Impact of climate change and watershed interventions on water balance and crop yield in West Seti river sub-basin of Nepal

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RESEARCH PAPER

Impact of climate change and watershed interventions on water balance and crop yield in West Seti river sub-basin of Nepal

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ABSTRACT The Soil and Water Assessment Tool (SWAT) was used to simulate water balances in different cropping patterns under current and future climates in West Seti river Sub-basin, which is located in the far western region of Nepal. The results show that total precipitation over rice, maize, millet, wheat and barley fields were 1002, 818, 788, 186 and 169 mm respectively, whereas total simulated actual evapo-transpiration (ET) are 534, 452, 322, 138 and 177 mm respectively under current climate. Actual ET will change by -1.9 % in rice, -1.1 % in maize, -2.0 % in millet, +6.7 % in wheat and +5.4 % in barley under future climate projections. Results show that yield of maize and millet will decrease by 5.9 % and 8.0 % whereas yield of rice, wheat and barley will increase by 1.2 %, 6.6 % and 7.0 % respectively. Therefore, the impact of climate change shows that summer crop yields will decrease except of rice and winter crop yields will increase. In general, a result of watersheds interventions shows that the crop yields will increase after the watershed interventions.

KEYWORDS Water balance, hydrological modeling, climate change, crop yields, SWAT

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INTRODUCTION

The South Asian region faces alarming environmental and socio-economic challenges in its effort to protect valuable natural resources. Furthermore, the uncertainty and risks associated with climate change are likely to exacerbate these challenges. The Himalayan catchments of Nepal, including watersheds in mountain regions, are considered vulnerable to risks of flooding, erosion, mudslides and glacial lake outburst floods because the melting snow coincides with the summer monsoon season and any intensification of the monsoon and/or increase in melting is likely to contribute to flood disasters. At the other extreme, water scarcity and droughts especially during the dry season pose a similar threat to the primarily agriculture based livelihood systems.

In Nepal, most of the agricultural land in the hills and middle mountains depend on rainfall and only few lands have access to irrigation from local streams. Around 85 % of rainfall occurs however, during the four monsoon months of June- September, therefore the temporal and spatial variability greatly impacts effective water use. Under these conditions, water sources catchment management and water storage are good strategies as it would increase dry season water availability as well as reliability throughout the year. The conventional method for water storage has been through construction of either large or small reservoirs in downstream reaches. However, there are many problems associated with reservoirs such as high evaporative losses, reservoirs have a tendency to be filled with silt very soon so the maintenance cost is high and usually they only provide water to the people living in close proximity and for downstream communities. So, the upland communities will generally not benefit. By slowing down and/or storing the water directly in the place where precipitation takes place, all inhabitants in the upland catchment area where poverty is starkest will benefit. Another principle is to make the time that water travels in the catchment as long as possible which will spread the discharge over a longer period and the peak discharge will decrease flood events downstream. Furthermore, springs which are points on the surface of the earth through which groundwater emerges, not only contribute to base flows of streams and rivers but most significantly, in the Himalayan watersheds, are used to meet basic needs during the dry season. Therefore, storage and management of spring flows, which might also include the management of spring recharge areas, are also important for increasing water availability for communities in the upper watersheds.

Water is a driving component of any watershed that directly or indirectly influences all processes and sectors. Proper management and utilization of water thus requires the overall management of watershed and vice versa. Watershed management is becoming increasingly important in countries where economy and livelihood depend on agriculture (Karpuzcu and Delipēnar 2011). Watershed management is the integrated use of land, vegetation and water in a geographically discrete drainage area for the benefit of its residents, with the objective of protecting or conserving the hydrologic services that the watershed provides and of reducing or avoiding negative downstream or groundwater impacts (Darghouth et al. 2008). Watershed management, in its broadest sense, can be considered as an attempt to ensure that hydrological, soil and biotic regimes, on the basis of which water related projects have been planned, can be maintained or even enhanced (Biswas 1990). In other words, watershed management is a concept of improving water availability and reducing disaster with appropriate watershed interventions to fulfill the agricultural, industrial and domestic demand and to conserve the natural resources. Watershed management increases the food production and is also beneficial to protect environment, increase biodiversity, improve livelihood of the people (Garg et al. 2013).

In general, watershed management practices are divided into two categories which include vegetative and engineering measures. Strip cropping, terrace construction, channel diversion, water ponds, reservoirs, drainage structures, flood protection, groundwater recharge, etc. are some of the widely adopted engineering measures for watershed management. The purpose of watershed management includes minimizing flood damage, sediment control, water protection, soil erosion control, etc. However the principle objective of any watershed management practice is the preservation and maintenance of its two vital resources, land and water (Das 2002). The application of these methods varies from watershed to watershed and also the purpose for which it is intended for (Sharma et al. 2010). Watershed management practices (erosion and conservation structures and water harvesting structures) influence the hydrologic cycle particularly to the runoff yield from the basin (Kapoor and Gosain 1987).

Watershed management in developing countries are mainly aimed at increasing agricultural productivity and reduction of poverty in hillside rural areas (Perez and Tschinkel 2003). In the present context, watershed management is considered as an effective tool for addressing many of the problems like food insecurity, land degradation, water security, etc. and recognized as potential engine for agricultural growth and development specially in fragile and rain-fed areas (Wani and Garg 2010). Climate change challenges for future food security seem immense (Hanjra and Qureshi 2010). Adaptation is thus necessary to tackle the risks associated with climate change. In this context, watershed management is viewed as a key tool for climate change adaptation (Srivastava 2005).

Implementation of watershed management activities in different parts of the world such as Brazil, China, India, Tunisia, and Turkeyhas shown positive impacts on different sectors (Darghouth et al. 2008). Since watersheds are complex systems where water, soil, geology, flora, fauna, and human natural resource use practices interact, Watershed management interventions may bring local, regional, and global environmental benefits (Darghouth et al. 2008). Watershed management has been successfully implemented in Northeast Thailand for improving land degradation and agricultural productivity (Wangkahart et al. 2005). To check unsustainable exploitation of groundwater resources in different areas of Indo-Gangetic basin, wide variety of potential physical, crop-related and policy interventions were tried with varying degree of success (Sharma et al. 2010). Similarly Indian government has intensified watershed management program in fragile and high risk ecosystems with excessive soil erosion and moisture stress. It is expected that these program would augment farm income, raise agricultural production and conserve soil and water resources in rain-fed areas (Joshi et al. 2005). Based on their study (Kumbhar et al. 2013) showed increase in groundwater recharge, increase in cereal and vegetable crop production as a direct impact of watershed interventions.

The studies on watersheds inventions show that impact of large scale implementation of agricultural watershed intervention will be only significant and small-scale water storage systems, like check dams and farm dam, have very limited downstream impacts

(Garg et al. 2012, 2013, Schreider et al. 2002, Sreedevi et al. 2004, Verstraeten and Prosser 2008). Typical watershed intervention using various widths of vegetation filter and application on high erosion risk show reduction of sediment yield (Awulachew et al. 2009, Verstraeten and Prosser 2008). Agricultural water interventions will reduce the risk of flooding and will increase green water use (Garg et al. 2013). Due to increase in green water availability, cropping pattern has changed from low-value cereal crops to high-value and long duration crops and vegetables.

The watershed development activities, which are being currently carried out by the government and non-government agencies in Nepal have not been addressing water management adequately. Most of the activities have been focused on degraded land rehabilitation, on-farm conservation, natural disaster prevention and forest management. It has however, been recognized by Poudel (2012) that the sustainable development of the watersheds will require a more water centric approach with simultaneous achievement of tasks like, afforestation, strict control of land use practices, and more emphasis on small-scale structures such as check dams to conserve soil and water. The objective of this study was therefore to to (i) Assess water balances under past and future climate conditions in the West Seti Sub-basin (ii) Assess the impact of watershed interventions on the hydrology of the sub-basin and subsequently to measure change in the yields of cereal crops. The Soil and Water Assessment Tool (SWAT) was used to simulate water balance and crop yields in this study.

MATERIALS AND METHODS

The study area as West Seti sub-basin (Fig 1) was selected on the basis of a study on climate change vulnerability in the middle and high mountain regions of Nepal and identified as one of the most vulnerable sub-basins in relation to climate change (Siddiqui et al. 2012). The West Seti river sub-basin located in far western region of Nepal has catchment area of 7,438 km^2 while taking confluence point with the Karnali River as the basin outlet. The sub-basin originates from the snow fields and glaciers around the twin peaks of Api and Nampa in the south facing slopes of the main Himalayas. It extends from latitude 30ę04ô north to 28ę 56ô south and longitude 80ę 36ô west to 81ę 36ô east. The average elevation of the sub-basin is 2505 m but it varies from 314 m at sub-basin outlet to 7043 m of Api and Nampa high mountain ranges. The West Seti river is one of the major tributaries of Sapta Karnali river (longest river of Nepal).

Hydro-meteorological data

SWAT requires time series of observed climate data i.e. rainfall, minimum and maximum temperature, solar radiation, wind speed and relative humidity. In this study, time series climate data from 1981to 2010 from Department of Hydrology and Meteorological (DHM) of Nepal was used for model input. In addition, daily observed hydrological data obtained from DHM was used to calibrate and validate the model output. Altogether, data from 15 climate stations and 3 hydro stations was used for this study.

In this study, projected climate data from DHM (downscaled from PRECIS, and WRF regional climate models) were used to model future scenarios. The downscaled climate variables were based on the five global climate models (GCMs): ECHAM5 in PRECIS, and, Era40, CCSM, ECHAM5, GFDL, and HadCM3 in WRF. The average of projected climate data from these seven projections, under A1B scenario, was used to assess climate change impacts. The projected climate time series data covered the periods from 1971 to 2000 as base line and 2031 to 2060 as the future projection.

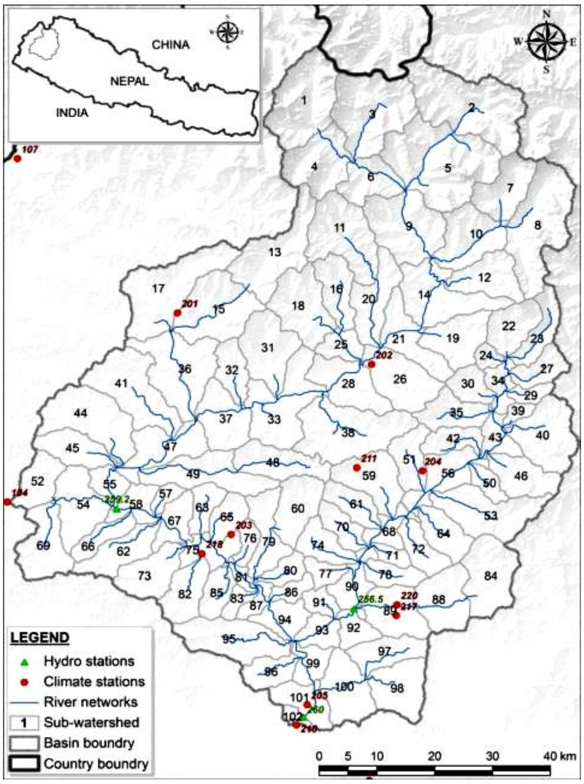

Fig 1 West Set river sub-basin/sub-watersheds with location of hydro meteorological stations

Spatial data

SWAT requires three basic files for delineating the basin into sub-basins and hydrologic response units: Digital Elevation Model (DEM), Soil map, and, Land Use/Land Cover (LULC) map. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model

Version 2 (GDEM V2) with 1-arc second (approximately 30 m at the equator) resolution was used for the DEM in this study. This ASTER GDEM was jointly developed by the Ministry of Economy, Trade, and Industry (METI) of Japan and the United States National Aeronautics and Space Administration (NASA). Sources of the land cover map and soil map are from National Land Use Project (NLUP), Ministry of Land Reform and Management (MoLRM), Nepal.

Agricultural data

Based on MoAC (2005), the crops considered in this study are: rice, maize, wheat, barley, millet, potato, oilseed, sugarcane and vegetables. Agricultural fields in level terraces are classified into rice (19 %), millet (16 %), sugarcane (1 %) and vegetables (64 %) whereas agricultural fields in slope terraces are classified into maize (36 %), oilseeds (6 %), potato (8 %) and vegetables (50 %). All the agricultural fields in river valleys were classified as rice fields. Wheat and barley were considered as winter crops in rotation with summer crops such as rice, maize, millet, oilseeds and vegetables, whereas sugarcane and potato do not contain a second crop.

Soil and water assessment tool (SWAT)

SWAT is a process-based continuous hydrological model that predicts the impact of land management practices on water, sediment and agricultural chemical yields in complex sub-basins with varying soils, land use and management conditions (Srinivasan et al. 1998, Arnold et al. 2011, Neitsch et al. 2011). The main components of the model include: climate, hydrology, erosion, soil temperature, plant growth, nutrients, pesticides, land management, and, channel and reservoir routing. Conceptually, SWAT divides a basin into sub-basins. Each sub-basin is connected through a stream channel and further divided in to Hydrologic Response Unit (HRU). HRUs are a unique combination of a soil and a vegetation type in a sub watershed, and SWAT simulates hydrology, vegetation growth, and management practices at the HRU level.

The hydrologic cycle as simulated by SWAT is based on the water balance equation:

$$SW_t = SW_o + \sum_{i=1}^{n}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \qquad (1)$$

where, SW_t = final soil water content (mm), SW_o = initial soil water content (mm), t = time (day), R_{day} = amount of precipitation on day i (mm), Q_{surf} = amount of surface runoff on day i (mm), E_a = amount of actual evapotranspiration on day i (mm), Wseep = amount of percolation on day i (mm), Q_{gw} = amount of return flow on day i (mm)

Since the model maintains a continuous water balance, the subdivision of the basin enables the model to reflect differences in ET for various crops and soils. Thus, runoff is predicted separately for each sub-basin and routed to obtain the total runoff for the basin. This increases the accuracy and gives a much better physical description of the water balance. More detailed descriptions of the model are available in literature (Arnold et al. 2011, Neitsch et al. 2011).

The SWAT model partitions crop yield from the total biomass on a daily basis (Arnold et al. 2011). The partitioning is based on the fraction of the above-ground plant dry biomass removed as dry economic yield and this fraction is known as harvest index (Neitsch et al. 2011). The harvest and kill operation is enabled to evaluate the crop yields in the modeling. The equations for the crop yield are,

$$YLD = bio_{ag} \times HI, \text{ when } HI \le 1 \qquad (2)$$

$$YLD = bio \times \left(1 - \frac{1}{1 + HI}\right), \text{ when } HI > 1 \qquad (3)$$

where, YLD = crop yield (kg/ha), bio_{ag} = above-ground biomass on the day of harvest (kg/ha),HI = harvest index on the day of harvest, bio = total plant biomass on the day of harvest (kg/ha)

In this study, the harvest index considered for optimal growing conditions were: rice, 0.50, maize, 0.50, millet, 0.25, wheat, 0.40, and, barley, 0.54. Whereas the harvest index considered under highly stressed growing conditions were 0.25, 0.30, 0.10, 0.20, and 0.20 for rice, maize, millet, wheat and barley respectively. The potential harvest index for a given day was dependent of the harvest index for the plant at maturity given ideal growing conditions and the fraction of potential heat units accumulated for the plant (Neitsch et al. 2011). Thus, SWAT takes into account the change in harvest index for the crops when there is water stress at certain phases of the crops. The equation for the actual harvest index in water stress condition is,

$$HI_{act} = (HI - HI_{min})\frac{\gamma_{wu}}{\gamma_{wu} + \exp[6.13 - 0.883\gamma_{wu}]} + HI_{min} \qquad (4)$$

$$\gamma_{wu} = 100 \frac{\sum_{i=1}^{m} E_a}{\sum_{i=1}^{m} E_o} \qquad (5)$$

where, HI_{act}= actual harvest index, HI_{min}= harvest index for the plant in drought conditions, γ_{wu}= water deficiency factor, E_a = amount of actual ET on day i (mm), E_o = amount of potential ET on day i (mm), i = day in the plant growing season, and m = day in harvest

Model calibration and validation

The model was calibrated at the 3 locations (Table 1). The daily observed hydrological data obtained from DHM was used to calibrate and validate the model. The model performance was determined by calculating the coefficient of determination (R^2) and the Nash-Sutcliffe Efficiency (NSE) with respect to the daily and monthly observed data. The performance was acceptable as described by Liu and Smedt (2004) and (Moriasi et al. 2007).

Table 1 Hydrological Stations in the West Seti river sub-basin

Station Index	River Name	Place	Coordinate		Period	
			Lati-tude	Longi-tude	Calib-ration	Vali-dation
256.5	Budhi Ganga	Chitreghat, Mangalsen	29.16	81.21	2001 ï 2003	2004 ï 2006
259.2	Seti River	Gopaghat Gaon	29.30	80.78	1986 ï 1990	1991 ï 1995
260	West Seti	Banga	28.98	81.14	1981 ï 1985	1986 ï 1990

Fig 2 shows model calibration and validation results at the sub-basin outlet Banga of West Seti river (DHM Station No. 260). The obtained NSE is 74 % for calibration and 68 % for the validation period under daily simulation whereas NSE is 93 % for the calibration and 85 % for the validation period under monthly simulations. The simulated cumulative volume increased by 1 % in calibration and decreased by 3 % in the validation period. Similarly, Fig 3 shows model calibration and validation results at Gopaghatgaon of Seti River (DHM Station No. 259.2). The obtained NSE is 67 % in the calibration and 54 % in the validation period under daily simulation whereas NSE is 86 % in the calibration and 90 % in the validation period under monthly simulations. The simulated cumulative volume is reduced by 11 % and 8 % in the calibration and validation period respectively. Fig 4 shows model calibration and validation results at Chitreghat-Mangalsen of Budhi Ganga River (DHM Station No. 256.5). The obtained NSE is 73 % for the calibration and 60 % for the validation period under daily simulation whereas NSE is 90 % for the calibration and 78 % for the validation period under monthly simulations.

Watershed interventions under current climate

The results from projected future climate data show that it is difficult to make conclusions regarding precipitation and flow trends therefore, uncertainty is the main risk that can be attributed to CC. From a water availability and use perspective, one can reduce risks through promoting water storage mechanisms. Storage development is an effective way to cope with temporal and spatial variability in water resources and as a result ï to enhance water and food security. Traditional storage infrastructure is now back on the agenda of multi-lateral donor agencies and governments of many developing countries. However, there are multiple and diverse storage types in addition to large infrastructure - ranging from natural storage (e.g. wetlands, glaciers, soil moisture, aquifers) to various smaller structures (e.g., terraced paddies, ditches, retention ponds). This óstorage continuumô often slips the attention of development organizations. Therefore in this study 4 specific interventions were tested with the objective to 1) delay the flow of surface runoff by shifting surface flow into soil moisture and groundwater 2) increase water availability through distributed small scale storages such as ponds and small reservoirs. The model was therefore utilized to assess the impact of various watershed interventions. The adopted 4 specific interventions in the study are afforestation of degraded lands, on-farm conservation, infiltration ponds, and, small water reservoirs.

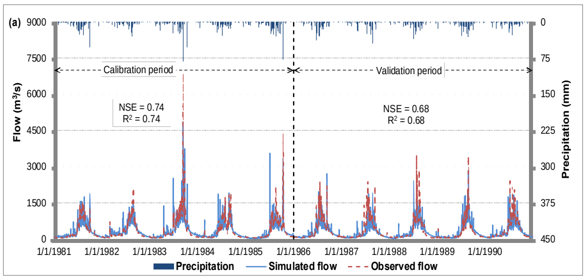

Fig 2 Calibration and validation results of daily flow at Banga, West Seti river (Hydro Station 260 and Sub-watersheds 101)

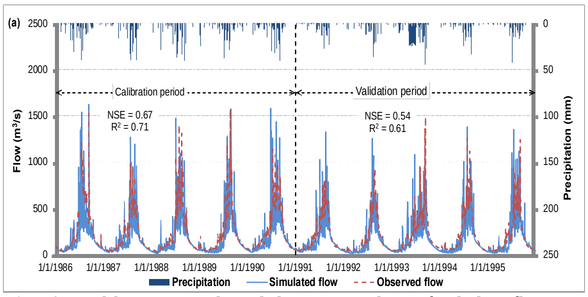

Fig 3 Calibration and validation results of daily flow at GopaghatGaon, Seti River (Hydro Station 259.2, Sub-watersheds 55)

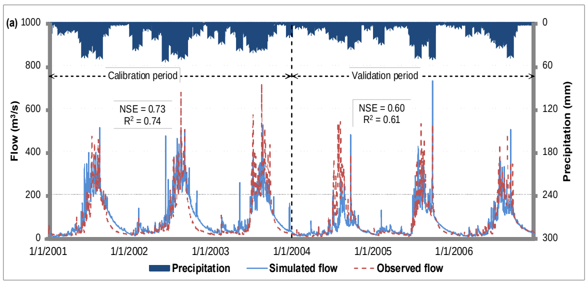

Fig 4 Daily calibration and validation results of daily flow at Chitreghat, Mangalsen, Budhi Ganga (Hydro Station 256.5, Sub-watersheds 90)

RESULTS AND DISCUSSION

In the period of 1981 to 2010, the average annual rainfall within the sub-basin was 1921 mm, whereas seasonal precipitation was 137 mm in the winter, 261 mm in the pre-monsoon, 1449 mm in the monsoon, and, 74 mm in the post-monsoon seasons. Therefore, in this sub-basin almost 75 % of annual rainfall occurred during the monsoon season. In the period 1981-2010, the mean monthly maximum temperature in the sub-basin varied from +7.5°C to +30.2°C and minimum temperature varied from -5.6°C to 16.8°C. The projected climate result shows that the mean monthly maximum temperature will change by -0.09°C to +0.44°C per decade and minimum temperature will change by +0.030°C to +0.031°C per decade in this study area. Therefore, the projected results show that the mean monthly average temperature will change by +0.06°C to +0.18°C per decade in the sub-basin.

Water balance and impact of climate change

Annual precipitation in the sub-basin varies from 743 mm to 3351 mm (Fig 5a) under the current climate, whereas annual water yield and annual actual evapo-transpiration in the sub-basin vary from 357 mm to 2720 mm (Fig 5b) and from 297 mm to 1398 mm (Fig 5c) respectively. In the climate change scenario (2031 to 2060), average percentage change in annual precipitation in the sub-basin will be +1.4 % but it will vary from -22.8 to +15.8 % (Fig 6a), whereas average percentage change in annual water yield will be -1.3 % (-74 to +29.5 %) (Fig 6b), and the average change in annual actual ET will be +7.6 % (-19.6 to +77.8 %) (Fig 6c). Based on climate change projection results, precipitation will increase in the lower sub-watersheds and decrease in the upper sub-watersheds of the sub-basin. Water yield will also increase in lower sub-watersheds and decrease in upper sub-watersheds.

Actual evapotranspiration (ET) and crop yields under current climate

This study considers three scenarios of crop rotations in a year, i.e. (a) Rice-Wheat-Vegetables rotation scenario, (b) Millet-Wheat rotation scenario, and (c) Maize-Barley rotation scenario (Fig 7). The study shows a positive correlation between actual ET and crop yields however, the correlation coefficients are less than 0.50 in all crop rotation scenarios. In scenarios (a) and (b), crop yields gradually increased with respect to increase in actual ET. Linear trend lines show that the ratios of actual ET by crop yields are 0.95 and 0.84 in scenarios (a) and (b) respectively. In contrary, the scenario (c) shows crop yields increase slightly with respect to an abrupt increasein actual ET. Hence, the linear trend line shows that the ratio of actual ET by crop yields is 3.52 in scenario (c).

Fig 8 illustrates the trend of change in actual ET and crop yields under the selected crop rotation scenarios in the period from 1981 to 2010. Results show a declining trend of both actual ET and crop yields in the simulation period. The trend of changes in crop yields is following the trend of change in actual ET in all crop rotation scenarios.

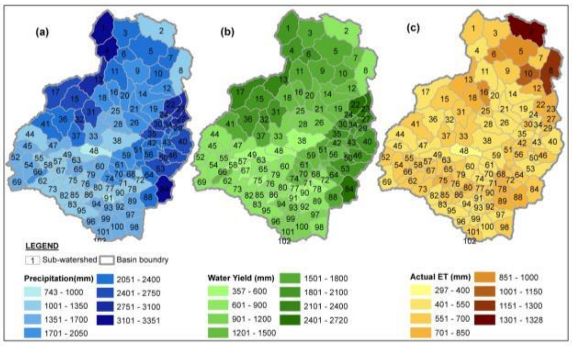

Fig 5 Annual water balance in the sub-watersheds of West Seti sub-basin under the current climate, (a) Precipitation, (b)Water yield, and (c)Actual ET

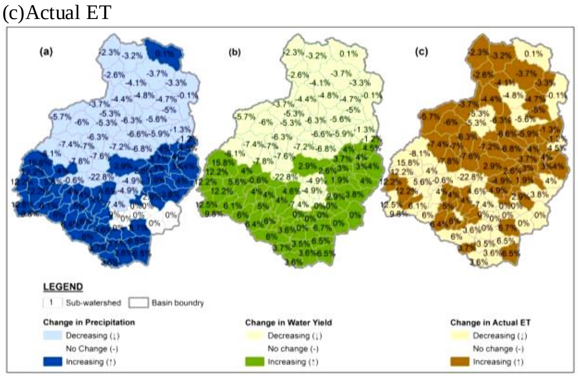

Fig 6 Percentage change in annual water balance in the sub-watersheds of the West Seti sub-basin under the future climate, (a) Precipitation, (b) Water yield, and (c) Actual ET

Water balance and crop yields under current climate

As afore mentioned, the model runs from 1981 to 2010 with daily climate data and the outcome of this study represents average results over a 30 year period as a current climate scenario. The model result shows that total precipitation over rice, maize, millet, wheat and barley fields are 1002 mm, 818 mm, 788 mm, 186 mm and 169 mm respectively whereas total simulated actual ET are 534 mm, 452 mm, 322 mm, 138 mm and 177 mm respectively under the current climate (Table 2). Similarly, simulated surface runoff from the crop fields and crop yields are presented in the Table 2. In the study, the total surface water yields are validated with the observed river flows however the simulated crop yields are not validated as there are no available data which spatially covers over the study area. All the crops are considered as rain-fed and the auto-irrigation option of model is enabled in the simulation. In auto-irrigation option, the model will automatically apply water up to a maximum amount whenever there is water stress in crops (Neitsch et al. 2011). Hence this study only looked into how climate change will impact on the crop yields.

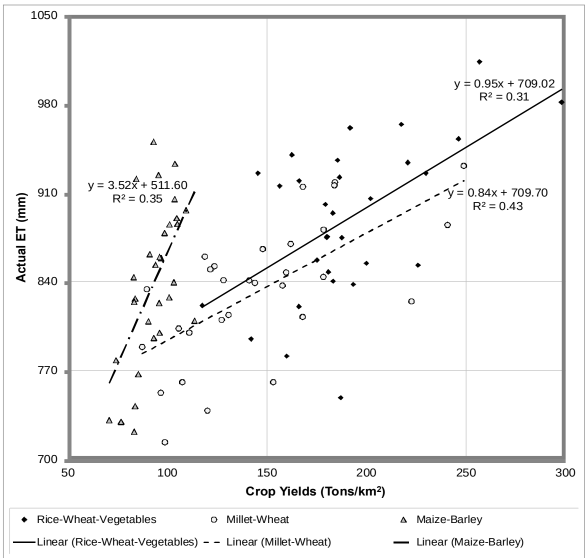

Fig 7 Correlation between simulated annual actual evapo-transpiration (ET) and crop yields under selected crop rotation scenarios for 1981-2010 periods

Table 2 Simulated water balance and crop yields under current climate

Variables	Summer Crop			Winter Crop	
	Rice	Maize	Millet	Wheat	Barley
Precipitation (mm)	1002	818	788	186	169
Actual ET (mm)	534	452	322	138	177
Surface Runoff (mm)	235	175	170	7	10
Crop Yields (Tons/km^2)	54	83	15	45	29

Impact of climate change on water balance and crop yields

The climate change impact study is assessed by comparing between the model results of baseline (from 1971 to 2000) and future projections (from 2031 to 2060). The model results show that the total precipitation will change by -5.1 % in rice, -4.2 % in maize, -10.9 % in millet, +16.1 % in wheat, and +16.3 % in barley fields. Similarly, actual ET will change by -1.9 % in rice, -1.1 % in maize, -2.0 % in millet, +6.7 % in wheat, and +5.4 % in barley, under future climate projections. Actual ET will decrease in the summer crops and will increase in the winter crops.

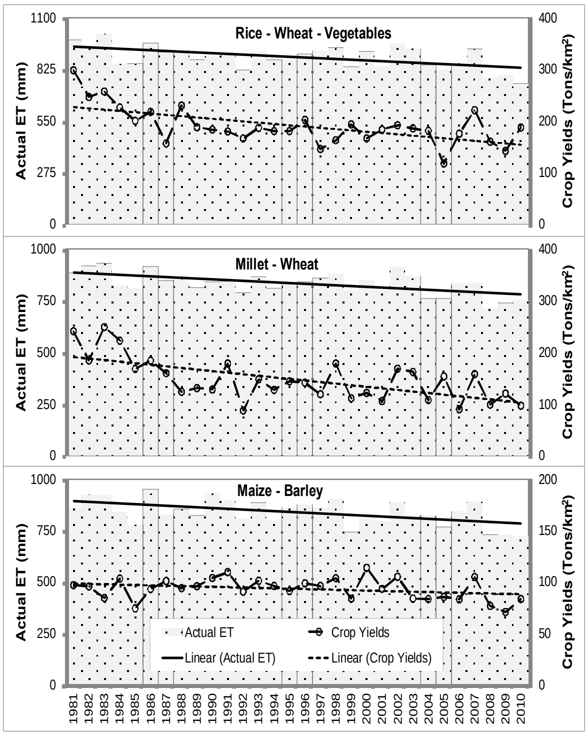

Fig 8 Actual evapotranspiration (ET) and crop yields trend under selected crop rotation scenarios for 1981-2010 periods

Table 3 Percentage change in simulated water balance and crop yields under future climate

Variables	Summer Crop			Winter Crop	
	Rice	Maize	Millet	Wheat	Barley
Precipitation	-5.1 %	-4.2 %	-10.9 %	+16.1 %	+16.3 %
Actual ET	-1.9 %	-1.1 %	-2.0 %	+6.7 %	+5.4 %
Surface Runoff	-33.1 %	-31.2 %	-40.7 %	-17.3 %	+0.9 %
Crop Yields	+1.2 %	-5.9 %	-8.0 %	+6.6 %	+7.0 %

The linear correlation will occur in the percentage change between precipitation and actual ET, between crops yield and actual ET (Fig 9).Whereas, impact of climate change results show that crop yields from maize and millet will decrease by 5.9 % and 8.0 % respectively, the yield of rice, wheat and barley will increase by 1.2 %, 6.6 % and 7.0 % respectively under future climate. Precipitation on the summer crops will decrease, which will impact negatively on the crop yields (Table 3). Whereas, precipitation on the winter crops will increase and this will lead to an increase in crop yields. Hence, impact of climate change shows that summer crop yields will decrease except for rice and winter crop yields will increase. Changes in amount of precipitation will impact on the actual ET, and then on the crop yields.

Impact of watershed interventions on water balance and crop yields under current climate

Surface runoff will decrease, and the ground water contribution to the stream flow will increase the watershed interventions at all crop fields (Table 4). In addition, the model shows that crop yields from rice, maize, millet and wheat will increase by 1.3 %, 2.3 %, 6.2 % and 13.3 % respectively, whereas the yield of barley will decrease by 4.6 %.

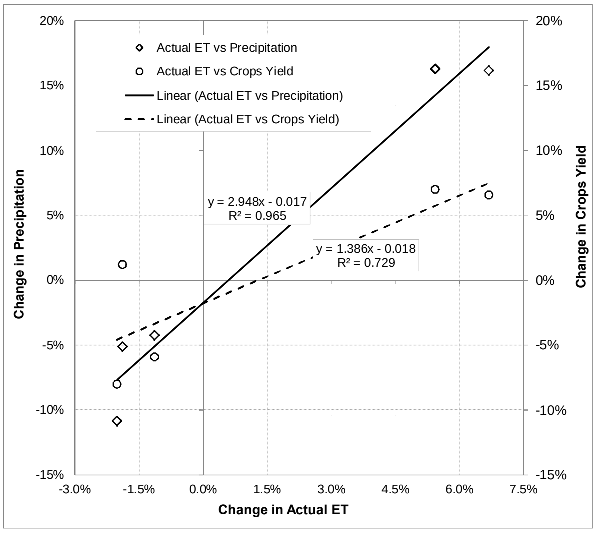

Fig 9 Correlation of change between precipitation and actual ET and between crop yields and actual ET under future climate scenario

Table 4 Percentage change in water balance and crop yields with all interventions

Variables	Summer Crop			Winter Crop	
	Rice	Maize	Millet	Wheat	Barley
Surface Runoff	-7.5 %	-26.1 %	-7.6 %	-11.8 %	-62.4 %
Ground water flow	+6.3 %	+74.5 %	+6.1 %	+6.9 %	+56.5 %
Crop Yields	+1.3 %	+2.3 %	+6.2 %	+13.3 %	-4.6 %

CONCLUSION

Model simulation under current climate conditions shows declining trend of actual ET and crop yields in this study area. Summer precipitation will decrease and winter precipitation will increase, likewise actual ET will decrease for the summer crops except in rice and will increase for the winter crops under future climate scenario. As a result, summer crop yields will decrease and winter crop yields will increase under projected climate change scenarios. In general, a result of watersheds interventions shows that the crop yields will increase after the watershed interventions. The SWAT modelǿs performance will depend on the model inputs and availability of observed data to validate the output. In this study, simulated water balance components are most precise due to the availability of observed river flow data. Whereas, due to unavailability of spatially coverage of crop yield data, the study is confident to present only changes in crop yields under future climate scenario.

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