariff to be applied per 1000m^3 of water, W_{ij} is total water required to crop i per ha in irrigation scheme$j$ under each scenario,W_{ij}^0 is the water requirement of crop i per ha under normal condition based on ET assuming irrigation efficiency is uniformly equal to 0.5 in Lake Tana Basin irrigation.

The decision variables considered for building the simulation models were the areas devoted to each of the predominant crops in the study area ($x_{i,j}$). Thus, there are a total of 10 decision variables for simulation of water policy effects in the two modern irrigation schemes. Total farm net income, an endogenous variable that is to be optimized, is income per unit land multiplied by the land in production summed over all crops. Total level of water applications and land used are constrained to base levels. After calibration, the base model optimization reproduces observed values without constraints.

III. Simulation of Water Policy Scenarios

Effectiveness of water policies depend on the method of water pricing that is to be applied in irrigation schemes. There are several water pricing methods that can be applied in irrigated agriculture. The most commonly used are area pricing, crop based area pricing, uniform volumetric pricing, two part volumetric pricing, increasing block rate pricing and market pricing (Johansson *et al.,* 2002). Each of these methods has specific characteristics and selection of each for use is based on the purpose of the water policy that is to be implemented.

In Ethiopia, currently irrigators have no incentives to conserve water as they pay no charges for the amount of water diverted to their plot for crop production. Part of operation and maintenance costs and all other major costs including investment and capital depreciation costs are met by the government budget as a form of hidden subsidy to irrigation users. In addition to these financial costs, irrigated agriculture produces environmental costs to the society as a whole which often is not taken into account by both irrigators. The total economic cost of irrigated agriculture takes into account all these costs.

The existing situation of free irrigation service is not in line with the country's existing water resource management policy (FDRE, 2004). This policy underscored that water is recognized as vulnerable and scarce natural resource on which water tariffs should be implemented so as to ensure equity, efficiency and sustainability. Thus, the pricing method that should be applied to meet environmental requirement of water policy is probably volumetric water pricing. For this reason, we selected volumetric pricing method to be simulated using PMP model to investigate its impact on sustainability of irrigated agriculture in LTB. One of the requirements for implementing volumetric water pricing is the availability of modern irrigation infrastructures for calibrating water volume and this is partly fulfilled in Koga large scale modern scheme.

An important application of the theoretical model to actual policy decisions lies in applying the calculated yield parameters to multiple crops under different future water policy scenarios. The future water policy is investigated based on six scenarios where the first one represents the base (business as usual) scenario. This scenario represents the situation of irrigation crop production in 2012/2013 in the two irrigation areas of LTB. The remaining five scenarios represent the alternative scenarios. Apart from the baseline scenario, each scenario reflects an expected water policy change to be implemented in the near future. Table 2 indicates the description of water policy scenarios to be implemented in Lake Tana Basin irrigated agriculture (Table 1).

Table 1. Definition of water policy scenarios

Scenario no.	Water policies		Situations to be simulated
	Water price (ETB/1000m^3/year)	Reduction in total water supply from base situation (%)	
Scenario 1	0	0	Business as usual
Scenario 2	200	0	lower water price level only
Scenario 3	400	0	Higher water price level only
Scenario 4	0	25	Reduced water supply only
Scenario 5	200	25	Lower water price and reduced supply
Scenario 6	400	25	Higher water price and reduced supply

Scenario 1 reflects the current situation or base year situation (2012/2013). This scenario serves as a reference for investigating the effects of other policy scenarios on sustainability of irrigated agriculture. Scenario 2 refers to the situation where a relatively lower water tariff of 200ETB/1000m^3/year is introduced to investigate its impact on the sustainability of irrigated agriculture. Scenario 3 is similar to scenario 2 except in this case water tariff is becoming doubled. This scenario is intended to evaluate the effect of water policy on sustainability of irrigated agriculture when water price becomes doubled given water supply level of the reference period (2012/2013) (Table 1).

Scenario4 refers to the situation where total water supply level is reduced by 25% while price level is set at zero level. This scenario allows assessing the impacts of water supply policy on sustainability of irrigated agriculture under no water tariff at all. Scenario 5 and scenario 6 are proposed to investigate the combined impacts water pricing and water supply policy scenarios. In these scenarios, a reduction of total water supply by 25% is integrated with two different water tariff levels (i.e., 200ETB/1000m^3 and 400ETB/1000m^{3}respectively) in order to investigate the joint impacts of water supply policy at different water price levels.

To assess the impacts of the future water policy scenarios, the base situation is retained and the new policies are treated as alternative policy scenarios for comparison of results. With the optimizing model used here, one can predict the water users' best response to alternative policy scenarios. The results of each scenario may contribute to the decision making process as they highlight the potential positive and negative economic, social and environmental implications of proposed policy changes based on indicators of sustainability.

Sustainability indicators of water policy impacts

The use of agri-environmental indicators is the most common method of integrating agricultural practices with environmental concerns in economic analysis. Irrigated agriculture has economic, social and environmental implications (Gomez-Limon and Sanchez-Fernandez, 2010). Increasingly many similar studies have applied a common set of indicators for analyzing the impacts that water policies will have on irrigated agriculture (Gallego-Ayala *et al*., 2011; Gallego-Ayala and Gómez-Limón, 2011; Moghaddasi*et al.,* 2009). These indicators in combination refer to sustainability indicators that would enable us to indicate the impacts from a change in water policy. These indicators will enable policy makers quantify the sustainable performance of the irrigated farms.

The empirical application to be performed in this study therefore needs to quantify the impacts of water policy scenarios proposed for the study area, through a range of indicators that covers them. Thus, we select a set of indicators that would make it possible to quantify the sustainable performance of the irrigated farms when faced with external shocks such as water pricing and water supply policies. These indicators would allow information to be collected about the performance of the three basic sustainability dimensions: economic, social and environmental under different future policy scenarios (Table 2).Analyzing the overall sustainability of irrigated agriculture is often difficult as it requires the consideration of changes in economic social and environmental parameters (Gomez-Limon and Sanchez-Fernandez, 2010). Based on literature review and the context of the study area, this paper has considered 7 indicators of sustainability performance of irrigated agriculture as shown in Table 2.

Table 2.Selected sustainability indicators of water policy impacts on irrigated agriculture

No.	**Sustainability dimensions**	**Indicators (%)**
1	Economic Impact	Total private income
		Net social income
2	Social Impact	Rural Employment
3	Environmental Impact	Water conservation
		Pesticide risk
		Chemical fertilizer
		Soil cover

Each scenario has been proposed to understand the three aspects of sustainability performance of irrigated agriculture in terms of basic indicators described in Table 4.The PMP simulation model has been built based on the GAMS modeling language and solved using GAMS software (Brooke *et al.,* 1998)

Basic information for PMP model simulation

The observed data shows that a total of 5127 ha of irrigated land in Koga large scale irrigation scheme was covered with different crops including wheat (38%), barley (22%), maize (10%), potato (26%) and vegetables (4%), and a total of 133ha of irrigated land was covered with maize (37%) and vegetables (84%) in Guanta-Lomidur small scale irrigation scheme during 2012/2013 irrigation season. The observed data pointed out that a larger proportion of irrigated land was covered with less profitable crops such as barley and wheat in Koga irrigation scheme. Table 3 shows basic information of irrigated agriculture in the study area for PMP model simulation.

Table 3.Basic information on observed cropping pattern, crop water requirement, and crop production data by location.

Location	Crop	Area(ha)	Crop water requirement (ET*)	Total cost of prodn (ETB/ ha)	Observed yield (qt/ha)	Value of production (ETB/qt)
Koga	Wheat	1967	3.5	11197	23	850
	Barley	1126	3.0	7140	13	600
	Maize	511	4.9	11380	55	480
	Potato	1318	4.8	17510	200	350
	Vegetables	205	4.9	16540	168	360
Guanta-Lomidur	Maize	49	4.6	6595	40	480
	Vegetables	84	4.2	13276	182	360

Source: own analysis from survey data

The crop water requirement (ET*) in this study is determined using climate and location data for the study area based on FAO (2009). Here, we used secondary data which include time series meteorological data such as maximum and minimum temperatures, precipitation, relative humidity, sunshine hours, and wind speed of the two study sites to calculate the reference crop water requirements for the two irrigation areas. In addition, information on geographical location, altitudes, soil type and planting dates were also used to analyze the crop water requirement for each irrigated crop in each irrigation scheme assuming water use efficiency of furrow irrigation system (dominant irrigation technique in the study area) equal to 0.5.

3. Empirical results

3.1. PMP model results of cropping pattern

The effects of implementation of hypothetical water policies (i.e. introduction of water prices and reduction in available water supply) on cropping pattern have been studied in six scenarios as discussed in Table 4. The table provides summary results of PMP simulation model on the total area of irrigated land and cropping pattern under each alternative water policy scenario.

Table 4. Impacts of water policy scenarios on cropping patterns in two irrigation schemes of LTB

Irrigscheme	Crop	**Scenarios**											
		S1		S2		S3		S4		S5		S6	
Koga		Ha	%	ha	%	ha	%	ha	%	ha	%	ha	%
	Wheat	1967	38.3	1802	35.1	1637	32	1658	32.3	1658	32.3	1637	31.9
	Barley	1126	21.9	0	0	0	0	0	0	0	0	0	0
	Maize	511	09.9	477	9.3	444	8.6	448	8.7	448	8.7	444	8.6
	Potato	1318	25.7	1294	25.2	1270	24.7	1273	24.8	1273	24.8	1269	24.7
	Vegetable	205	3.9	200	3.9	195	3.8	196	3.8	196	3.8	195	3.8
	All crops	5127	100	3773	73.6	3546	69	3575	69.7	3575	69.7	3545	69.1
Guanta-Lomidur	Maize	49	36.8	45.4	34.1	41.8	31.4	25.6	19.2	25.6	19.2	25.6	19.2
	Vegetable	84	63.1	82.6	62.1	81.2	61	75.1	56.4	75.1	56.4	75.1	56.4
	All crops	13	10	12	96.	12	92.	100.	75.	100.	75.	100.	75.

3	0	8	2	3	4	7	7	7	7	7	7

Source: own analysis (2012/2013)

As expected, the PMP model results indicated that land allocation to each crop in the base scenario exactly fits the observed situation in both Koga and Guanta-Lomidur irrigation areas. Under the baseline scenario the land allocated to wheat, barley, maize, potato and vegetables in Koga large scale irrigation scheme are 1967ha (38.3%), 1126ha (22%), 511ha (10%) and 205ha (4%), respectively. The PMP model simulation for the base line scenario also resulted in the same cropping pattern as observed in Guanta-Lomidur where maize and vegetables cover 49ha (36.8 %) and 84ha (63.8 %) of total irrigated area, respectively.

As explained earlier, scenarios S1, S2, and S3 refer to the situations where irrigation water prices equal to 0, 200 and 400 ETB per 1000m^3 respectively, given that the total water available remains the same as the base year. These three scenarios were designed with the intention of measuring the effects of water pricing scenarios on irrigated agriculture under normal water supply condition. The simulation results of PMP model shows that compared to the baseline scenario, the area of land allocated to each crop will drop subsequently as higher water prices are introduced in both irrigation areas (Table 4). This is because introducing higher water prices will surge the production costs and therefore, farmers will reduce size of their irrigation land following the classical microeconomic theory. However, for a given water policy scenario, the rate of reduction in size of irrigation land is different for different crops depending on the shadow price of water that will be allocated to each crop.

Consequently, the cultivation of barley in Koga will drop substantially to zero as the shadow price of the observed allocation of water to barley will enter into negative value immediately after the introduction of lower water price. This implies irrigators will find it not profitable to grow barley even at very low level of water price. Table 4 also indicated that implementation of S2 and S3 will result in no substantial decrease in the cultivation of potato and vegetables in Koga Large scale irrigation scheme and vegetables in Guanta-lomidur small scale irrigation as the shadow price of water allocated to such crops is relatively higher.

Table 4had indicated that irrigators in Koga large scale irrigation are relatively more responsive to water pricing policy scenarios than irrigators in Guanta-Lomidur small scale irrigation scheme in terms of reduction in total area of irrigation land. This is because the shadow price of water is relatively higher in Guanta-Lomidur and, as a result they will show less response to the introduction of water prices. In Koga large scale irrigation scheme, implementation of scenarios S2 and S3 will lead to reduction of total cultivation by about 26% and 21%, respectively, from the baseline scenario. However, implementation of these two scenarios will result in reduction of total cultivation by only 4% and 6%, respectively, in Guanta-Lomidur irrigation scheme.

The fourth water policy scenario (S4) is designed to measure the impact of water supply policy when total water available is reduced by 25%, while water tariff is set at zero. This scenario is proposed to measure irrigators' response when they are facing with reduced irrigation water supply. As indicated in Table 4, implementation of this scenario resulted to reductions in cultivation of all crops in both Koga and Guanta-Lomidur irrigation schemes as compared to the baseline scenario. The cultivation of barley in Koga large scale irrigation will be totally eliminated as in the previous two alternative water pricing scenarios. This scenario will also result in modest reduction of wheat and maize cultivations in Koga Large scale, and vegetables and maize cultivations in Guanta-Lomidur small scale irrigation. Since water will become more scarce resource in both irrigation areas due to the implementation of this hypothetical water supply policy, irrigators will prefer to grow higher value crops.

For the last two scenarios (i.e. S5 and S6) total water supply remains as it was in S4 (i.e., 25 % of reduction from that of the base year), but water tariff levels of 200 ETB and 400 ETB per 1000m^3 were introduced respectively. The results of PMP simulation model found that implementation of these two scenarios will have no further effects beyond that of S4 on cropping patterns for all crops. This is an interesting result implying the importance of implementing water pricing and water supply policies complementarilyfor achieving desirable results on water conservation with no further impacts on total area of irrigated land. But as water prices increases progressively, the cultivation of crops will drop step by step depending on their profitability. For instance, production of lower profitable crops such as wheat will fall when water prices are set a bit more than 400ETB per 1000m^3 and the impact is expected to be more evident as water price level increases.

3.2. Sustainability of irrigated agriculture under water policy scenarios

This section discusses the impacts of water policy scenarios on sustainability of irrigated agriculture as measured in terms of sustainability indicators. Table 5 shows the results PMP model simulation on *ex ante* impact analyses of hypothetical water policy scenarios on sustainability of irrigated agriculture. The different impacts of water policy scenarios are first grouped into the three dimensions of sustainability (i.e. economic, social and environmental) and then each sustainability dimension is discussed based on one or more indicators as follows.

Table 5.Impacts of water policy scenarios based on sustainability indicators

Irr area	**Indicators**	**Scenarios**					
		S1 base level	S2 %	S3 %	S4 %	S5 %	S6 %
Koga	Economic indicators						
	Total private income(million)	102.31	-6.3	-53.7	-0.6	-6.5	-53.7
	net social income (million)	102.31	-0.1	-42.0	-0.6	-0.6	-42.0
	Social indicator						
	Employment (1000mandays)	534.31	-18.7	-23.0	-22.5	-22.5	-23.0
	Environmental indicators						
	Water consumption (1000m^3)	40194.6	-21.1	-25.5	-25.0	-25.0	-25.5
	Pesticide risk (1000liter)	4.406	-17.1	-21.4	-20.9	-20.9	-21.4
	Chemical Fertilizer (ton)	2119.44	-17.3	-21.9	-21.3	-21.3	-21.9
	Soil cover (ha)	5127	-26.4	-30.8	-30.7	-31.1	-31.5
Guanta-Lomidur	Economic indicators						
	Total private income (million)	5.0081	-4.5	-8.8	-3.7	-7.2	-10.7
	Net social income (million)	5.0081	-0.3	-0.9	-3.7	-5.2	-5.2
	Social indicator						
	Employment (1000 mandays)	20.79	-2.6	-5.3	-17.3	-17.3	-17.3
	Environmental indicators						
	Water consumption (1000m^3)	1156.4	-3.8	-7.6	-25.0	-25.0	-25.0
	Pesticide risk (1000 liter)	1.058	-1.6	-3.2	-10.5	-10.5	-10.5
	Chemical Fertilizer (ton)	16.436	-5.1	-10.3	-34.0	-34.0	-34.0
	Soil cover (ha)	133	-3.7	-7.5	-27.8	-27.8	-28.2

Source: own analysis (2012/2013)

3.2.1. Economic impact

The economic impact of hypothetical water policy scenarios is measured using two indicators. The first indicator refers to the percentage change between the total private income that will be resulted from implementation of alternative water policy scenarios and that of the baseline scenario. The second indicator of income impact (i.e. net social economic impact) can be measured in a similar way where the net social income is equal to total private income less total public revenue collected from irrigation fees.

Based on the first income indicator of sustainability, all alternative water policies result in a reduction in total private income though the impacts vary among the different scenarios as expected. For example, introduction of 200ETB per1000m^{3}water price scenario (S2) resulted in reduction of 6.3% and 4.5% in total private income in Koga and Guanta-Lomidur irrigation schemes respectively. Whereas; introduction of 400ETB per 1000m^{3}scenario (S3) resulted in more substantial negative impact on total private income in Koga irrigation scheme (53.7%) as compared to Guanta-Lomidur (8.8%). This implies that water pricing policy scenarios may result in considerable differences in terms of their impacts on private income between the two irrigation schemes.

Simulation results of scenario 4 (i.e. 25% reduction of the baseline water supply) indicated very low level of impact (i.e., 0.6%) on total private income in Koga irrigation scheme. But its impact is comparatively greater (i.e., 5.2%) in Guanta-Lomidur irrigation scheme. Given a 25% reduction in baseline total water supply, implementation of with water tariff levels of 200ETB and 400ETB per 1000m^3 will result in similar economic impacts as with the baseline water supply level. This result is particularly more evident in Koga large scale irrigation scheme.

The results in general indicated that the impact of each hypothetical water policy scenario on net social income is less severe than as its impact on total private income. This is because part of the total private income loss will go to the public as a transfer of income via water fee.

3.2.2. Social impact

The other dimension of sustainability measure for the impacts water policy scenarios on irrigated agriculture is the social impact. The social impact is measured as a percent change between the demand for rural labor that will be resulted from implementation of a given water policy scenario and that of baseline scenario. Overall, implementation of alternative water policy scenarios will negatively affect the demand for rural labor and hence, will affect sustainability of irrigated agriculture. The social impact is expected to be more severe in Koga large scale irrigation. This is due to the fact that water policy scenarios have greater contraction effect on crop production plan in Koga irrigation scheme as compared to Guanta-Lomidur. The results also indicated that, given a 25% reduction in base year water supply, each water pricing level of 0ETB, 200ETB and 400ETB will result in similar social impacts.

3.2.3. Environmental impacts

The third component of sustainability measure of water policy impacts is environmental impact. The basic motive for implementation of volumetric water pricing and water supply policy instruments is for environmental reason. This is because, as discussed in the previous sections, irrigated agriculture poses significant pressure on the local and downstream environment by releasing harmful chemicals and pollutants and obstructing river flows. Though the off-farm impacts of irrigated agriculture are more severe and difficult to control, irrigated agriculture can also cause on-farm environmental problems such as water logging and salinization. The present study didn’t take into account the latter environmental problems.

The environmental impact of water policy scenarios on irrigated agriculture is measured in terms of four different indicators: total water consumption, total pesticide application, total chemical fertilizer application and soil cover. Table 5had shown that simulation of water policy scenarios resulted in positive impacts on environmental aspects sustainability in the two modern irrigation schemes of Lake Tana Basin. This is because alternative water policy scenarios are expected to have negative effects on total level of water consumption, and application of pesticides and organic fertilizers which would result in conservation of water resources, reduction in nitrate pollution of water resources and lower emissions of toxins into the air and the surrounding environment. However, the extent of these positive environmental impacts will be different between the two modern irrigation schemes as evidenced in this study (Table 5).

i. Water consumption

The simulation result of water consumption level (measured in 1000m3 per ha) is the variable that policy makers wish to control via different policy options. Indicator of water conservationis measured by the percentage reduction in demand for irrigation water due to implementation of a certain policy. Based on the results water conservation indicator will be significantly and almost uniformly improved for each policy scenario in Koga irrigation scheme.

However, scenarios S2 and S3 will result in lower levels of impacts on water conservation in Guanta-Lomidur irrigation scheme (i.e., 3.8% and 7.6% respectively) as compared with Koga irrigation scheme (i.e., 21.1 % and 25.5%). This implies that these two water pricing policy scenarios may result in relatively higher impact on water conservation when they are implemented in Koga irrigation area than Guanta-Lomidur. Alternatively stated, demand for irrigation water is more elastic in Koga irrigation schemes than in Guanta-Lomidur for lower water price levels. Given a 25% reduction in baseline total water supply in both irrigation schemes, implementation of 0ETB, 200ETB and 400ETB will lead to similar levels of water conservation.

ii. Reduction in Chemical fertilizer Application

Irrigated agriculture affects water quality in several ways. This is associated with its higher chemical consumption rates including accelerated pollutant transport with drainage flows, groundwater degradation due to increased deep percolation, and greater instream pollutant concentrations due to water flow reductions. Table 5 also indicated that total amount of chemical fertilizer application is expected to reduce in both irrigation areas in response to the implementation of those water policy scenarios. The impacts of water pricing policies under scenarios S2 and S3 show remarkable differences between irrigation schemes in terms of their impacts on total fertilizer application. Implementation of scenarios S2 and S3 imply a reduction in total chemical application by 17.3% and 21.4%, respectively, in Koga while, the effects of these policy scenarios in Guanta-Lomidur will be only 5 % and 10.3%, respectively. That is farmers in Koga irrigation area are also more responsive to the implementation of water pricing policies in terms of reduction in chemical fertilizer use. This is related to the contraction effects of these policies on area of total irrigated crop land. However, irrigators in Guanta-Lomidur are more responsive if they are faced with reduced supply of irrigation water for environmental flow requirements. When water pricing alternatives are jointly implemented with a 25% reduction in total available water, total amount chemical fertilizer use will reduce by 25% and 34% in Koga and Guanta-Lomidur, respectively, regardless of the level of water prices considered in this study.

iii. Reduction in total pesticide use

Alternative water policy scenarios are also expected to result in positive environmental impacts in terms of a reduction in total pesticide use. However, irrigators from the two irrigation schemes will show different responses to alternative scenarios. In Koga irrigation scheme, the percent reduction in total pesticide use under each policy scenario nearly coincides with percent reduction in total chemical fertilizer use for each scenario considered. This implies that the two inputs are often applied complementarily in Koga irrigation scheme. But, this is not the case in Guanta-Lomidur where the percent reduction in total pesticide use is considerably lower than the percent reduction in total chemical fertilizer use under each alternative water policy scenario.

In particular, total pesticide will reduce at very small proportion when water policy scenarios S2 and S3 are implemented in Guanta-Lomidur and hence, will result in low level of positive environmental impacts. But, the environmental impacts will become considerably improved when total water available is reduced by 25% despite the level of water prices considered. In Koga irrigation area, the proportion of a reduction in total pesticide use remains fairly constant under each alternative water policy scenario. In general farmers in Koga irrigation scheme are more responsive to implementation of water policy scenarios in terms of pesticide use. This is due to the contraction effects of water policies on total irrigated land.

iv. Reduction in soil Cover

In contrast to the negative environmental consequences of irrigation development discussed here, irrigation development results in positive externality in terms of reduced soil erosion, mitigating climate change, improved microclimates, biodiversity, etc. In many previous studies water policy analysis, soil cover is considered as an important environmental indicator of water policy impacts on irrigated agriculture. Soils covered by crops, grass or tree plants are less exposed to soil erosion. Beyond this, soil cover contributes positive externalities towards mitigating climate change and thereby providing a sink for CO_2 emission. Furthermore, soil cover produces positive externalities in terms of improved landscape scene, microclimates, and biodiversity.

As indicated in Table 5, the hypothetical policy scenarios considered in this study will leave a substantial proportion of irrigable land out of cultivation during the dry season, in particular. Such impacts will have indirect negative impacts on the benefits of positive externalities that would have been ensured from irrigation development in Lake Tana Basin.

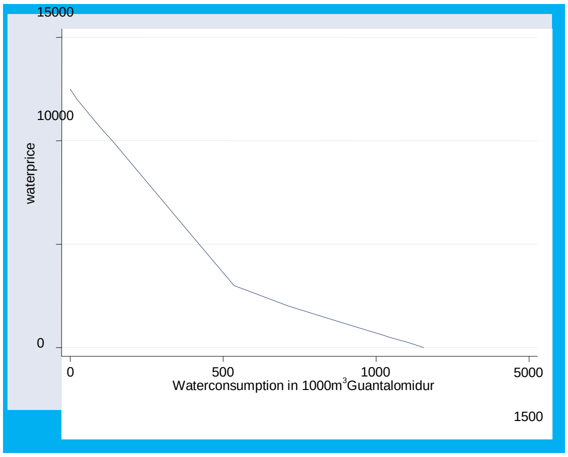
A reduction in area of irrigated land due to imposition of water policy scenarios means reduction in supply of these positive externalities.

This study indicated that soil cover will almost consistently decline due to the implementation of the prospective water policy scenarios, which will then affect the supply of these positive externalities. The effect will be more serious as water pricing policies are implemented jointly with reduced supply of irrigation water. Comparatively, soil cover will reduce at a relatively faster rate in Koga irrigation scheme. This is due to the fact that irrigated agriculture is more sensitive to policy changes in Koga irrigation scheme as the shadow price of water is relatively lower.In general, the results of environmental impacts of water policies underlined that if the prime objective of water policy is to meet environmental objectives, water supply policies are found to be more effective than water pricing policies.

3.3. Irrigation water demand

The demand for irrigation water comes from the market demand of agricultural products (Zamanian*et al.,* 2013). Total irrigation water demand at irrigation scheme level can be defined as total amount of water that will be required by all irrigators at each level of water charges. Thus, irrigation water demand in the two irrigation schemes have been derived by simulating the effects that would be resulted in total water demand when water charges are progressively increased starting from zero. The total water demand at zero level of water charge corresponds to the baseline crop water requirement. Thus, irrigation water demand would enable us to calculate the total amount of water that will be conserved at each level water charge.

Figure 4 shows the demand curves of total water consumption in Koga and Guanta-Lomidur irrigation areas. In line with the classical microeconomic theory, both demand curves are negatively sloped and are relatively inelastic at lower levels of irrigation water price. When the level of water price in each irrigation area reaches at certain level, the water demand curves will become more elastic. This implies the availability of limited scope for reducing farm water consumption at lower levels of water prices. That is if water prices are to be implemented for the purpose of water conservation, water prices should be set at higher levels.



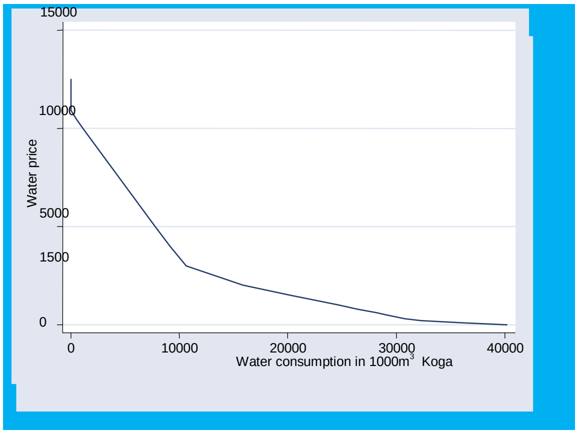


Figure 1. Irrigation water demands for Koga (right) and Guanta-Lomidur (left) irrigation

Source: own construction from survey data

3.4. Economic productivity of water (EPW) in Lake Tana Basin irrigated agriculture

Economic Productivity Water has also been analyzed in this study to investigate the economic efficiency of water use in LTB irrigated agriculture. Economic Productivity Water (EPW) is defined as the ratio of net farm return to total amount irrigation water used. Table 6 shows the PMP model simulation results of EPW for alternative water policy scenarios from both producers' and society's point of views. The results indicate substantial variations in EPW from both producers' and society's point of views among each water policy scenario, and between irrigation schemes considered in this study.

Results of the PMP simulation model indicated that the performance of irrigated agriculture in terms of EPW is better in Guanta-Lomidur irrigation scheme as compared to Koga irrigation scheme under all water policy scenarios from producers' and the society's point of views. This result implies that there is better capability of deriving more income from irrigated agriculture in Guanta-Lomidur than in Koga for the same volume of water supplied. Table 6 also indicated that most of the water policy scenarios considered in this study will result in an improvement in EPW. And all water policy scenarios are expected to result in positive effects on EPW in Guanta-Lomidur from society's point of view, in particular.

However, water policy scenarios may result in diverse effects on EPW between the two irrigation areas from the producers' point of view. For instance, S3 and S6 will generate negative impacts on EPW in Koga from both producers' and society's point of views. However S3 and S2 will result in negative effect on EPW in Guanta-Lomidur when it is measured from producers' point of view.

Table 6 points out those significant positive effects will be observed on EPW in both irrigation areas for water policy scenarios S4 and S5. The results also indicated that water policy scenariosS2 and S6 will result in contrasting effects on economic productivity of irrigation water between Koga and Guanta-Lomidurfrom producers' point of view. While EPW will be increased by 19% in Koga due to introduction of 200ETB/1000m^3 water charges, very slight negative impact will be observed on EPW in Guanta-Lomidur under this scenario.

Simulation results also denoted that substantial positive effect will be observed on EPW from both producers' and society's point of views when 25% total water supply reduction is jointly implemented with zero and 200ETB per 1000m^3 in both irrigation areas. However, substantial negative effect (38%) will be observed in Koga irrigation area, in particular, from both producer's and society's point of views if 25% water supply reduction is implemented complementarily with 400ETB per 1000m^3 water charges. The same policy scenario will result in positive effects in EPW from both producers' and society's point of views in Guanta-Lomidur.

The other important result here is that implementation of water policy scenarios S4, S5 and S6 in Guanta-Lomidur will result almost similar effects on EPW. This implies that water pricing policy scenarios in Guanta-Lomidur may not have considerable impact on EPW given total available water is reduced by 25% which is not the case in Koga irrigation area. In short, water pricing policy scenarios do have different effects on EPW between the two irrigation areas.

Table 6. Economic productivity of water under water policy scenarios

Irrig.Scheme	**Scenario**	**Economic productivity of irrigation water**			
		From producer point of view		From the society point of view	
		ETB/1000m3	variation from observed value %	ETB/1000m^3	variation from observed value %
Koga	Scenario 1	2538	0	2545	0
	Scenario 2	3024	19.1	3223	26.6
	Scenario 3	1581	-37.7	1982	-22.1
	Scenario 4	3384	33.3	3372	32.4
	Scenario 5	3171	25.0	3373	32.5
	Scenario 6	1581	-37.7	1982	-22.4
Guanta-Lomidur	Scenario 1	4331	0	4331	0
	Scenario 2	4299	-0.7	4486	3.5
	Scenario 3	4272	-1.3	4644	7.2
	Scenario 4	5556	28.2	5474	26.3
	Scenario 5	5356	23.6	5469	26.2
	Scenario 6	5156	19	5469	26.2

Source: own calculation from survey data

4. **Conclusion**

This study deals with the investigation of the impacts of alternative water policy scenarios on sustainability of irrigation development in two modern irrigation schemes of Lake Tana Basin, Ethiopia by applying a PMP simulation model.The PMP model results indicated that land allocations to each crop willdrop subsequently as a result of implementation of alternative water pricing scenarios (water pricing and/or water supply scenarios). The rate of reduction in area of irrigated land is different for different crops depending on the shadow price of water that will be allocated to each crop.

Analysis of the impacts of alternative water policy scenarios also indicated how each scenario would have specific economic, social and environmental impacts on sustainability of irrigation development in the study area. In general, this study found that implementation of eachalternative water policy scenario maylead to a reduction in total private income and rural labor demand and hence, may affect the economic and social aspects of irrigation development negatively. On the contrary, the simulation resultsindicated that implementation of water policy scenarioswill result in a positive environmental impact by reducingthe quantitative pressures posed by irrigation development on the environment such as reduction of water abstraction and agrochemical use.However, this study has indicated that implementation of alternative water policy scenarios mayresult in a substantial proportion of irrigable land out of cultivation during the dry season. This in turn may lead to negative impacts on the provision of positive externalities such as reduced soil erosion, mitigation of climate change, improved local microclimates, etc. that would otherwise have been resulted from irrigation development.

A larger proportion of irrigated land in the study area is covered with less profitable cereal crops such as barley, wheat and maizeduring the base line situation.The implementation of alternative water policy indicated that this situation can be improved in favor of more profitable crops such as vegetables and potatoesif appropriate water price and water supply levels are introduced complementarily.The findings of this studyalso indicated animprovementin water use efficiency (WUE) as a result of implementation of alternative water policy scenarios.

Although measuring the overall impacts of alternative policies requires composite indicators of sustainability, relatively lower water price levels are conducive to meet the environmental requirements with less economic and social impacts in Lake Tana basin. Water policies should be designed in such a way that they are able to address a specific objective(s) of water resource management.For instance, if water policies are planned to meet only the environmental objectives reduction of the available water could play more significant role than other water pricing options. In sum, these results of this study can be useful because they will enable policy makers to reflect the design and implementation of policies that affect the sustainability of irrigated agriculture. The results of this analysis are also relevant for improving the existing water policy at national level.

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