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Climate Change Impact on Water Requirement and Yield of Wheat: An Application of AquaCrop in Madabhar Irrigation Project, Chitwan

Sudarshan Sedhai [a], Vishnu Prasad Pandey [b], Madhav Narayan Shrestha [c], Ananta Man Singh Pradhan [d], Nirman Shrestha [e]

[a, b, c] *Department of Civil Engineering, Pulchowk Campus, Institute of Engineering, Tribhuvan University, Lalitpur, Nepal*
[b] *Center for Water Resources Studies, Institute of Engineering, Tribhuvan University, Lalitpur, Nepal*
[d] *Water Resources Research and Development Centre, Ministry of Energy, Water Resources and Irrigation, Government of Nepal*
[e] *International Water Management Institute, Nepal Office, Lalitpur*
[a] 078mswre016.sudarshan@pcampus.edu.np, [b] vishnu.pandey@pcampus.edu.np, [c] mnshrestha@gmail.com, [d] anantageo@hotmail.com, [e] N.Shrestha@cgiar.org

Abstract
Wheat is a staple crop contributing to food security in Nepal.To ensure adequate crop yield in the context of changing drivers such as climate change, water management, soil quality, and fertilizer.There is a need to know how these drivers will impact crop phenology and, ultimately, its production.Study used the AquaCrop 7.0 model in a farmer-managed irrigation system in order to evaluate predicted changes in crop water requirements and wheat crop yield in Chitwan in the context of climate change. The future climate was projected by using couple model intercomparison project phase 6 (CMIP6).An ensemble of five Global Climate Models (GCMs) was used with two scenarios (SSP245 and SSP585) for the near (2025-2050), mid-2051-2075, and far future (2076-2099). Crop yield was simulated for three scenarios (rainfed, partially-irrigated, and fully irrigated). Baseline period was taken from 1985 to 2015. Results showed, in general, there is increase in crop water requirement, and mixed results for crop yield depending upon context. Wheat yield is projected to increase by 13-29% for rainfed and 10-17% for irrigated conditions in SSP245 scenarios. And the net irrigation requirement is projected to decrease slightly from baseline period of 130 mm in the climate change context.

Keywords
AquaCrop,Climate Change,CMIP6, Crop yield,Wheat

1. Introduction

Wheat in most parts of Nepal is grown in rainfed condition.It is cultivated in 711,067 hectares of land with an average yield of 2.99 Mt/ha [1]. It is C3 [2] pant sown on shallow depth and in some places, it may be deepened more than normal due to dryness of soil. Normally, sowing is done in moist soil condition. Length of total growing period of spring wheat may vary from 100 to 170 days according to cultivar type and climatic conditions while winter wheat needs 180 to 300 days [3].The phenology of wheat crop depends on temperature. Its major development stages are leaf emergence, booting, heading, flowering and senescence. Early water stress on crop hampers the tiller number and late water can reduce the grain number and size [4]. Irrigation plays a vital role in optimal crop yield where natural rainfall is insufficient or unpredictable [5]. This irrigation water supply helps crops withstand in dry conditions, heat stress, and other environmental factors that might otherwise reduce their productivity [6]. On the other hand, Climate change also impacts crop productivity and quality in multiple ways.

Literature on the impact of irrigation and climate change on crop yield with specific focus on Nepal is limited. Malla (2008) reported that double CO2 enrichment increases wheat yield by 18.4%. In Sikkim, climate change is projected to increase wheat yield by 2 to 44% till 2099 [7]. Wheat yield is projected to change in the Indrawati river basin from -26% to 37% by the end of the century [8].

This study aims to estimate how water requirements and crop yield will be altered with climate change in the Madhabhar irrigation project, in Chitwan, Nepal. To quantify the contribution of irrigation to wheat crop yield during the baseline period is another objective of the study. It also examines how future climate change may affect crop productivity, evapotranspiration, and the amount of water needed for irrigation. It is anticipated that the findings would aid with better policy development and contribute to national food security. The following are the objectives:

- To quantify the contribution of irrigation in crop yield.
- To assess the climate change impact on crop yield and crop water requirement.

2. Literature Review

Food security relate that people have access on enough safe and nutritious food (FAO,2023). According to FAO report on state of food security and nutrition in the world 2023, due to the Covid-19 pandemic, 90M world's population had faced food shortage just in one year (2019 to 2020). The Covid-19 epidemic and the newly established Russian-Ukrainian war have hampered efforts to reduce poverty. Both Russia and Ukraine are major wheat exporter. Having interrupted on wheat production and export, price increasing in developing nation that's why food security scenario would be worsen in many developing countries like Nepal.50% reduction of export of wheat from Russia and Ukraine has increased price by 15% [9]. Global hunger has increased by 9.2% of world population in 2022 in compared to the 7.9% in 2019(FAO,2023). In the context of southern Asia, percentage of prevalence of undernourishment has decreased by 20.2 to 15.6, period from 2005 to 2022. It is still very high. To cope with hunger, only one option is to increase crop productivity. Extreme weather events, a lack of water, and violent conflicts are only a few of the causes of the worsening food insecurity.

2.1 Net Irrigation Water Requirement

Crop water requirement (CWR) is amount of water (in millimeters) required for a disease-free crop to evapotranspiration (ET) as much as it needs to in order to grow in a large field with unrestricted soil conditions, including soil water and fertility, and produce to its fullest extent possible in the given growing environment. According to the definition of "crop evapotranspiration" (ET), it is the rate of evapotranspiration (millimeters per day) of a specific crop as influenced by its growth stages, environmental conditions, and crop management to achieve the potential crop production. The CWR is the total of ET over the entire crop growth period [10]. Actual crop evapotranspiration is the rate of evapotranspiration that must be adjusted to the prevailing conditions when management or environmental variables diverge from the optimal (ET) [11].

Net irrigation water requirement is:

$$NIWR = \mathrm{WR}_{LS} + \mathrm{WR}_{LP} + \mathrm{WR}_{NC} + \mathrm{WR}_{L} \quad (1)$$

Where $NIWR$ is the net irrigation water requirement for successive crop cultivation (mm). WR_{LS} is depth of water requirement for land soaking. WR_{LP} is depth of water for land preparation. WR_{NC} is equal to CWR_i that has been mentioned in the above equation, and finally, WR_L is the amount of water required for leaching. For all crops and for all conditions, not all components mentioned above may be required.

2.2 Wheat Crop

Wheat (Triticum aestivum L.) is the third-most important grain crop and is widely cultivated all over the world. In 2022, the total production of wheat will be about 779 million metric tons (FAO). Wheat is a cool-season crop that was first cultivated in the Fertile Crescent and has since expanded far around the world. It can be grown at humid, arctic, and tropical elevations as well as at sea level. The growth circumstances are quite varied due to the large range of climatic areas and altitudes, as well as the variety of soil types and crop management practices. In the context of Nepal, it is cultivated on 711,067 hectares of land with an average yield of 2.99 Mt/ha [1]. Most of the Nepal wheat is grown in rainfed conditions.

It is long grass (Figure 1) raised up to 1.2 m with hollow culm. It is C3 pant [2]. This plant is shown at shallow depth, and in some places, it may be deeper than normal due to the dryness of the soil. Normally, sowing is done in moist soil. Sowing is done by broadcasting seeds. The length of the total growing period of spring wheat may vary from 100 to 170 days according to cultivar type and climatic conditions, while winter wheat needs 180 to 300 days [3]. Wheat is grown in

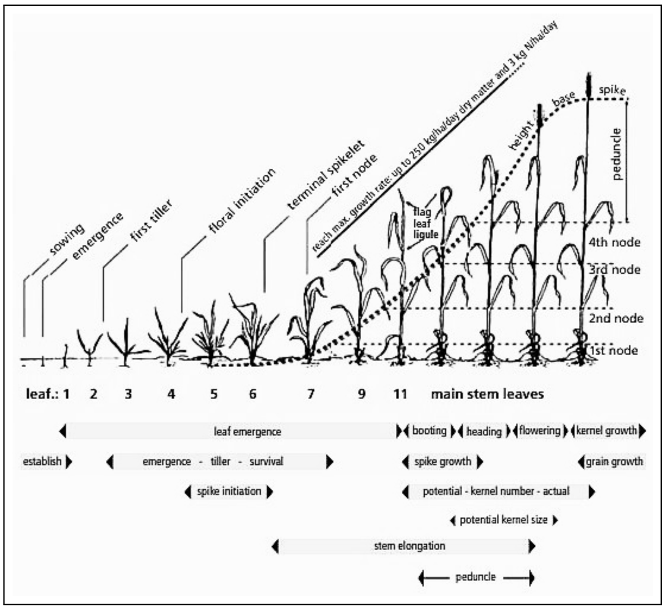


Figure 1: Growth stages of wheat crop

both rainfed and irrigated condition in Nepal. But due to the limited irrigation water access most part of country has grown in rainfed condition. Being cold season crop its evapotranspiration is lower than maize and paddy. Like other cereals, the three factors that make up wheat yield are the number of ears planted per unit area, the number of grains per ear, and the size of the grains. Early water stress on crop hampers the tiller number and late water can reduce the grain number and size [4].

2.3 Crop Simulation Models

There are a variety of crop models available, some of which, like the Agriculture Crop modeling has been successfully validated in numerous farmlands around the world and some of them are the Production Systems Simulator (APSIM), the Decision Support System for Agrotechnology Transfer (DSSAT), CROPWAT, AquaCrop, ORYZA, CERES, Dynamically Computed General Equilibrium (DCGE), CropSyst, and Simple Simulation Models (SSM) [12].

The United Nations' Food and Agriculture Organization (FAO) created the crop growth model AquaCrop [13]. The crop development and yield under various water regimes, such as irrigation and rainfed circumstances, are simulated by the model [14]. It can be used to assess agricultural production potential under various climate change scenarios and to support farmers' and policymakers' water management decisions. The model was developed primarily to meet the requirements of crop growth in water-limited situations. It is based on the FAO's WOFOST model for water-limited crop growth.

2.4 Assessing the Climate Change Impact on Crop Yield

Water plays a vital role for crop production. Agriculture uses a large amount of water for crop production and other processes. Different studies have revealed that global available

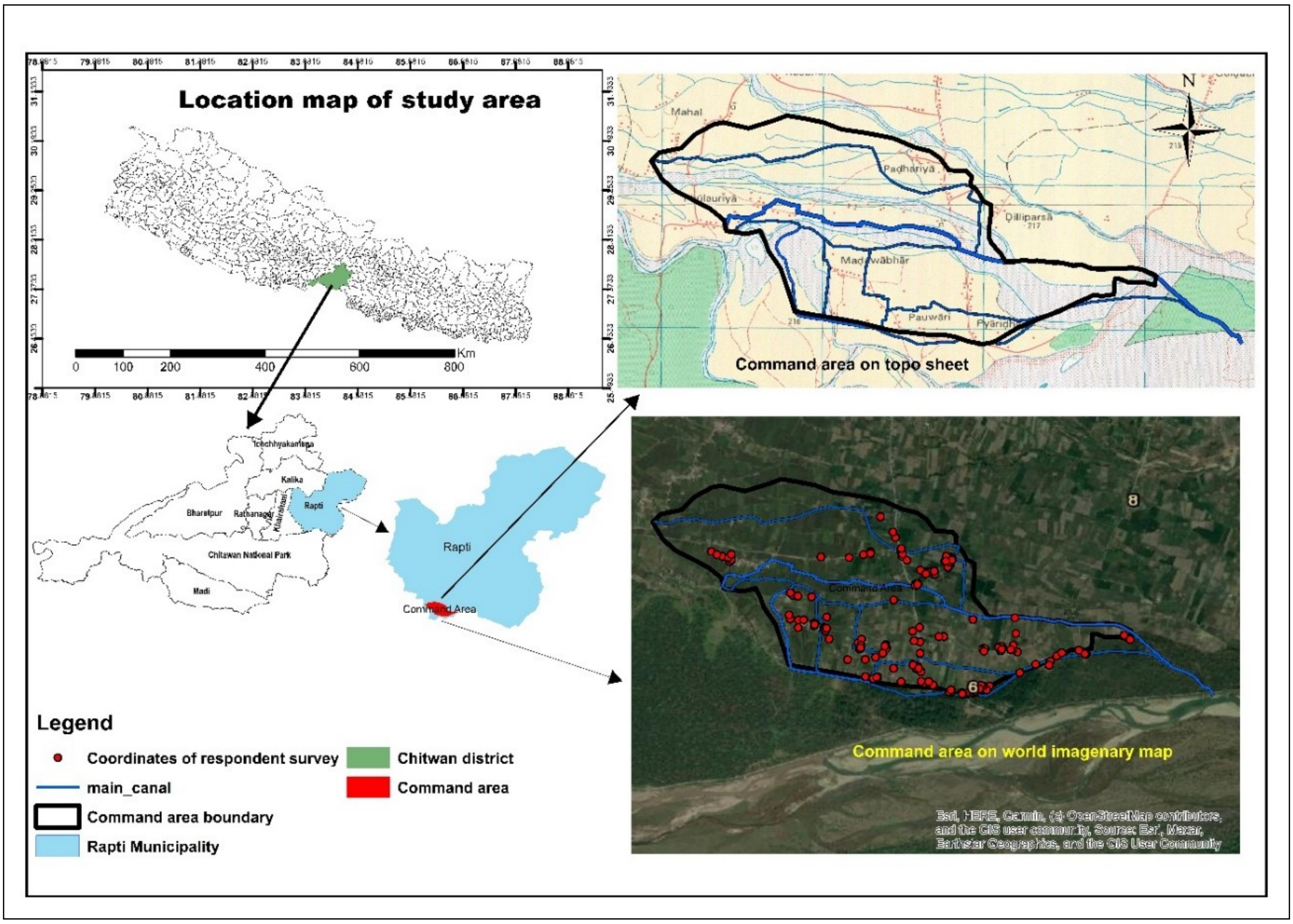


Figure 2: Location map of study area

water is going to decrease. This pose threatens food production. However, water availability is not homogeneous all around the world. Some places are going to have severe water stress, and some places have enough water, but its extraction cost is very high. According to FAO freshwater availability has decreased by 20%. In East Rapti region of Nepal total water demand is expected to increase by 52% about mid-century [15] Water stress impacts severely on plant phenology like flowering day, day to maturity, root architecture, decrease leaf number, flowering duration, stomatal closure and ultimately in yield [16]. In order to escape from this adverse effect not compromising food security different adaption plan are required.

Not only irrigation crop yield depends on different climatic variability like maximum temperature, minimum temperature, precipitation, environmental CO2 concentration [17]. Both positive and negative impact have been explored by different study in different region. So, it is contextual to study climate change on crop yield.

3. Study Area

The Madabhar irrigation project is located on the Rapti River's flood plain in the southern section of Rapti Municipality (Figure 2). Farmers have been managing irrigation in this project for years. The beneficiaries' total household are 543 HH. The net culturable command area is 310 hectares.

4. Data and Methodology

4.1 Data

This study is based on field survey and secondary data collected from different sources. Field data are related to crop, irrigation practice, groundwater, field management, soil profile, initial condition and crop yield. Secondary data are related to soil constituents, climatic data and crop conservative parameters. Cocharn's formula was used to determine sample size [18]. A random sampling technique was applied for selecting respondents. Questionnaire was prepared and implemented using Kobo toolbox. Questionnaire included questions on socio-demographic, crop, climate change and adaptation practices. All the field data were directly extracted in excel and then it analysed.

Soil data (percentage of sand, silt, clay and organic matter) was based on digital soil map created by Nepal Agriculture Research Council (https://soil.narc.gov.np/soil/soilmap/). Obtained values were fed into the Soil -plant-air- water (SPAW) tool to calculate permanent wilting point (PWP), field capacity (FC), saturated hydraulic conductivity (SAT) and total available water (TAW). These outputs were used to set up the AquaCrop model. Daily hydraulic water budgets for agriculture landscape are computed by using SPAW [19].

Historical climate data (daily, for the baseline of 1985-2020) at a representative climate station for the study area (Rampur

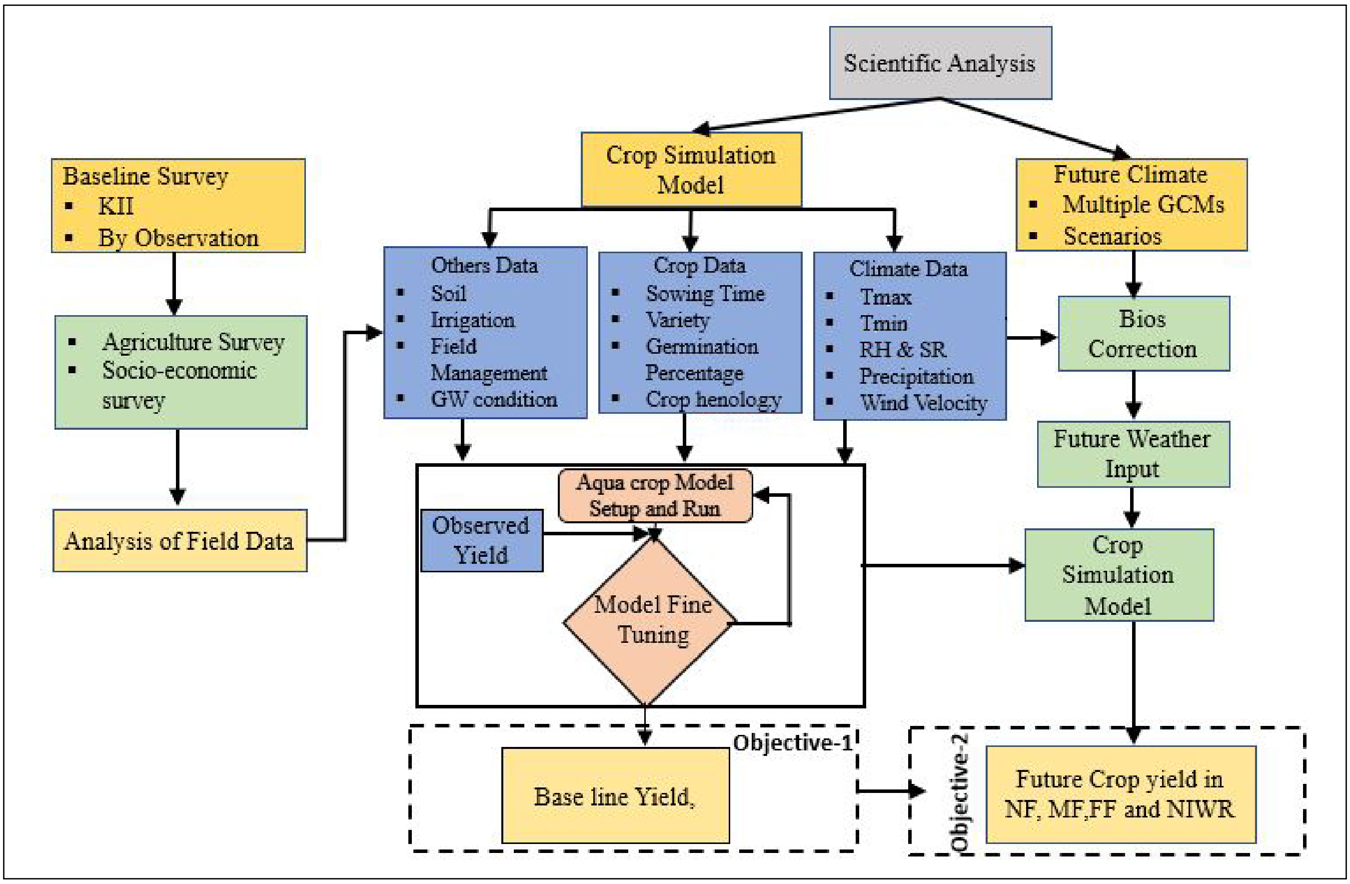


Figure 3: Methodological framework for AquaCrop simulation model

Station, index: 902) was acquired from the Department of Hydrology and Meteorology. Reference evapotranspiration (ETo) was calculated through the ETo calculator developed by the Food and Agriculture Organization (FAO) [20].

Future climate was projected based on an ensemble of five Global Climate Models (GCMs) taken from a pool suggested by [21]. They are ACCESS-ESM1-5, BCC-CCM2-MR, CanESM5, INM-CM4-8, EC-Earth3, and ACCESS-CM4-8. Analysis was carried out for two scenarios (SSP245 and SSP585). Crop yield was simulated for the near (2025-2050), mid (2051-2075), and far (2076-2099) future.

4.2 Methods

The AquCrop model was set up and validated for wheat with field data from the study area to simulate baseline crop yield and project the impact of climate change on the yield. It is a simple crop productivity model that relates atmosphere, soil, and climate conditions (Figure 3).AquaCrop model has number of advantages over other crop simulation models. It has an easy, user-friendly interface, requires a smaller number of inputs, is robust in nature, and gives good results with better accuracy.

AquaCrop simulates crop yield in four steps [22]: i) Simulation of green canopy development (CC), ii) Simulation of transpiration (Tr), iii) Simulation of the above-ground biomass (B) production, and iv) Simulation of crop yield (Y). A calibrated and validated crop file was taken from Shrestha (2014). Parameters were fine-tuned according to field data obtained during the survey. Table 1 presents the conservative and non-conservative values derived from the field survey to calibrate the model, the non-conservative parameters harvest index, initial canopy cover, and canopy growth coefficient had to be changed until the simulated crop's canopy cover, biomass, and yield closely matched to the obtain data.

Table 1: Input parameter for wheat crop

SN	Parameters	Input values
1	Wheat variety	Gautam
2	Climatic Parameter	Maximum and minimum temperature, precipitation, relative humidity, sunshine hour, windspeed and ET_o in both baseline and future predicted on a daily basis.
3	Sowing time	November 22
4	Seed rate	150 (Kg/ha)
5	Emergence	7 Days after sowing(DAS)
6	Maximum canopy cover	54 DAS
7	Flowering time	63 DAS
8	Irrigation method	Surface(border) irrigation
9	Soil profile	Loam (sand 46%, clay 14%, organic matter 22%,PH 6,wilting point10% by volume, field capacity23.9% by volume, saturation 44.8% by volume, saturated hydraulic conductivity 24.92 mm/hr.
10	Harvest index	34%
11	Fertilizer dose (UREA)	88 (Kg/ha)
12	ETo	From ETo calculator by FAO

5. Result and Discussion

5.1 Baseline Wheat Yield

Wheat yield over the time period for rainfed and fully-irrigated conditions is shown in (Figure 4). It indicates that the average wheat yield in rainfed and fully-irrigated conditions are 2.24 tons/ha and 3.04 tons/ha, respectively. The average yield of wheat over the baseline period has been increasing at the rate of 26% in irrigated crop than in rainfed. It is clear that winter wheat seems to be more sensitive to irrigation. This result is in line with the findings of Gairhe et al (2018) which reported an average increase of wheat productivity in Nepal by 39% over the period of 1995 to 2014 [23]. It also aligns with Shrestha et al (2013) which reported an increase of 67-197% in wheat yield in the Chitwan district with proper irrigation and fertilizer management compared to rainfed crop yield [24]. Wang et al (2021) found the contribution of irrigation to wheat yield at the global scale as 34±9% [25].

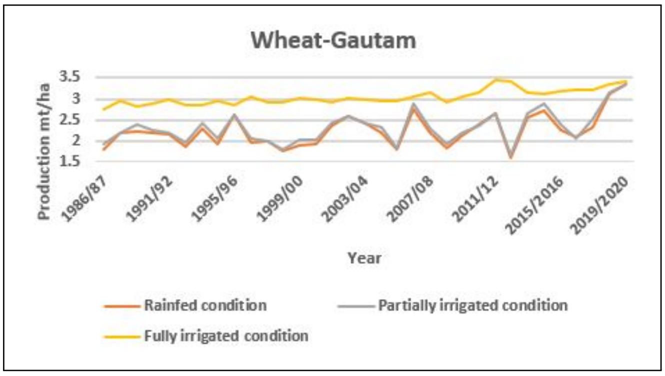
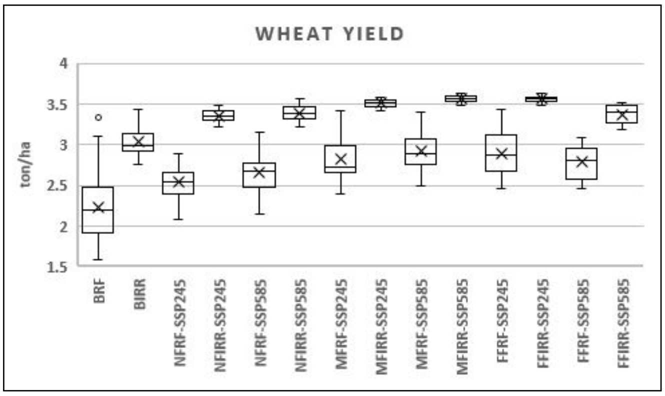


Figure 4: Yield scenarios of different irrigation conditions)

5.2 Future Wheat Yield

Climate change is projected to impact wheat yield positively for all future scenarios considered in this study. Wheat yield is projected to increase by 13-29% for rainfed conditions and 10-17% for irrigated conditions under SSP245 scenarios than baseline yield. Similarly, it is projected to be 18-30% for rainfed conditions and 10-17% for irrigated conditions under SSP585 scenarios. (Figure 5) shows the variation of wheat yield in different scenarios:



Note: B= baseline yield, RF = rainfed, IRR = irrigated condition, NF = near future, MF = mid future and FF = far future

Figure 5: Wheat yield

5.3 Changes in Net Irrigation Water Requirement

Crop evapotranspiration (ET) and net irrigation water requirement (NIWR), which were 256 mm and 130 mm, respectively, for the baseline period (1985-2020),and are projected to increase and decrease, respectively, slightly in the future(Figure 6).It makes very evident that the future ET of the wheat crop is increasing during the crop season. The amount of water needed for net irrigation is projected to decrease in the meantime. Increase in ET of Wheat crop in future is because of increase of mean temperature of season.While, decrease in net irrigation is because of increase in rainfall event and shortening of crop period.

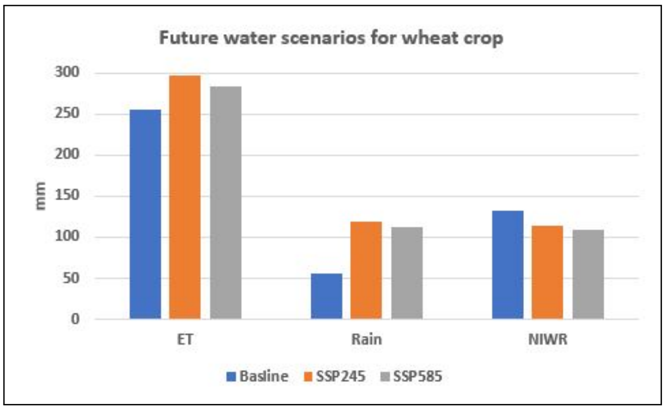


Figure 6: Wheat yield

6. Conclusions

Wheat is an important staple food in Nepal. Wheat yield in the study area is estimated as 3.4 tons/ha. With projected changes in future precipitation and temperature during crop season by +106% and +2^{o}C, wheat yield is projected to increase by 13% (irrigated condition) in the study area.Though temperature rise is projected to increase evapotranspiration and subsequently the irrigation demand, the projected increase in precipitation is estimated to overcome those demands and contribute to an increase in crop yield. Fertility stress and weed stress, however, are estimated to impact negatively to crop yield.

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References

[1] MoALD Government of Nepal. Statistical-information-on-nepalese-agriculture-2077-78, 2022.

[2] Nirman Shrestha, Dirk Raes, Okke Batelaan, and Shrawan Kumar Sah. Improving cereal production in the terai region of nepal: assessment of field management strategies through a model-based approach. 2014.

[3] Pasquale Steduto, Theodore C Hsiao, Elias Fereres, Dirk Raes, et al. *Crop yield response to water*, volume 1028. fao Rome, 2012.

[4] A Ahmadi and DA Baker. The effect of water stress on grain filling processes in wheat. *The Journal of Agricultural Science*, 136(3):257–269, 2001.

[5] Esha Zaveri and David B. Lobell. The role of irrigation in changing wheat yields and heat sensitivity in india. *Nature communications*, 10(1):4144, 2019.

[6] A Sio-Se Mardeh, A Ahmadi, K Poustini, and V Mohammadi. Evaluation of drought resistance indices under various environmental conditions. *Field Crops Research*, 98(2-3):222–229, 2006.

[7] Jew Das, Vikas Poonia, Srinidhi Jha, and Manish Kumar Goyal. Understanding the climate change impact on crop yield over eastern himalayan region: ascertaining gcm and scenario uncertainty. *Theoretical and Applied Climatology*, 142:467–482, 2020.

[8] IRENE Palazzoli, S Maskey, S Uhlenbrook, ESTER Nana, and DANIELE Bocchiola. Aquacrop reference manual. *Agricultural Systems*, 133:143–157, 2015.

[9] Khondoker Abdul Mottaleb, Gideon Kruseman, and Sieglinde Snapp. Potential impacts of ukraine-russia armed conflict on global wheat food security: A quantitative exploration. *Global Food Security*, 35:100659, 2022.

[10] Andreas P Savva and Karen Frenken. *Crop water requirements and irrigation scheduling*. FAO Sub-Regional Office for East and Southern Africa Harare, 2002.

[11] LS Pereira, Paula Paredes, R López-Urrea, DJ Hunsaker, M Mota, and Z Mohammadi Shad. Standard single and basal crop coefficients for vegetable crops, an update of fao56 crop water requirements approach. *Agricultural Water Management*, 243:106196, 2021.

[12] Claudio O Stöckle, Marcello Donatelli, and Roger Nelson. Cropsyst, a cropping systems simulation model. *European journal of agronomy*, 18(3-4):289–307, 2003.

[13] Timothy Foster, N Brozović, AP Butler, CMU Neale, Dirk Raes, Pasquale Steduto, E Fereres, and Theodore C Hsiao. Aquacrop-os: An open source version of fao's crop water productivity model. *Agricultural water management*, 181:18–22, 2017.

[14] Krishna P Devkota, Jagadish Timsina, Lal P Amgain, and Mina Devkota. Potential of crop simulation models to increase food and nutrition security under a changing climate in nepal. In *Agriculture, Natural Resources and Food Security: Lessons from Nepal*, pages 415–437. Springer, 2022.

[15] Anupama Ray, Vishnu Prasad Pandey, and Bhesh Raj Thapa. An assessment of climate change impacts on water sufficiency: The case of extended east rapti watershed, nepal. *Environmental Research*, 212:113434, 2022.

[16] Hasnae Choukri, Kamal Hejjaoui, Adil El-Baouchi, Noureddine El Haddad, Abdelaziz Smouni, Fouad Maalouf, Dil Thavarajah, and Shiv Kumar. Heat and drought stress impact on phenology, grain yield, and nutritional quality of lentil (lens culinaris medikus). *Frontiers in Nutrition*, 7:596307, 2020.

[17] Benjamin Kipkemboi Kogo, Lalit Kumar, and Richard Koech. Climate change and variability in kenya: a review of impacts on agriculture and food security. *Environment, Development and Sustainability*, 23:23–43, 2021.

[18] W.G. COCHRAN. Sampling techniques, 1977.

[19] Keith E Saxton and Walter J Rawls. Soil water characteristic estimates by texture and organic matter for hydrologic solutions. *Soil Science Society of America Journal*, 70(5):1569–1578, 2006.

[20] Richard G Allen. Fao irrigation and drainage paper, 1977.

[21] Vimal Mishra, Udit Bhatia, and Amar Deep Tiwari. Bias-corrected climate projections for south asia from coupled model intercomparison project-6. *Scientific data*, 7(1):338, 2020.

[22] Theodore C. HSIAO Dirk RAES, Pasquale STEDUTO and Elias FERERES. Referenceemanual for fao crop-water productivity model to simulate yield response to water, 2023.

[23] Samaya Gairhe, Hari Krishna Shrestha, and Krishna Timsina. Dynamics of major cereals productivity in nepal. *Journal of Nepal Agricultural Research Council*, 4:60–71, 2018.

[24] Nirman Shrestha, Dirk Raes, Eline Vanuytrecht, and Shrawan Kumar Sah. Cereal yield stabilization in terai (nepal) by water and soil fertility management modeling. *Agricultural Water Management*, 122:53–62, 2013.

[25] Xuhui Wang, Christoph Müller, Joshua Elliot, Nathaniel D Mueller, Philippe Ciais, Jonas Jägermeyr, James Gerber, Patrice Dumas, Chenzhi Wang, Hui Yang, et al. Global irrigation contribution to wheat and maize yield. *Nature Communications*, 12(1):1235, 2021.