Research Article
Volume 11:11, 2022

Irrigation & Drainage Systems Engineering

ISSN: 2168-9768 Open Access

Agro-Hydrological Modeling for Improved Agricultural Irrigation Water Management under Climate and Land Use Change for River Basin Scale Irrigation Projects Planning in Ethiopia: A Review

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Abstract

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climactic volatility and land transformation in any country. Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. According to climate change assessments, less precipitation and higher temperatures can be expected in the country. Besides, an increment in drought studies shows high land degradation and nutrient depletion of agricultural land as well. Such climatic and land conditions require an effort to improve agricultural water management efficiency and to optimize irrigation technologies. There are currently available water-use and crop-growth simulation models, which can be combined with climate and land use scenarios in order to recommend, through many simulations, the most reliable irrigation management, as a result, agriculture will have to reduce either its relative water consumption per output by improving usage efficiency or its absolute water demand by decreasing agricultural production. More agricultural output per area and per drop of water used (crop yield and crop water productivity) means achieving more crops per drop. This review was, therefore, targeted at finding a better method for optimal irrigation water management that relies on accurate knowledge of plant water consumption, water flows, and soil moisture dynamics throughout the growing season. The decision-supporting tools should therefore capture the temporal and spatial variability of rainfall, soils, and crops. It is better to model the agricultural water management fully from field measurements or remote sensing using dynamic simulation models. In this paper, it is needed to review the Agro-hydrological model to investigate the agricultural water management. This agro-hydrological model is a good software package for crop water requirement computation as the inputs of the model are based on the real field conditions. As with any model, the reliability of the results depends on the reliability of the input data. The model can generate daily crop water needs (or irrigation requirements), which can assist the user in adjusting irrigation schedules based on weather conditions. On the other hand, with SWAP, an estimation can be made of the losses due to over irrigation.

Introduction

Background

Water resource management in agriculture is a critical contributor to the economic and social development of Ethiopia, and if successful, irrigation in Ethiopia could represent a cornerstone of the agricultural development of the country. There are high expectations for the potential of improved water management to drive agricultural growth and poverty reduction. These expectations are understandable; the regions include major farming systems and have a high likelihood of drought occurrence due to temperature increase and soil nutrient depletion caused by human-induced factors and climate change [1]. A systems approach that identifies and assesses the roles of multiple actors is required to achieve sustainable development outcomes. Despite significant efforts by the Government of Ethiopia (GOE) and other stakeholders, improving agricultural water management is hampered by constraints in policy, institutions, technologies, capacity, infrastructure, and markets. Addressing these constraints is vital to achieve sustainable growth and accelerate the development of the sector in Ethiopia. In the country's basin scale irrigation projects, there are no institutions that try to optimize the use of water for agriculture and to improve the competitiveness of this sector to achieve sustainable development. IPCC findings indicate that developing countries such as Ethiopia will be more vulnerable to climate change, and climate change may have far-reaching implications for Ethiopia because of its economic, climatic, and geographic settings (IPCC, 2007). The country has a fragile highland ecosystem that is currently under stress due to increasing population pressure. In addition to climate change, land use will continue to evolve in a watershed and may affect water quality. Historical agricultural land use changes have been found to increase sediment loads and nitrate and phosphorus concentrations in agricultural water. The analysis and modelling of agricultural water supply and demand under climate change and land transformation in a fast-growing environment that has experienced significant climate change and land use over the last few decades is challenging in the sub basin.

Agriculture is an important economic sector and is arguably the largest contributor to non-point source pollution [2]. A significant transformation in agricultural activity in a watershed will likely affect the quality of the contiguous surface water to some degree. But research pertaining to combined future climate and agricultural land use change is very limited. Best farming practices implemented as adaptation strategies to improve agricultural water management can help to alleviate the negative impacts on crop yield and transport mechanisms from within the whole watershed need to be addressed

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Date of Submission: 02 November 2022, Manuscript No. idse-22-55677; **Editor assigned:** 03 November, 2022, PreQC No. P-55677; **Reviewed:** 16 November 2022, QC No. Q-55677; **Revised:** 17 November 2022, Manuscript No. R-55677; **Published:** 24 November, 2022, DOI: 10.37421/2168-9768.2022.11.358

for managing nutrient export, but such practices need to be investigated to determine whether they will withstand potentially important impacts of climate change and land use conversions. Furthermore, in order to adapt to the future impacts, decision-makers are in need of information regarding the uncertainty of modelled predictions. The investment irrigation projects in Ethiopia are mainly designed with crop-oriented models, and this model does not consider the effect of soil texture. Soil interacts with water, and therefore its characteristics are a reflection of, and sometimes the reason for, agronomical decisions. In addition to this, in some areas of the country, information on soil and the effects of irrigation techniques on it is scarce (FAO irrigation and drainage paper No. 56).

In the following subtopics, we review different literature of agricultural water management for climate change and land transformation with their impacts separately and together, and then I review previous studies of modelling agricultural water management that incorporate change adaptation strategies. An essential feature of agriculture is the ability to adapt to natural variability to ensure the long-term sustainability of food production [3]. To this end, a large number of existing farm-level management practices are already available as a basis for devising climate change response strategies needed in coming decades. These include growing new varieties and species that are more adapted to altered thermal and hydrological conditions; rescheduling of farm management practices such as irrigation and nutrient application to better match altered phonological cycles; implementation of technologies that conserve water and soil, etc. We have seen the impact of climate change and land transformation on and with adaptation methods in the literature review section. Therefore, the strategies for adaption to the changes in climate and land transformation are based on the assumption that agricultural water consumption will decrease. As a result, agriculture will have to reduce either its relative water consumption per output by improving usage efficiency or its absolute water demand by decreasing agricultural production. More agricultural output per area and per drop of water used (crop yield and crop water productivity) means achieving more crops per drop, which has also been presented by the Food and Agricultural Organization as a strategy to resolve the country's water problems.

A gap between potential and actual yields is observed in many regions of the world. It has been shown that the average yield in rain fed systems is commonly 50% or less of the yield potential, suggesting ample room for improvement [4]. Reported that adapting nutrient management could close yield gaps in most agricultural areas across the world, except for drier regions in East Africa, where irrigation plays a more important role. Previous studies generally ignored interactions between different ecosystem functions [4]. However, the results of such studies can be misleading since it is known that adaptation strategies for improving crop yield may lead to new conflicts or aggravate existing ones with other agricultural functions [5]. Typically, a trade-off exists between food production and regulating functions, but recent studies suggest that this trade-off is not inevitable [6]. For instance, Mueller et al. (2012) found that opportunities exist to reduce the environmental impacts of agriculture by eliminating nutrient overuse while still allowing an approximately 30% increase in production of major cereals. To prevent degradation of natural resources while maintaining decent yield levels, there is a need to carry out impact studies that consider interactions between multiple functions [7]. Moreover, policy will need to support the adaptation of agriculture while considering the multifunctional role of agriculture to strike a balance between economic, environmental, and social functions for example [5,7]. Developed a framework to explore conflicts between financial returns from agriculture, landscape quality, nature conservation, and environmental quality and to generate alternative solutions to support discussions with stakeholders on various topics. Landscape planning approaches focus on a wide range of ecosystem services rather than just agricultural functions; thus, studies in this field include the representation of agronomic processes and agronomic studies whose goal is to identify optimal combinations of agricultural practices with regard to one or more goals, usually at the farm-level, as well as climate change adaptation studies aimed at developing adaptation strategies.

Most quantitative studies on the vulnerability of agricultural systems to climate change and land degradation focus on impacts, while adaptation strategies are often highly simplified [8]. Although the latter is a key factor that will alter the impacts of climate change and land degradation [9]. Thanks to their ability to explore large sets of management options, biophysical models are being used more and more often to examine options for adaptation, as evidenced by a large number of recent studies [10]. Several studies suggest great potential for short-term adaptations associated with low costs, such as change in crops changing cultivation practices adjustment of fertilization intensity change in irrigation intensity se of alternative tillage practices for erosion for productivity and leaching). Longer-term adaptations with higher technical difficulties and higher costs have also been tested occasionally such as the introduction of irrigation to rained areas or the development of climate change resilient crops (for instance, later maturing new cultivars to take advantage of longer growing seasons)

Crop-simulation studies are often incomplete with respect to the crops investigated (often only one) and the number of agricultural practices considered. Typically, only one cropping practice is tested, sometimes two, but rarely more than three. To the latter category belongs the study by 9who investigated the effects of season length, planting date, fallow period, soil type, cultivar choice, and fertilizer use on maize growth in Panama. They found that planting dates and soil types are important drivers of crop yield. In general, modelling studies exploring the effects of climate change and land transformation potential for adaptation focus on the impacts on economic yield, neglecting other functions. However, exceptions can be found in the literature. This is, for example, the case of Van Ittersum who assessed the impacts of climate change and agricultural practices on numerous variables connected to biomass and N allocation. Soil erosion and nutrient leaching were analysed in relatively few cases. Only a few quantitative studies have been conducted to address the possibilities for adaptation to climate change in Ethiopian agriculture, in particular to minimize yield decreases.) found that early sowing and use of crops with longer growth cycles greatly offset the negative impacts of climate change on maize yields and can even lead to higher yields than under the present climate [7]. Showed that a longer growth cycle was an efficient adaptation strategy to reduce vulnerability to climate change in crops. Investigated adaptation options to mitigate erosion on Swiss agricultural lands and found that soil conservation practices are effective methods to control soil erosion under climate change, especially the use of mulching or catch crops. The efficiency of direct seeding is expected to decrease in a warmer climate due to faster decomposed residues, but it remains the most effective way to reduce erosion.

Options for improved agricultural water management through simulation tool

Two main objectives to assess and identify adaptation options for both climate change impacts and land transformation include assessing climate change and land transformation impacts and adaptations from a scientific aspect and providing a model as well as information for policymakers and decision-makers to choose a set of adaptation options and develop an appropriate mix or new strategies for responding and combining adaptation and mitigation measures. Implications for Building Adaptive Capacity is to minimize the effects of climate change and land transformation in the sub basin as pointed out above, using simulation tools that incorporate management actions for improved water availability and for improved functionality, which shows a better way for improved agriculture water management under climate change and land transformation. Negative climate-variability impacts could be reduced by the following adaptation options, which can be obtained from crop-model simulations combined with climate scenarios. When we see tools simulating yield gains due to adaptation options, the adaptation analysis can be done by quantifying the response of different varieties, sowing time, nutrient management, water management, introduction of new crops, shifts in cropping sequences, altered resource management, and introduction of new technologies, etc., in various climate change scenarios and land use, so as to derive the best suitable technology package for reducing the impacts of climate change and land transformation at the irrigation land level and then up-scaling to state at the sub-basin level. The difference between mean yields in the future scenario (impact) and mean yields due to adaptation options in the future scenario is called the adaptation gain and may be expressed as a percent gain over impacts these are called "adaptation gains." If the crop yields are still negative even after adaptation, the magnitude represents the vulnerability of the crop [11].

The agriculture management option includes a land and soil management approach and a decision support tool, and it is an option to scale up improved agriculture water management with water and soil benefit In this section, we will review relevant soil and water management actions as best option adaptation strategies relating to climate change and land transformation mitigation and adaptation objectives in agriculture. Decision-making support tools have been identified mainly for the agriculture sector and can involve different types of users. For farmers, such tools can provide advice on irrigation scheduling to help determine the optimal use of water depending on the plant's needs. Thus, water can be saved through avoiding unnecessary irrigation while harvest levels are maintained. And so that is why it is important to review agricultural water management research in different places in different countries in response to climate change and land transformation and irrigated areas' experience in different levels of advisory systems in order to find the best options to find adaptation strategies that optimize the use of water for agriculture. Despite the fact that agricultural water management needs wide research, this paper tries to see only the line of research and new approach for modeling agricultural water management in the sub basin. Good policy practices on sustainable water use should be distinguished here from technical actions, while recognizing that a policy might be the strategic implementation or support for these actions. Below, we will see different methodologies that have the option of improving agricultural water management.

There are three methodological approaches for assessing climate change and land transformation impacts and adaptation strategies. First, the simplest methodology is the impact approach. It is considered simple because it follows a straightforward "cause and effect" pathway, or it can be thought of as an "If-Then-What" approach. We can understand that if climate change or land transformation happens, then what would be its impacts? The second approach is the interaction approach. This approach recognizes that a climate factor or land use factor is only one of a set of factors that influence or are influenced by the exposure unit. This means that the exposure unit is not only affected by climate factors but also by land transformation. The Interaction approach can be thought of as a "What-Then-If". We can understand what issues in a system are sensitive to climate change and land transformation, and then what fields will be impacted if climate change happens? This approach is similar to the irrigation level adaptation plan, which considers the best option for agricultural land soil and water benefit management in order to increase yield. The third approach, the integrated approach, is the most comprehensive regarding the interactions between climate factors and land transformation. This approach seeks interaction within sectors, between sectors and feedback. It also refers to adaptation strategies to moderate negative impacts. An agent-based model that simulates the farmer and different stakeholders' effects on the land use change under a policy framework is included in this approach.

In a changing climate and land transformation, it is very uncertain whether and how the evapotranspiration properties of the crops will change and also how crop management practices are adapted. It is thought that a warmer climate and changes in soil water content will shift sowing and planting dates and change crop development times, generally leading to faster development, including earlier flowering and earlier sowing of spring crops. Here, the effect of changes in the crop dates and development times on the hydrology in the watershed is studied by shifting the sowing date to achieve a greater yield. Consequently, the option for better agricultural water management that targets the most sensitive parameters for climate and land use changes is to analyze for soil and water benefit, which is soil management for improving agriculture water management. Soil management can be targeted to benefit soil protection and its fertility as well as water availability and quality. It often has co-benefits and trade-offs with other environmental priorities, including climate change mitigation and adaptation, biodiversity protection, and farmers' economic objectives. Conscious prioritization between these various benefits and tailoring to local conditions is a key success factor.

The purpose of the field scale adaptation strategy is to develop a better understanding of how farmers and irrigators perceive and use climate, plant growth, and soil information to assist in their irrigation schedule decision making. This is to ensure that when scientific information is provided to assist irrigators, it is presented in a way that is useful and encourages uptake. The benefit is to both the irrigators and the service providers, as maximum benefit is being gained from such services. Key areas for improvement have been identified in this study, like water losses should be reduced and water savings and efficiency should be increased, in particular in agricultural water scarce areas. Land and soil management approaches aimed at combating soil erosion, preventing loss of soil organic matter, sequestering soil carbon and improving water retention are critical for the long-term sustainability of farming and healthy ecosystems. The corporation should play a role in promoting these approaches, but farmers and national and regional administrations should also take action.

Further research should entail applying agro-hydrological models using parameter non-uniqueness to provide an even greater global indication of the uncertainty. The uncertainty in the reported outcomes is therefore correspondingly high, and the results must be interpreted with caution. I have chosen an option that was current and most suitable to provide some indication of the direction and the magnitude in which agricultural water management may be impacted and adapted by future changes. Soil salinity prediction, monitoring and mapping using modern technology and the need for the use of electrodes for measuring soil salinity and field scale soil moisture measuring instruments like lysimeters for measuring the soil moisture content of the soil is better if used and integrated with GIS and remote sensing technology when modeling using an Agro hydrological model. Soil salinity prediction monitoring and mapping using modern technology should also include how the impact can be quantified after assessing the effect to identify the adaptation strategy. Tube well technology, which advances agricultural water management, is also important to measure ground water level, which is an input data for hydrology models, as stated earlier, and this data can be integrated with remote sensing technology through models like MODFLOW. Furthermore, working in coordination with specialists in the development of new techniques and methodologies to be applied to an understanding of the physical environment is important. Some of the better developed lines of research within this field are crop monitoring, detection of land cover alteration, and estimation of evapotranspiration through remote sensing.

Agro-hydrological model for improved agricultural water management

The unsaturated zone, i.e., the zone between the soil surface and the groundwater, is a complicated system governed by highly non-linear processes and interactions. Flow processes can alternatively be described by means of physical-mathematical models. According to [12]. Unsaturated-zone models can be used to simulate the timing of irrigation and irrigation depths, drain spacing and drain depth, and system behaviour and response. The models have increased our understanding of irrigation and drainage processes in the context of soil-plant-atmosphere systems. Progress in modelling can be attributed to merging separate theories of infiltration, plant growth, evapotranspiration, and flow to drain pipes into a single numerical code [13].

According to Mdemu MV, et al. [14] Agro-hydrological models are more suitable for irrigation and water-use assessments than crop-growth-oriented models, although both approaches have been used. Simulation models are strong in understanding physical processes and scenario testing, but one cannot say if this combination of management alternatives can give the optimum return from scarce resources (Van Dam, J.C 2008). Simulation and optimization make a strong tandem in water resources analysis, and if used together, they could broaden the capacity to manage available resources. Combining a simulation model with an optimization algorithm is a promising tool for better water resources management. With land and water managers considering lining irrigation canals, it is important to consider how interactions between surface water and groundwater may be affected by reducing or removing canal seepage [15]. In the water balance, shallow groundwater levels depend on recharge from irrigation canal seepage. Modifications to the canals, such as lining them with impermeable materials, could lead to a reduction in groundwater recharge and changes in crop production patterns due to lowered groundwater levels.

As described earlier, water demand for plants significantly influences crop yield. In order to have a good prediction of the impact of water management and meteorological conditions, understanding and mathematical models are needed to optimize crop yield. This has been a subject of study for many years. An agro-hydrological simulation model is useful for agriculture monitoring and remote sensing provides useful information over a large area. Combining both information by data assimilation is used in agro-hydrological modelling and predictions, where multiple remotely sensed data, ground measurement data, and model forecasts are routinely combined in operational mapping procedures. Remote sensing cannot observe the input parameters of agro-hydrological models directly. Remotely sensed ET data and ground measurement data from experiment fields were then combined in a data assimilation to estimate the Agro hydrological model's parameters. The system is initialized with a population of random solutions and searches for the optimum by updating generations. The reasonable parameters (sowing date and harvesting date, ground water level) can be estimated. On the basis of estimated parameters, soil moisture is predicted by the model. The agro-hydrological model driven by the observed ET produces reasonable water cycle states and fluxes, and the estimates are moderately improved by assimilating ET measurements that provide information on the surface soil moisture state.

How agro hydrological model integrate with agent based adaptation strategy

Currently, there are different models that incorporate agent-based models and economic models with agro-hydrological models to simulate the policy option on agricultural water management. For developing countries, like Ethiopia, and also, though soil physical and hydraulic properties are of prime interest in agro-hydrological models, such data is commonly unavailable over large areas and has limitations in accounting for regional spatial variability, and it is prohibitively expensive, tedious, and time-consuming. To address this gap, the relevance and successful impact of the applicability of satellite remote sensing (SRS) within a geographic area is preferable today, allowing decision makers to retrieve information on ground measured physical parameters such as soil moisture content and extrapolate, predict, update, plan, evaluate, compare, simulate, and visualize various management actions. to predict the future scenario of temperature increase and predict variability of the river discharge and sedimentation, it is better to use remote sensing and GIS data input where precipitation and temperature scenarios are downscaled using the SDSM model from the nearest GCM point to each weather observation station.

This paper tries to address agronomy in general and crop modelling in particular, so besides modelling the impact of climate change, the paper also focuses on adapting strategies for the impact of climate change and land degradation, focusing on the need for integrated agricultural water management techniques and models that incorporate these adapting strategies [16]. Therefore, I recommend further research to fulfil the preliminary assessment of the sensitivity of the soil, water, atmosphere, and plant models to variations of climate and land use change variables based on this paper due to the occurrence of uncertainty on soil property unless it is checked in a laboratory. To get a good result from the agro-hydrological model, it is necessary to get periodic satellite input data for processing in Landsat and subsequent properties of shape file data processed by arc GIS, which shows the cropping pattern and stage that are used to estimate crop coefficient as an input for crop evapotranspiration and water requirement. The sub basin's agricultural water management, which has a high potential for land water resources for both farming and livestock, will also optimize water demand.

To mitigate climate change and land transformation effects, the occurrence of drought and flood, deficit of irrigation water supply, salinity and siltation monitoring systems like early warning systems and assessment of performance indicators of the agriculture system using the output of this paper as a procedure will be useful in the future. Agro-hydrological models are the best for quantifying and comparing the effects of climate change, land and soil change on agricultural yield of projects in the basin environment, so that we can recommend the need for environmental protection works such as deforestation, soil and water protection works to deal with the effects of climate and land change in the future. This kind of research is also useful to observe problems in the agricultural water management research trends and to prepare a proposal for different tasks in the area of modernization of irrigation water management, knowing plant water stress, the need for integrated water management, coping mechanisms like new technologies in agricultural water management, and selecting different types of crop species suitable for the climate and soil type of the area that can withstand drought.

Recent development in agro-hydrological model

As I mentioned earlier, agro-hydrological integrated with other climate-based models and agent-based models simulates the impact of current and future climate change and also the impact of the community in the basin as an agent for the land use change. This capacity of the model enables decision makers to simulate different factors that have an influence on agricultural water management in irrigation fields and basin level [17]. Agro-hydrological water management frameworks help to integrate expected planned management and expedite regulation of water allocation for agricultural production. Low production is not only due to the variability of available water during the crop growing seasons, but also due to poor water management decisions, such as not considering the available water for irrigation.

Agro-hydrological or water-oriented models have been significantly developed during the last few years. The models SWAP [17]. DRAINMOD [18]. WAVE ISAREG and HYDRUS can be considered as agro-hydrological models, among others. Agro-hydrological models are suitable nowadays for modelling climate change effects on irrigation water demand, not only the effect of temperature and rainfall variability, but also the effect of soil erosion and nutrient leaching at irrigation scale and sub-basin scale. According to Gadédjisso TA, et al. [19] Agro-hydrological models are more suitable for irrigation and water-use assessments than crop-growth oriented models, although both approaches have been used. However, agro-hydrological models are widely used to examine options for adaptation by stakeholders and policy makers as they have the ability to explore large sets of agricultural practices.

Here we see the application of an agro-hydrological model at field scale and basin scale independently to compare different types of agro-hydrological models and select the one suitable to Ethiopia's agricultural basin context. The selection criteria will be better if we see both the field-scale and basin-scale conditions of agriculture and the hydrological situation. Explaining how this model integrates with other climate and agent-based models and the capacity to assimilate different data products like remote sensing data and socioeconomic data has been considered in the selection of the model suitable for our country's context [20]. A climate smart agro-hydrological model can be a robust solution for wise water management decisions in a large scale irrigation scheme to cope with the risk of water and food security under the new realities of climate change. Several approaches have been adopted for the integration and analysis of large input data sets to improve decision-making in agriculture. For instance, a context-aware system (CAS) was developed to automate a manual irrigation method by integrating two engineering methodologies: ontology and information systems.

A climate smart decision support system (CSDSS) was developed for analyzing the water demand of a large scale rice irrigation scheme. An agricultural data analysis approach, which can estimate the weight of onions during the growth stages, was introduced using a functional regression model. A seasonal furrow irrigation model was developed using different data sets to estimate and analyse information on every event of furrow irrigation for maize crop production. A process based regional economic optimization (PBREOP) tool was developed to optimize the irrigation water use efficiency and economic benefit of an irrigation area, which reduced the total amount of irrigation water used by an average of 23% without a reduction in benefits. The PBREOP model is a two level optimization model with the combined use of an agro-hydrological model (SWAPEPIC). An agro-hydrological model, Soil Water Atmosphere Plant (SWAP), was applied to assess the effects of management of irrigation water on water and salt balances.

The study's authors found that the adopted water management in the area leads to excessive irrigation and leaching, as well as elevated groundwater salinity. The agro-hydrological SWAP model was applied under deficit irrigation to assess water cycles in an irrigation area. The optimal practices in irrigation management for hydrologic years were obtained, and the average percentage of water saved and groundwater recharge under the optimal irrigation schedules were simulated. Similarly, the agro-hydrological SWAP model was applied to address the salinization of soil and deterioration of water quality. The tool effectively predicted water and salt concentrations in the soil and the reduced effectiveness of relative crop output and water use efficiency [21].

Models could be useful in the assessment of the impacts of agricultural management and environmental shifts to support sustainable water management in agriculture at scales ranging from field to catchment. Despite the availability of a number of available tools, there are still limited studies of the coupling of hydrological and crop models to simulate processes within agro-hydrological watersheds. An integrated system is crucial to address the complexity of various agricultural water management phases within the context of the agro-hydrological watershed, particularly with the emerging issue of climate change. Agricultural use of water is based on various variables, including climatic circumstances, topography, lithology, soil, management methods, and plant type. Understanding these parameters enables crop water requirements to be estimated and crop management processes to be established.

Existing water management methods might not be sufficient to deal with climate change effects on reliable water supplies for irrigation. Spatial and temporal climate variations have affected water availability in different water catchments globally. An agro-hydrological or eco-hydrological river basin model includes a hydrological sub model as a basic component. Other components describing biogeochemical cycles (carbon, nitrogen, and phosphorus) and vegetation are coupled with the hydrological component in order to include important interactions and feedbacks between the processes, such as water and nutrient drivers for plant growth, water transpiration by plants, and nutrient transport with water. Generally, vertical and lateral fluxes of water and nutrients in catchments are modelled separately, whereas climate and land-use related parameters are treated as external drivers.

The spatial and temporal resolution of a model depends on data availability and the aim of the study. The scale of application, spatial resolution, and objective of the study are connected: a fine spatial resolution may be needed for a small catchment in order to study water flow components and their pathways using tracers; a lumped model may be sufficient for the case where "precipitation–runoff" relationships are investigated in a homogeneous medium-scale catchment; whereas a coarser resolution could be applied to a large river basin for climate impact assessment. Continuous dynamic models that are based on mathematical descriptions of physical, biogeochemical, and hydro chemical processes by combining elements of both a physical and conceptual semi-empirical nature and including a reasonable spatial disaggregation scheme (e.g. in sub-basins and hydrological response units, HRUs) can be called process-based eco-hydrological river basin models. Such deterministic models may also include stochastic elements. Numerous studies have demonstrated that such models are able to adequately represent natural processes at the catchment scale.

An important question is: what is the appropriate level of detail in the parameterization of processes in an agro-hydrological model, and what details are included in the model so that better and more complex models ensure better representation of reality? However, the experience of using complex process-based models during the last few decades has led to the conclusion that model complexity should not be a purpose in itself and should be generally defined as a compromise solution. If a complex phenomenon or process can be described mathematically in a simplified form and parameterized using available information, this is often preferable to a more rigorous, physically-based approach with a high level of detail and unknown parameters. In the latter case, parameterization of the model may be problematic, and control of the model's behaviour may become difficult. In other words, one should only include sub models that are essential and necessary, parameters that can be estimated, and interrelations that can be understood and validated in simulation experiments. In addition, the level of complexity in the representation of different model components must be comparable.

Over parameterization can easily lead to loss of control over the model behaviour. Besides, the global optimum parameter set usually does not exist in such models, as there are several parameter sets leading to similar simulation results. This is usually called the problem of equifinality, which suggests that, due to limitations in both the model structure and input data, there are several representations of a river basin that are equally valid in terms of their ability to reproduce studied processes. Therefore, the modelling results should not be interpreted as exact predictions but within the uncertainty ranges related to uncertain model parameters and input data, as indicators of possible trends, as qualitative differences, etc. SWAT and DWSM are process-based modelling tools for river basins. The SWAT model is a continuous-time, semi-distributed, process-based river basin model. It was developed to evaluate the effects of alternative management decisions on water resources and diffuse pollution in large river basins.

There was a long period of modeling experience leading to this model. In the mid-1970s, the US Department of Agriculture's Agricultural Research Service invited a team of interdisciplinary scientists to develop a process-based, nonpoint source simulation model for the field scale. From that effort, a model called CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) was developed to simulate the impacts of land management on water yield, sediments, and nutrients. In the 1980s, several new models were developed based on CREAMS. One of them, the EPIC model (Erosion-Productivity Impact Calculator) was originally developed to simulate the impacts of erosion on crop productivity and later evolved into a comprehensive agricultural field-scale model for the assessment of agricultural management and nonpoint source loads. Another model, called GLEAMS (Groundwater Loading Effects on Agricultural Management Systems) was focused on pesticide and nutrient loads to groundwater. The next step was the development of the SWRRB model (Simulator for Water Resources in Rural Basins) which was designed for watersheds divided into multiple sub-basins. The SWRRB tool was developed by modifying components of CREAMS, EPIC, and GLEAMS and included several new components. The new tool aims to simulate management impacts on water and sediment transport for ungagged rural basins across the USA.

In the early 1990s, the SWAT model was developed by merging SWRRB, ROTO (Routing Outputs to Outlet Geographic Resources Analysis Support System) GIS interface in order to overcome the limitations of the inadequately-simple flood routing, restrictions on the number of sub-basins, and to facilitate the model parameterization for nonhomogeneous basins. Since then, SWAT has undergone continuous review, modification, and enhancement. During the last decade, a number of SWAT model versions have appeared, adapted to applications outside the USA for specific purposes and using different data formats. Among them are: SWIM (Soil and Water Integrated Model) based on SWAT-93 and aiming mainly at climate and land-use change assessment; the SWAT-G model based on SWAT99.2 and aiming at flow prediction for low mountain ranges in Germany; and the ESWAT (Extended SWAT) model with a number of adjustments for the hourly time step. This aim is achieved by using a modelling approach with multiple scenarios applied. In the SWAT model, the models used to simulate changes that may occur in climate simulations from regional climate models were chosen to obtain a suite of future climates. Also, land use scenarios were developed using storylines of the future that examine a range of possible agricultural crop changes. A farmer survey was undertaken to help develop a descriptive land use storyline for one of these land use scenarios. All the land use storylines were applied to a dynamic land use model that was able to spatially distribute land use scenarios.

Finally, the climate simulations were applied alone and in combination with the land use change scenarios in a hydrological model to determine their unique and synergetic impacts on soil water content and solute content in an irrigation field. Field-level management adaptation strategies were investigated regarding their effectiveness to counteract the negative impacts on water and solute content. Therefore, agricultural policies also influence how farmers make decisions. In addition, global scale changes, such as precipitation and temperature, play a key role as they affect crop suitability in a region and also nutrient transportation processes from farmland. This research examines detailed changes at the local scale (decisions pertaining to agricultural land use) and at the regional scale (policy drivers of agricultural land use) to develop land use change scenarios coupled to changes to global scale processes (climate). Of principal interest is how these combined effects may impact agricultural water management at the basin level.

Discussion and Conclusion

With the increasing population, climate change and water scarcity, the use of improved technology models and management practices is a must. Several basins are exploring options for enhancing water productivity to achieve various social, economic, and environmental goals. Irrigation models commonly focus on a limited portion of the water balance, missing important sources and uses of water within irrigation projects. For this particular reason, however, they are generally of limited value in managing irrigation water within the broader context. Despite the recent developments in the use of agro-hydrological models for improved agricultural water management and efficiency of irrigation projects under climate and land use change at river basin scale, several remaining challenges can be identified in the application of the model at field scale and basin scale level to assess agricultural water management in a climate change and land use change context. Since field scale or irrigation level agricultural water management focuses more on crop evapotranspiration and soil water content, whereas basin scale agricultural water management focuses on hydrological components, integrating two types of agro-hydrological models that are effective at field scale and basin scale is important for improved agricultural water management in the climate change and land use change scenario.

Clearly, the model selection is based on the problem identified and the policy evaluation to be addressed. Although the irrigation scale may be useful to analyse farm decisions and impacts on different farms, regional or catchment models are optimal to determine the socially optimal allocation of water resources and adaptation work done on catchment to reduce land degradation. However, the model applied for field scale modelling may not be applicable at the basin scale level. At the same time, model linking has become increasingly important in certain modelling contexts. There are a number of sophisticated models able to address these challenges, such as Soil–Water–Atmosphere–Plant MIKE SHE and the Soil and Water Assessment Tool the SWAP model simulates vertical water flow, solute transport, and heat flow in close interaction with crop growth in agricultural fields. This permits water productivity analysis and estimation of agricultural water use. However, this model focuses on hydrological processes at the field scale, and it is not suitable for large-scale simulations or areas with great spatial variability.

While SWAT is a basin-scale, physically-based continuous distributed model developed to predict the impacts of management on water, sediment, and agricultural chemical yields in ungagged watersheds, It allows for relatively complete agricultural management practices (e.g., planting, fertilization, irrigation, and drainage) and spatial distribution characteristics (e.g., ponds, reservoirs) in irrigation areas. As a result, SWAT is regarded as the preferred tool for agricultural watershed modelling in this study. Recently, there have been a few studies concerning hydrological processes based on SWAT in irrigation areas [21]. Used SWAT to estimate the irrigation water requirements and monthly runoff on the Gulf Coast of the United States. Their results showed the capability of SWAT to deal with large-scale problems [18]. Tested the SWAT model in a coastal plain agricultural watershed and concluded that a modification and more extensive calibration may be required to improve the accuracy of daily flow estimation.(19,20) identified the critical areas of an agricultural watershed and recommended best management practices using SWAT, and their work revealed the robust performance of the model in different simulation conditions. Since data scarcity is a common problem in hydrological modelling, Immerzeel and Droogers integrated remote sensing and observed monthly discharge to calibrate the SWAT model. In addition to assessed the crop growth and soil water modules in SWAT2000 based on field experiments in an irrigation district of the Yellow River Basin (in China), and they proposed some improvements to the soil water and groundwater evaporation modules. There are other studies concerning the application of SWAT. Comprehensive reviews of the SWAT model were given by Narayanan K and Mulugeta MS [17] and Yenesew M and Ketema T [18].

It is important to use field-scale numerical models with adaptive agricultural water management to solve the problem of climate impact on irrigation water use. And build resilience in agricultural water management. If it is at farm level and field scale, we can use agro-hydrological models like SWAP for field scale and SWAT for basin scale simulation of water and nutrients. They are helpful for better management of agricultural systems, and if we use integrated scale water management, it is better to use the SWAT model because it is the most common agro-hydrological model implemented in basin hydrological studies. Field scale numerical models like SWAP mode are mostly used in farm level simulations of water and nutrient movement in the irrigation field and are helpful in simulating the impact of climate change on irrigation water use. The other advantage of these agro-hydrological models is that they can be integrated with other models like climate models from remote sensing products, assimilating evapotranspiration data SWAP to simulate the impact of climate change on future irrigation water needs.

Integrated basin scale agricultural water management, in contrast, is helpful for adaptive agricultural water management by simulating different adaptation practices like soil conservation works to minimize the impact of land use change on soil erosion and nutrient leaching. SWAT, the common agro-hydrological model, is helpful in this regard, simulating water and nutrient movement and evapotranspiration of the basin. The other advantage of this SWAT model is that it can be integrated with agent-based models like the CLUE model to simulate the different agents like farmers and stakeholders in the land use change both negatively, as in land degradation, and positively, as in soil conservation adaptation, for current and future conditions so that we can quantify the impact on an economic basis.

And currently, the use of remote sensing with GIS technology products and soil moisture sensors is helpful for precision and good data management. Irrigation and agro-hydrological models are helpful in this regard because SWAP simulates soil water movement from other sources like capillary water and ground water sources that are not considered with crop-oriented models. To sum up, my main conclusion regarding agro-hydrological modelling for improved agricultural water management and efficiency of irrigation projects under climate and land use change at river basin scale will be to simulate both the impact of climate and land use change and also to simulate the adaptation strategy to mitigate the impact of climate change. The SWAP model at field scale and the SWAT model at basin scale are the best for the Ethiopian agricultural basin.

This agro-hydrological model, as stated above, when integrated with climate models and agent-based models, enables us to simulate and optimize the effects of climate change and adaptation options for agricultural basins. They are widely used to examine options for adaptation by stakeholders and policy makers as they have the ability to explore large sets of agricultural practices that maintain agricultural production while preventing degradation of natural resources. The result of this study helps institutions in basin and irrigation corporations to control the effect of climate change impact on crops and agriculture by selecting and applying the adaptation and mitigation measures at field and basin scale. It will also be an input for policy formulators to choose the best adaptation option and action taken to mitigate the impact of climate change and to know the quantified impact on crop yield and economic benefit using optimization techniques. Consequently, the combination and integration of a number of technical, institutional, and economic improvements should be considered in the future, and further research should cover a broad range of options for improving water productivity. Research institutions should forge partnerships with the government and private sector, which are extremely active in the development of irrigation technology. The challenge will be to bring private research down to the level of the needs of investors in developing countries and to get affordable technology [21].

There should be sectorial evaluation and strategies for improvement with the target of avoiding water scarcity and pollution. Every region has its own natural, economic, and socio-cultural preconditions and requires different reasonable measures in order to establish a sustainable and integrated water resource management system. Regional boundary conditions, such as precipitation distribution and main water body characteristics, as simulated for the various scenarios. Adaptation measures would not be achieved without creating public awareness as a means of knowledge transfer and helping organizations and people develop the attitudes necessary to adopt practices and formulate new positive behaviour patterns towards water conservation through community mobilization and sensitization. Although the problem of water scarcity has been recognized at the community level, however, the transfer of knowledge and technology would be needed to implement adaptation measures.

The main reason for the lack of adoption of water-saving measures by farmers and organizations is the lack of incentives to save water. Water saving can be encouraged by supporting institutions, providing incentives and information, financial assistance and coordination. Several complementary approaches must be promoted. First, water savings and more efficient use of water should be achieved through water metering, improving irrigation efficiency, reducing leakages to a sustainable economic leakage level, and irrigation scheduling. In particular, water metering should be introduced and enforced via water policies and could potentially target water-scarce areas or water-intensive cropping systems. Second, improved water availability should be achieved through water re-use, rainwater harvesting, and storage. Improved land and soil management approaches will provide important water benefits. Policies that encourage sustainable use of shallow groundwater to buffer inter-annual droughts and supply shortages will offer the most scope for autonomous adaptation, but pose some major challenges in the design of regulatory and incentive structures that ensure equity and long-term resilience. In the short to medium term, modernization strategies for irrigation systems should aim to minimize capital investments and seek the most cost-effective options in water control. In summary, focusing on: a) Promoting an integrated vision of water resources at the basin; b) Strengthening the management capability of user organizations; c) Strengthening the management and institutional operation of extra property irrigation infrastructure; d) Generating coordination to improve the market of water resources for irrigation; e) Controlling environmental pollution caused by irrigation; and f) Strengthening intra-property land management.

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How to cite this article: Yimer, Natan Molla. "Agro-Hydrological Modeling for Improved Agricultural Irrigation Water Management under Climate and Land Use Change for River Basin Scale Irrigation Projects Planning in Ethiopia: A Review." *Irrigat Drainage Sys Eng* 11 (2022): 358.