HYDROLOGY-BASED SCENARIO PLANNING FOR WATER PRODUCTIVITY AND OPTIMIZATION OF INCOME FROM FARMING PRACTICES IN MEWAT REGION, HARYANA

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2023-2024

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Abstract

Availability of water for various purposes such as irrigation, drinking water supply, industrial use is under tremendous stress due to overuse of water from surface and ground water resources, drought and climate change. Practicing traditional farming activities under the stressed condition is either unsustainable or end up with low yield. Crop diversity with food security will improve the income of the farming community. An optimal utilization of available water and land with scientific approach will optimize the farmers' income. In this study, WEAP model in combination with LINGO is applied for the area of three blocks, Nuh, Nagina and Punhana of Nuh (Mewat) district in Haryana for the optimization of farmers' income considering crop area for Kharif and Rabi seasons, crop productivity, population, livestock, water supply from different resources, cost of cultivation, rainfall and evapotranspiration. The current water demand and supply gap is analyzed by setting up of WEAP with required input data. The scenario analysis such as dry, very dry, wet, very wet, population and industrial growth, crop diversification, climate scenario for SSP245 and SSP 370 in WEAP will give the water demand and supply gap for the considered scenario. LINGO with the inputs obtained from current and scenario analysis will evolve optimal land and water resources and thus optimal income for the scenarios considered. The current population in Nuh, Nagina and Punhana is projected from data of 2011 census based on the report of the technical group on population projections constituted by National Commission on Population, May 2006 for the period from 2001-2026. The gridded data of rainfall, maximum and minimum temperature is obtained from IMD for the period from 1951 to 2019 and processed for Nuh, Nagina and Punhana. The extra-terrestrial radiation for the area is obtained from website. The daily evapotranspiration is estimated from gridded maximum and minimum temperature, extra-terrestrial radiation for the period from 1951 to 2019. The initial run of WEAP model has been carried out with crop area and water requirement for Kharif and Rabi season, livestock population and their water requirement, Urban and rural population and their water consumption, monthly crop coefficient for Kharif and Rabi crops, different landuses, effective precipitation for evapotranspiration from various state departments and literature. The LP model is formulated for optimizing the farmers' income with various input variables for current and various scenarios. The cost of cultivation, crop yield and market price for Kahrif and Rabi crops have been collected from Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare for the year 2018-19 for the implementation of LP model.

Chapter 1 Introduction

The rising population and industrial growth with climate change makes difficult to meet the demand of agricultural activities. Continuous over exploitation of ground water under uncertain occurrence of rainfall is inevitable to continue the traditional cropping pattern. Traditional cropping pattern is neither good for soil health nor for food security. Farmer's income is often below optimal with traditional cropping pattern under water stressed condition. Scientific planning considering cropped area, climate smart crop types, crop productivity, cropping pattern, farming input costs, and crop revenues, will evolve optimal utilization of available water and optimize farmer's income from farming practices. Scenario analysis with projected population growth, landuse changes, climatic conditions, water-efficient irrigation technologies, etc. shall provide a canvas of options to be considered for optimal income from farming practices in future. A scientific plan is needed to guide the farming community about optimizing their income from farming practices that lead to food and water security. Water allocation simulation model, Water Evaluation and Planning (WEAP) is a powerful tool to analyze the water demand and supply gap for current and various scenarios. The WEAP model is an Integrated Water Resources Management (IWRM) based tool which integrates all the components of watershed and provides a modelling framework for the evaluation of water demand and supply across various sectors of a watershed be it simple or complex. Its advanced version i.e. WEAP21 incorporates an enhanced feature of demand analysis in which user can customize the model as per the assigned priorities to demand sites using water from the preferred source of supply (Yates et al. 2005a; Yates et al. 2005b). This model has been widely used for water resources planning and management in areas subjected to frequent droughts, floods, rainfed areas, water quality issues, conjunctive use management, etc. The WEAP model with the combination of LINGO for current and different scenario conditions will give a numerous options which can be adopted in the area to obtain the optimal income from the farming practices by allocating the land and water resources with the diversified cropping pattern considering the food security.

1.1 Overview of WEAP Tool

Water Evaluation And Planning (WEAP) is a microcomputer tool for integrated water resources planning. It provides a flexible, comprehensive and user-friendly framework for policy analysis. WEAP is found to be useful by a growing number of water professionals, in addition to their toolbox of models, databases, spreadsheets and other software. This overview summarizes purpose, approach and structure of WEAP. WEAP tutorial contents are also introduced; a series of modules that takes through all aspects of WEAP modelling capabilities constructs the tutorial. WEAP focuses to include various demands and resources supply values into a practical tool for water resources planning. It is differentiated by its integrated approach towards simulating water systems and by its policy orientation. WEAP places the demand side of the equation - water use patterns, allocation, equipment efficiency, re-use, and prices on an equal footing with the supply side - streamflow, reservoirs, groundwater, and water transfers. WEAP is a laboratory for examining alternative water management strategies and water development.

WEAP is comprehensive, straightforward, and easy-to-use, and does not substitute but attempts to assist the skilled planner. A system for maintaining water demand and supply information is provided by WEAP as a database. WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge as a forecasting tool. WEAP assess a full range of water development and management options, and takes into account of multiple and competing applications of water systems as a policy analysis tool.

1.1.1 WEAP Development

The Stockholm Environment Institute provided basic support for the development of WEAP. The Hydrologic Engineering Centre of the US Army Corps of Engineers funded significant enhancements. A number of agencies, including the World Bank, USAID and the Global Infrastructure Fund of Japan have provided project support. WEAP has been applied in water assessments in over one hundred countries.

1.1.2 WEAP Capabilities

- Water balance database: WEAP provides a system for maintaining supply information and water demand.
- Scenario generation tool: WEAP simulates water storage, runoff, demand, supply, streamflow, instream water quality, pollution generation, treatment and discharge.

- Policy analysis tool: WEAP takes account of multiple and competing uses of water systems and assess a full range of water development and management options.

1.2 Overview of LINGO

LINGO is a comprehensive tool designed to make building and solving Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Semi-Definite, Stochastic, and Integer optimization models faster, easier and more efficient. LINGO provides a completely integrated package that includes a powerful language for expressing optimization models, a full featured environment for building and editing problems, and a set of fast built-in solvers.

1.2.1 Benefits of LINGO

Easy Model Expression

LINGO will help the modeler in cutting the development time. It lets to formulate linear, nonlinear and integer problems quickly in a highly readable form. LINGO's modeling language allows to express models in a straightforward intuitive manner using summations and subscripted variables. Models are easier to build, easier to understand, and, therefore, easier to maintain. LINGO can exploit multiple CPU cores for faster model generation.

Convenient Data Options

LINGO takes the time and hassle out of managing the data. It allows to build models that pull information directly from databases and spreadsheets. Similarly, LINGO can output solution information right into a database or spreadsheet making it easier to generate reports in the application of opted choice.

Powerful Solvers

LINGO is available with a comprehensive set of fast, built-in solvers for **Linear, Nonlinear (convex & nonconvex/Global), Quadratic, Quadratically Constrained, Second Order Cone, Stochastic**, and **Integer** optimization. It is not necessary to specify or load a separate solver, because LINGO reads the formulation and automatically selects the appropriate one.

Model Interactively or Create Turn-key Applications

Models can be built and solved within LINGO, the LINGO application can be called from any application the modeler has developed. For developing models interactively, LINGO provides a complete modeling environment to build, solve, and analyze any models developed. For building turn-key solutions, LINGO comes with callable DLL and OLE interfaces that can be called from user written applications. LINGO can also be called directly from an Excel macro or database application.

Extensive Documentation and Help

LINGO provides all of the tools that will be needed to get up and running quickly. LINGO User Manual fully describes the commands and features of the program in online mode. It mainly includes *Optimization Modeling with LINGO*, a comprehensive modeling text discussing all major classes of linear, integer and nonlinear optimization problems. LINGO also comes with dozens of real-world based examples which can be modified and expanded according to the modeller's requirement.

1.3 Objectives of the study

The objectives of the study are given as follows:

a. To evaluate the existing cropping pattern and farming practices for estimation of farmer's income
b. To carry out scenario analysis considering combinations of crop types and cropping pattern, land allocation, water allocation under climatic variability, etc.
c. To develop plan for optimized income from farming practices encompassing food and water security.

The study area considered for achieving the objectives is area of three blocks, Nuh, Nagina and Punhana of Nuh (Mewat) district in Haryana. Nuh (Mewat) is figured at the bottom of Niti Ayog's report on aspirational districts (Niti Ayog, 2018) and the most backward district in India.

Chapter 2.0 Literature review

The WEAP tool has been used for planning water management in current scenario as well as future changes in demand and supply due to population growth, developmental activities in the watershed, cropping pattern and climate change.

Strzepek et al. (1999) reported new methods of linking climate change scenarios with agricultural, hydrologic and water planning models to study future water availability for agriculture, an essential element of sustainability. They studied the integration of models for water supply and demand, and of crop growth and irrigation management. Rosenzweig and Strzepek M. (2004) examined the implications of water availability for the reliability of irrigation and changes in crop water demand, taking into account changes in competing industrial and municipal demands, and explores the effectiveness of adaptation options in maintaining reliability. They reported on methods of linking climate change scenarios with hydrologic, agricultural, and planning models to study water availability for agriculture under changing climate conditions, to evaluate adaptation strategies for the water resources and agriculture sectors and to estimate changes in ecosystem services.

Jenkins et al. (2005) presents a study of the Water Evaluation and Planning System (WEAP) as a decision support tool (DST) in addressing shared water issues in the River Njoro watershed for local stakeholders and communities. The watershed includes a large shallow saline lake designated a RAMSAR wetlands site of international importance, an important downstream habitat at Lake Nakuru, and a broad mix of water uses and users located in the semi-arid Rift Valley of Kenya. Purkey et. al. (2008) looked at the impact of climate change on agricultural water management and the potential for adaptation in the Sacramento River Basin of California. In terms of improving irrigation efficiency and shifts in cropping patterns during dry periods, climate time series were used to simulate agricultural water management with and without adaptation. They found WEAP more robust than any other tool in evaluating future climate scenarios and also the water demand associated with high temperatures and low rainfall.

Bharati et al. (2008) used the model to evaluate the water availability as against water demand in the link from Godavari River (at Polavaram) to Krishna River (at Vijayawada). This study helped in examining whether the planned water transfers (Polavaram reservoir and link canal) would satisfy the growing agricultural water demands in the Polavaram link command area. Young et al. (2008) worked with WEAP, which is simulation modelling software that includes a robust and flexible representation of water demands from all sectors and flexible, programmable operating rules for infrastructure elements such as reservoirs, canals, and hydropower projects. Additionally, it allows all portions of the water infrastructure and demand to be dynamically nested within the underlying hydrological processes with its watershed rainfall-runoff modelling capabilities. WEAP also allows for linking with other models to provide feedback mechanisms whereby the management regime can be altered to respond to changing water supply conditions.

Mounir et al. (2011) used WEAP as a forecasting tool of future water balance. They investigated the scenarios for future water resource development in the Niger River basin in Niger Republic for three main purposes: for human needs (domestic), for irrigation (agriculture) and for industrial purpose in the Niamey and Tillabery cities. Results for satisfied and unsatisfied (unmet) water demands were obtained by running and comparing the scenarios.

Mehta et al. (2013) studied on WEAP that includes a dynamically integrated watershed hydrology module that is forced by input climate time series. This software allows direct simulation of water management response to climate and land use change. They represented a WEAP application for the Yuba, Bear and American River (ABY) watersheds of the Sierra Nevada.

Usha and Mudgal (2014) studied that the effect of climate variability/climate change on runoff is limited in humid tropical regions. Climate change has effects on agriculture and fisheries other than the water resources sector. Their study provides information on climate variability/changes and its impacts on runoff in the Kosasthaliyar sub-basin.

Sampath et al. (2014) developed a model for water management in development area of LB canal and for the assessment of diversion requirement from the Deduru Oya reservoir through the LB Canal to supplement LB irrigation demand. For water balance simulations in Deduru Oya LB canal development area and to calculate water requirements from LB canal for the period of recent 10years, Water Evaluation and Planning (WEAP) model was used. Suryawanshi and Shirke (2014) worked with the software Water Evaluation And Planning System (WEAP 21) which operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of water demands, supply withdrawals and ecosystem requirements.

Malla et al. (2014) used WEAP to study the global climatic concerns, which began to cast their shadows on the climate of Jammu and Kashmir as well. This model is a tool for integrated water resource management and planning like, forecasting water use, supply, demand, inflows, outflows, reuse, water quality, priority areas and Hydropower generation, etc.

Varela-Ortega et al. (2016) considered WEAP as a policy making tool. By doing economic valuation of water resources and managing them in economized and executable manner, it helps the stakeholders and policy makers to take decision. They applied WEAP21 to manage the water resources of Guadiana river basin of Portugal through stakeholder participation for vulnerability and adaptation.

Mhiribidi et al. (2018) used WEAP model to evaluate the water allocation system of the catchment for the reference scenario for the catchment of the multi-reservoir system in the Southern Lowveld of Zimbabve and found that 40 % deficit in the irrigation water allocation in the reference scenario.

Yang et al. (2020) studied the present balance of water supply and demand based on current water resources policy (reference year) and predicted the water demand and shortages in Beijing for the years 2019 to 2035 using WEAP. They found that the total unmet demand would be more than 45.48 %. The population control policy would reduce the water demand. The results of the scenario studies would solve water demand and supply by rational allocation of water resources.

Moncada et al. (2021) used WEAP to develop the model to quantify the balance between water supply and demand. They found that estimated future flows would not be sufficient to meet demand which would create significant water stress. A tool was developed to identify potential future water conflicts as well as strategies to reduce system vulnerabilities.

Chapter 3.0 Study area

Nuh (Mewat) district in Hayrana lies between 26° 39´ 00´´N and 28° 32´ 25´´ N latitude and between 76° 39´ 30´´ E and 77° 20´ 45´´ E longitudes. It has a geographical area of 1507.00 square kilometres comprising 1441.71 square kilometres of rural area and 65.29 square kilometres of urban area. Mewat district has a rolling plain and interspersed by extensions of Aravallis. The district is divided into three sub-parts: Nuh undulating Plain, Nuh-Punahana Plain and Ferozepur Jhirka Dissected Upland. The entire region is covered with rocky surfaces of Aravalli Offshoots. These landforms make a series of flat topped ridges. Only some patches of land are under cultivation. The district consists of five tehsils such as Nuh, Ferozpur Jhirka, Punhana, Tauru and Nagina and consists of five blocks such as Nuh, Ferozpur Jhirka, Punhana, Tauru and Nagina. There is no perennial river in the district. Seasonal streams are only a few, smaller in size and are inland. The drainage of the district is typical of the arid and semi-arid areas. Because of topographic diversity, the streams do not flow in any uniform direction. The district is characterized by dryness, extreme temperatures and uncertain and scanty rainfall. The district has a sub-tropical continental monsoonal climate with hot summer, cool winter, unreliable rainfall and great variation in temperature. January is the coldest month when mean daily maximum temperature is about 21.4°C and mean daily minimum at 5.4°C. The mean daily maximum temperature in the month of May is around 40.2°C. The day temperature may occasionally exceed 45°C. The average rainfall varies from 336 mm to 440 mm and about 80 percent of the normal annual rainfall in the district is received during June to September (https://nuh.gov.in/climate/). On an average there are 35 rainy days in a year. The heaviest rainfall in 24 hours recorded at adjoining district Gurgaon was 282.2 mm. on July 14, 1968. The district has light soils as sandy loam, medium soil particularly light loam (Seoti) and loam (Bhangar and Nardak), coarse loam (Dahar and choeknote) and rocky surfaces as per the classification of National Bureau of Soil Survey and Land Use Planning (ICAR), Nagpur. The sub-soil water in 70 percent Mewat area is brackish. In brackish water areas, crops are taken under rain-fed conditions. It is a main constraint in diversification of agriculture. The crops grown in the district are divided into two main categories viz. kharif and rabi, locally called as sawani and sadhi. The major kharif crops of the district include paddy, jowar and bajra, while the minor ones include kharif oilseeds, kharif pulses like massar and kharif vegetables (kaddu, karela, bhindi, kakri, tinda, ghia, chillies, tomato, brinjal and onion). The major rabi crops are wheat, barley, rapeseed & mustard oil seeds while the minor ones include rabi pulses, gram, fodder crops and rabi vegetables (raddish, carrot, turnip, brinjal, cauliflower, potato, pea, tomato, band gobhi, palak, methi). (**District Census Handbook, Mewat, Census of India 2011**). The irrigation is possible by constructing bunds across the streams which ends in inland. The main source of irrigation is from tube wells for both Kharif and Rabi season with small portion from canal irrigation. The canal water is available from Gurgaon canal which takes off from Agra canal at a distance of around 8 km from its off take at Okhla Barrage.

Chapter 4 Methodology

The optimal income from agriculture for various scenarios of crop types and land resources in Mewat region, Haryana is evolved by setting up of WEAP tool with the combination of LINGO. The inputs to WEAP tool such as water demand from various sectors, priority of the demand, catchment details, hydrologic conditions and inflows, catchment hydrology (river flow, ground water, lakes/reservoir/storage tanks, springs, other storage structures etc), supply preference (operating rules/policy), return flows, minimum flow requirements, economic variables such as cost of water transmission etc are prepared from the data obtained from various sources such as irrigation department, IMD, CWC and census department. The future climatic scenarios will be downscaled from GCM models for SSP245 and SSP370. The hydrological processes occurring in the catchment will be modeled and will be compared with the measured discharge time series. After the proper calibration of the model, the demand sites will be added into a model framework and different scenarios will be generated to assess the gaps in the water demand and supply and water availability at different locations and at the different period of time. The optimum income for agricultural sector will be arrived by LINGO using the input variables obtained from the scenario analysis of WEAP model for crop types and land resources. The optimization functions such as maximizing the net income from agriculture, minimizing the water usage, minimizing the cost of cultivation with the constraints of land area for crops, water availability based on the scenario analysis and cost of cultivation are considered for achieving the objectives. The scenarios such as change of cropping pattern (crop diversity) considering food security, change of cropping area with allowable limits, availability of water (normal, dry, very dry, wet and very wet), industrial and population growth and climate scenarios SSP245 and RCP370 from GCM models.

Chapter 5 Setup of WEAP model and LP model

5.1 WEAP model

Nuh (Mewat) district consists of five blocks such as Nuh, Taoru, Punhana, Nagina and Firozpur Jhirka. The drainage network for these blocks has been created by digitizing the topo sheets (53D/15, 53D/16, 53H/3, 53H/4, 54A/13, 54A/14, 54E/1, 54E/2) of 1: 50000 scale downloaded from Survey of India (SOI) website. Three blocks, Nuh, Nagina and Punhana, have been considered for setting up of WEAP model based on the drainage map with single outlet. The drainage and block boundaries are given in Fig 1. The initial setting up of WEAP model and schematic diagram is given in Fig 2. The area of three blocks lies in between 27° 45´ N to 28° 15´ N and 76° 45´ E to 77° 15´ E. The data required for setting up of the WEAP model are catchment details, water demand from various sectors such as domestic, livestock, irrigation and industrial uses, catchment hydrology such as river flow, ground water, lakes/reservoir/storage tanks, springs, other storage structures etc, meteorological data such as rainfall, solar radiation, minimum and maximum temperature and priority of demand. The area of Nuh, Punhana and Nagina are 459.16, 282.46 and 216.16 sqkm respectively. The population of Nuh, Punhana and Nagina are 2,70,841; 2,62,809 and 1,47, 426 respectively based on the 2011 census. The population projection of Haryana state based on the report of the technical group on population projections constituted by National Commission on Population, May 2006 for the period from 2001-2026 is given in Table 1 as follows:

Table 1 Population growth rate of Haryana

2001-05	2006-10	2011-15	2016-20	2021-25
2.0	1.7	1.5	1.3	1.1

The population of Nuh, Punhana and Nagina are 3,06,634; 2,97,544, and 1,66,911 respectively by the end of 2020 based on the population projection rate as mentioned above. The total urban and rural population of all the three blocks by the end of 2020 are 80101 and 690992 respectively. The landuse for Mewat district is prepared from the image of USGS earth explorer, LANDSAT 8 of 24 December 2018 and is given figure 3. The landuse for the three blocks of Nuh, Punhana and Nagina is extracted and given in Table 2. The gridded rainfall, maximum and minimum temperature for the period 1951-2019 have been obtained from IMD website for girds lies between 27° 45´ N to 28° 15´ N and 76° 45´ E to 77° 15´ E and the average values are plotted in the figures 4, 5 and 6. The computation of evapotranspiration requires the data of extra-terrestrial radiation for the latitudes 27° 45´ N, 28 N, 28° 15´ N and have been obtained from https://www.engr.scu.edu/~emaurer/tools/calc_solar_cgi.pl. The extra-terrestrial radiation values are given in Fig 7.

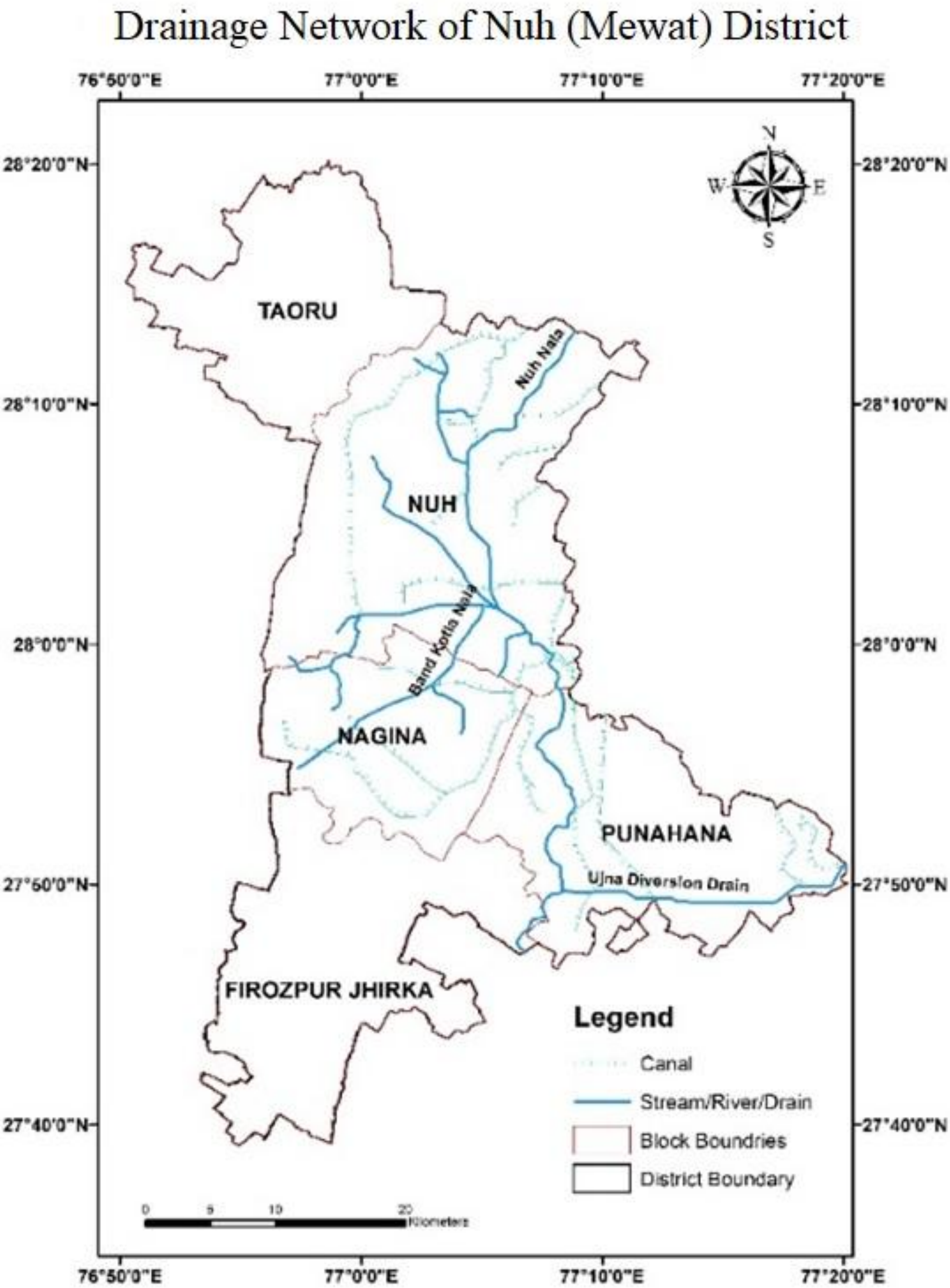

Fig 1 Drainage network of Nuh (Mewat) district (Nuh, Punhana, Nagina)

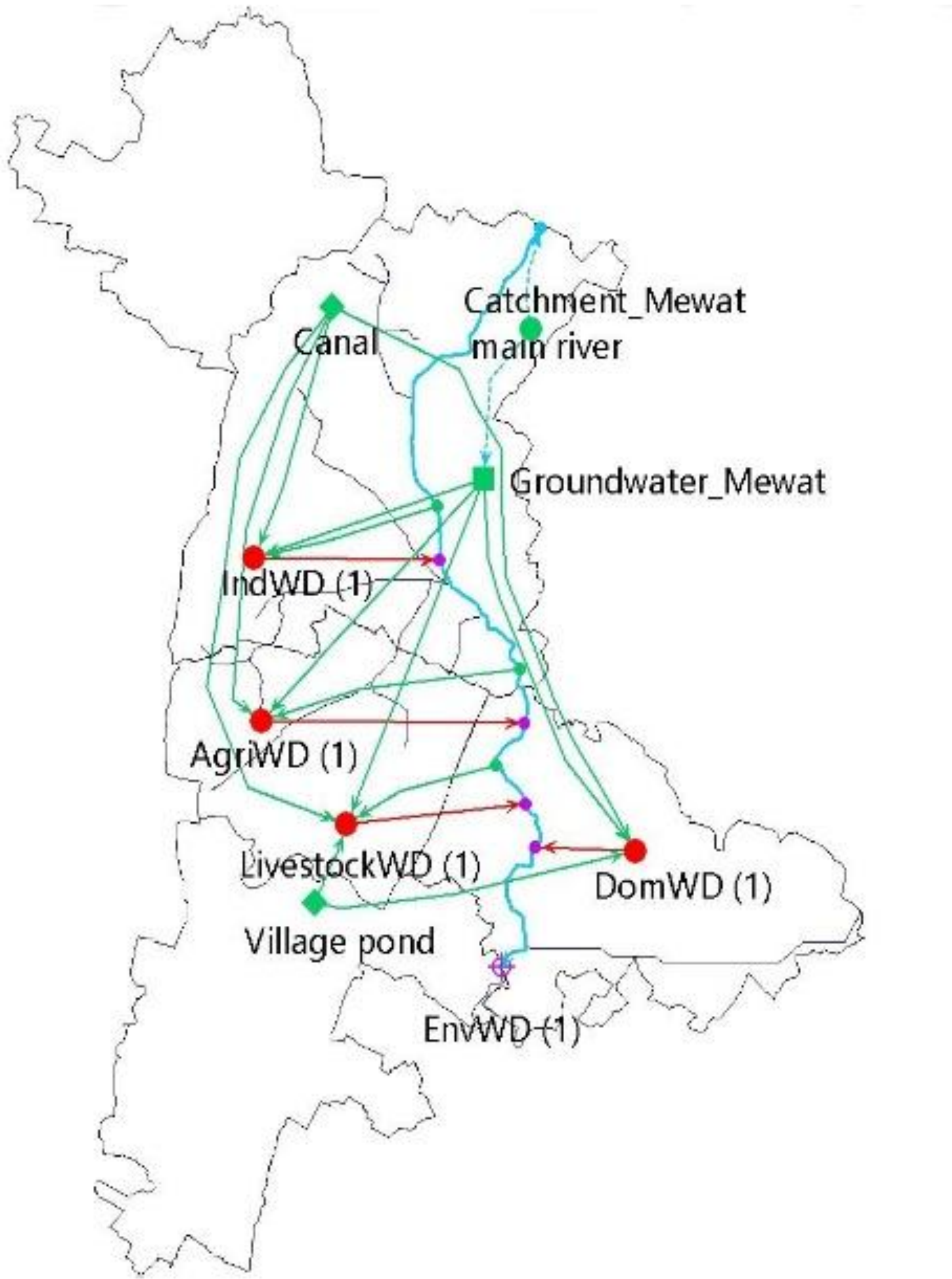

Fig 2 Schematic diagram of WEAP model for Nuh (Mewat) district (Nuh, Punhana, Nagina)

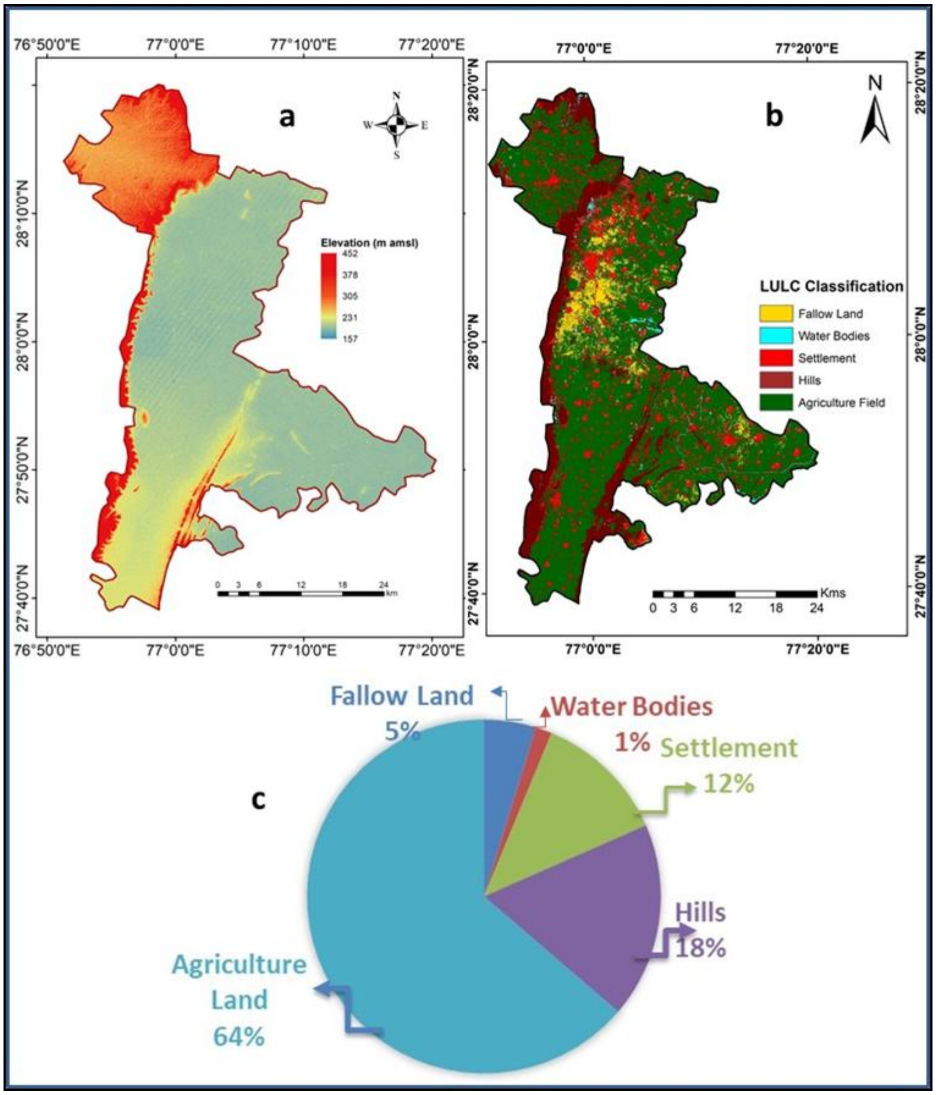

Fig 3. Landuse landcover map of Mewat District, Harynana

Table 2 Landuse of three blocks (Nuh, Punhana and Nagina)

Landuse	Percentage share
Agricultural Land	74
Forest Land	8
Settlement	12
Fallow land	5
Water bodies	1

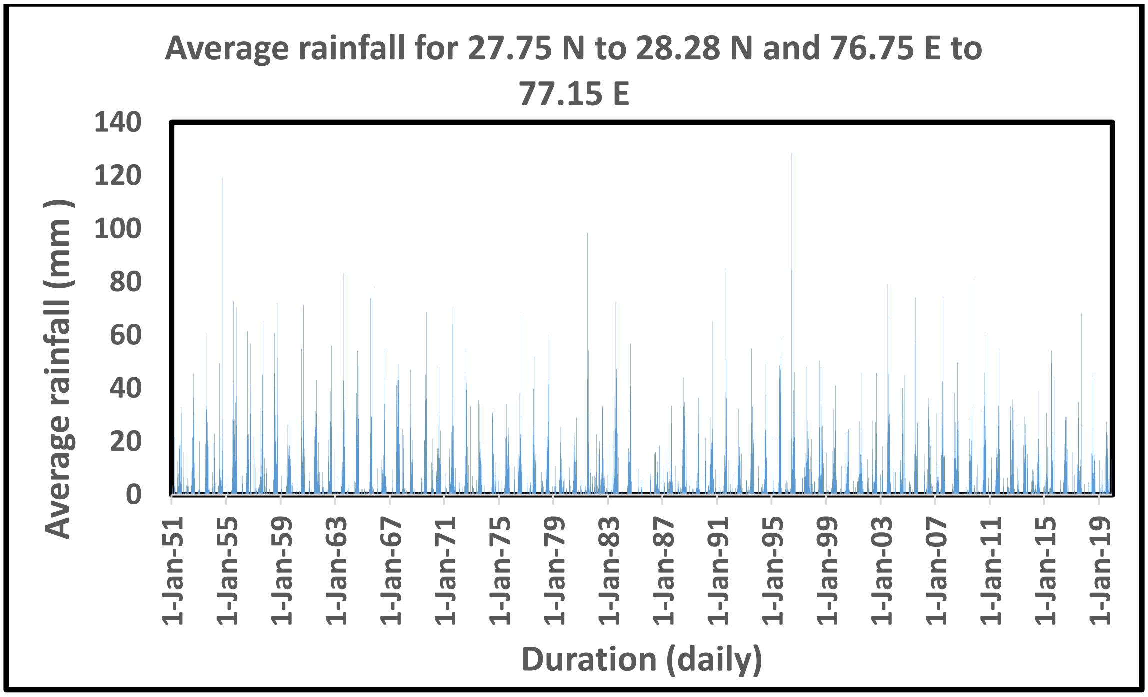

Fig 4. Average rainfall for 27.75 N to 28.28 N and 76.75 E to 77.15 E

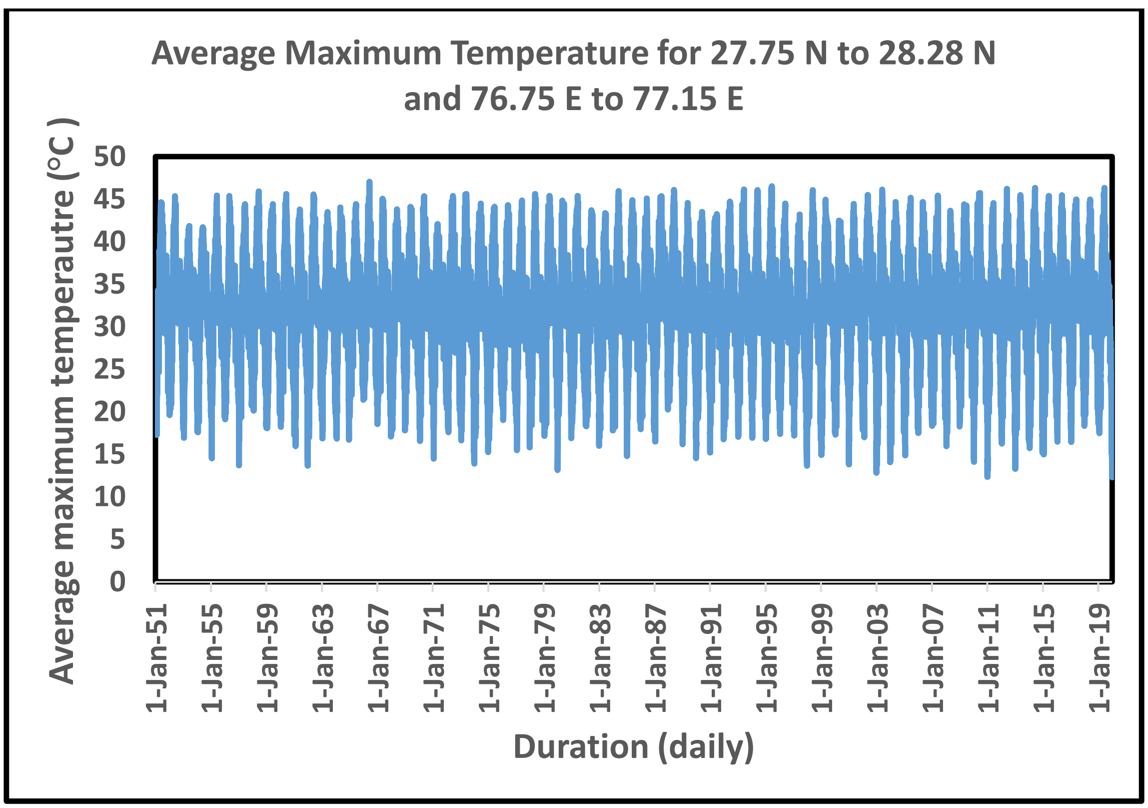

Fig 5. Average maximum temperature for 27.75 N to 28.28 N and 76.75 E to 77.15 E

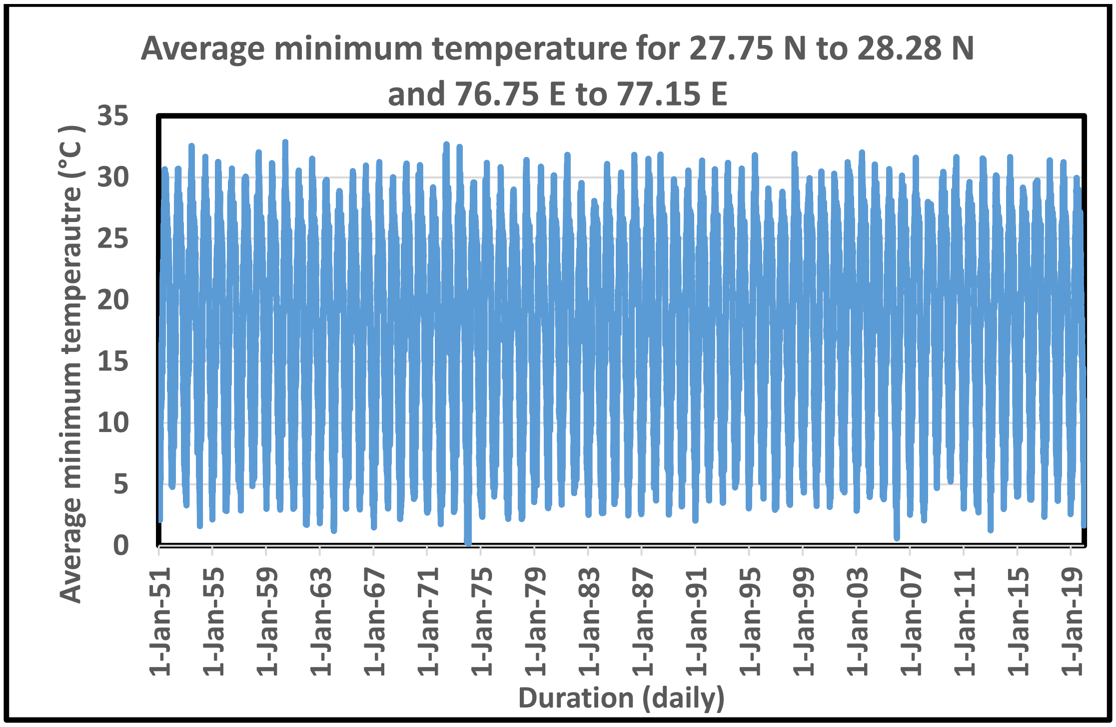

Fig 6. Average minimum temperature for 27.75 N to 28.28 N and 76.75 E to 77.15 E

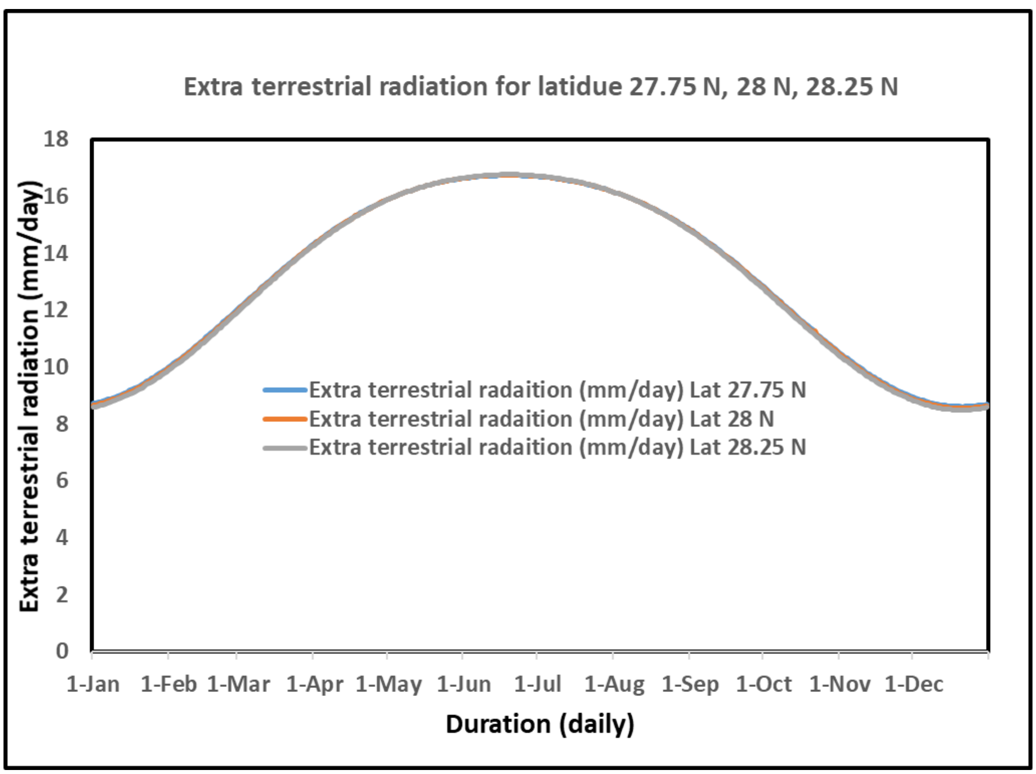

Fig 7. Extra terrestrial radiation for latidue 27.75 N, 28 N, 28.25 N

The average daily evapotranspiration has been computed by Hargreaves method by considering the maximum and minimum temperature and extra-terrestrial radiation and is given in Fig. 8.

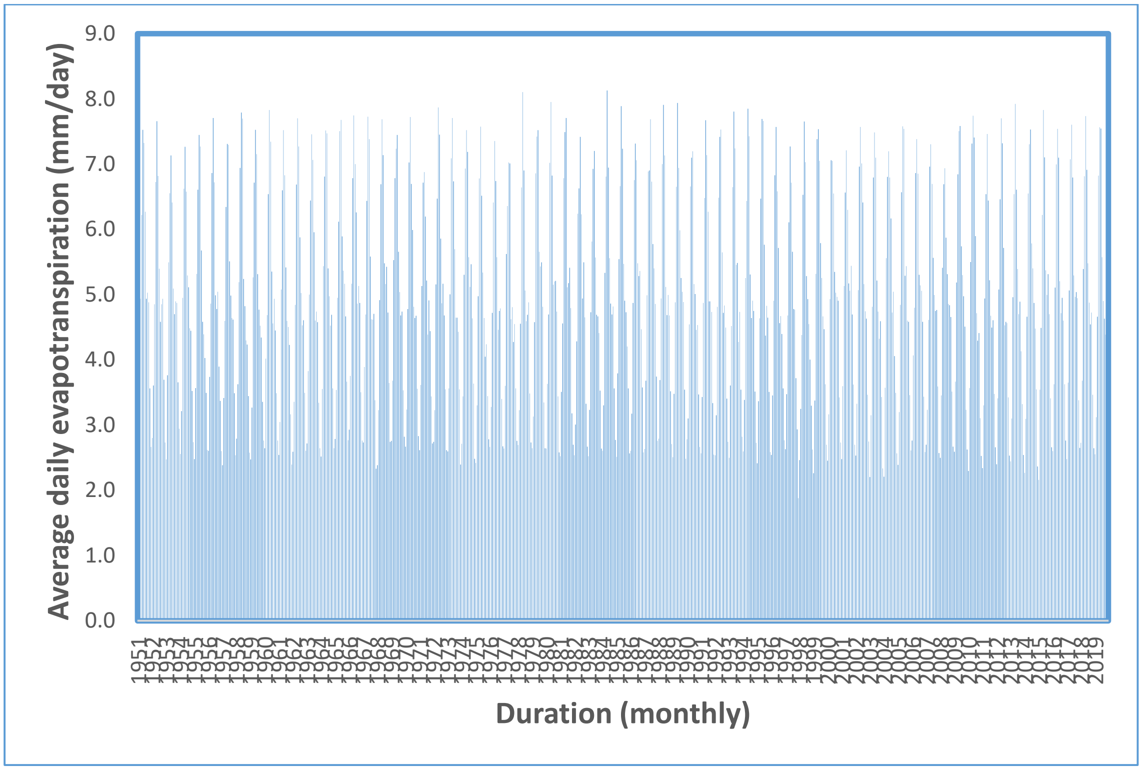

Fig 8. Average daily evapotranspiration for 27.75 N to 28.28 N and 76.75 E to 77.15 E

The study team visited district head Quarter Nuh, Agriculture department and Animal Husbandry and Dairying Department on 24.09.2021 and collected crop and livestock details and given in Table 3, 4 and 5 as follows:

Table 3. Crop area and water requirement for Kharif season

Crop	Area (ha)	Crop water requirement (mm)	Crop water requirement (m^3/ha)
Sorghum	4843	300	3000
Millet	18639	150	1500
Cotton	4900	420	4200
Paddy	7994	1200	12000
Fodder	19614	225	2250
Sugar cane	310	1500	15000
Legumes	49	200	2000
Vegetables	170	400	4000
Garden mango	38	1000	10000
oil seed	52	300	3000

Table 4. Crop area and water requirement for Rabi season

Crop	Area (ha)	Crop water requirement (mm)	Crop water requirement (m^3/ha)
Wheat	56152	400	4000
Mustard	11846	240	2400
Barley	252	300	3000
Chick pea	314	150	1500
Lentil	439	200	2000
Tomato	489	500	5000
Vegetables	531	400	4000
Barseem Fodder	98	900	9000
Garden mango	17	1000	10000
Sugar cane	5	1500	15000
Nursery	15	1000	10000

Table 5. Livestock population for Nuh, Nagina and Punhana blocks

SL No.	Block Name	Buffalo	Cattle	Goat	Rabbit	Sheep	Horses	Mules	Ponies	Pigs	Dogs	Camels	Donkey	Poultry
1	Nuh	47255	13704	9409	1920	2369	80	13	4	611	158	1	1	0
5	Nagina	11522	1152	1714	6	214	7	0	0	0	26	67	5	0
6	Punhana	54028	3727	6067	30	1191	15	7	0	107	53	6	1	0

The monthly water consumption urban (135 lpd per person) and rural (70 lpd per person) population and livestock palpation are given in Table 6 and 7 as follows:

Table 6 Monthly water consumption per person for rural and urban population (m^3)

Month	Urban	Rural
Jan	4.185	2.17
Feb	3.915	2.03
Mar	4.185	2.17
Apr	4.05	2.1
May	4.185	2.17
Jun	4.05	2.1
Jul	4.185	2.17
Aug	4.185	2.17
Sep	4.05	2.1
Oct	4.185	2.17
Nov	4.05	2.1
Dec	4.185	2.17

Table 7 Monthly water consumption for livestock (m^3) per animal

Month	Buffalo/ cattle	Goat	Rabbit	Sheep	Pig	Dog	Horse family	Camel
Jan	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Feb	2.465	0.29	0.0435	0.29	0.435	0.0348	1.16	2.175
Mar	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Apr	2.55	0.3	0.045	0.3	0.45	0.036	1.2	2.25
May	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Jun	2.55	0.3	0.045	0.3	0.45	0.036	1.2	2.25
Jul	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Aug	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Sep	2.55	0.3	0.045	0.3	0.45	0.036	1.2	2.25
Oct	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325
Nov	2.55	0.3	0.045	0.3	0.45	0.036	1.2	2.25
Dec	2.635	0.31	0.0465	0.31	0.465	0.0372	1.24	2.325

The monthly crop coefficient (Kc) for different landuses and crops (FAO) and the effective precipitation for evapotranspiration are given in Table 8, 9 and 10 as follows:

Table 8 Monthly crop coefficient (Kc) for Kharif and Rabi crops

Landuse	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural Land	0.98	0.41	0.25	0.36	0.35	0.79	0.51	1.09	1.00	0.53	0.77	1.12
Forest land	0.75	0.75	0.75	0.75	0.95	0.95	0.95	0.95	0.95	0.85	0.85	0.85
Settlement	0.08	0.08	0.08	0.08	0.12	0.12	0.12	0.12	0.12	0.09	0.09	0.09
Fallow land	0.15	0.15	0.15	0.15	0.19	0.19	0.19	0.19	0.19	0.17	0.17	0.17
Water bodies	0.90	0.90	0.90	1.05	1.05	1.05	1.05	1.05	1.05	1.00	1.00	1.00

Table 9 Monthly crop coefficient (Kc) for Kharif and Rabi crops

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sorghum (Jwar)	0	0	0	0	0	0	0.3	1.1	1	0.55	0	0
Millet	0	0	0	0	0	0	0.3	1	1	0.3	0	0
Cotton	0.5	0	0	0.35	0.35	0.35	1.2	1.15	1.15	1.15	0.7	0.7
Paddy	0	0	0	0	0	1.05	1.2	1.2	0.9	0.9	0	0
Fodder (Sorghum)	0	0	0	0	0	0	0.3	1.1	1	0.55	0	0
Sugar cane	0.75	0.55	0.4	0.4	0.4	1.25	1.3	1.25	1.25	0.75	0.75	0.75
Vegetables (Brinjal)_kh	0	0	0	0	0	0.6	1.1	1.05	1.05	0.8	0	0
Wheat	1.15	0.4	0.25	0	0	0	0	0	0	0	0.7	1.15
Mustard	0.35	0	0	0	0	0	0	0	0	0.35	1.15	1.15
Barley	1.15	1.15	0.4	0	0	0	0	0	0	0	0.3	1.15
Chickpea (Chana)	1	0.35	0	0	0	0	0	0	0	0.4	1	1
Lentil (Masoor)	1.1	1.1	0.3	0	0	0	0	0	0	0	0.4	1.1
Tomato	0.9	0.7	0	0	0	0	0	0	0	0.6	1.15	1.15
Vegetables (Cauliflower)_Rb	0.95	0	0	0	0	0	0	0	0	0.7	1.05	1.05
Berseem Fodder	0.9	0.9	0.85	0.85	0	0	0	0	0	0.4	0.4	0.9

Table 10 Effective precipitation for evapotranspiration

Landuse	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Agricultural land	60	60	60	50	50	70	70	70	70	60	60	60
Forest land	65	65	65	60	60	80	80	80	80	65	65	65
Settlement	50	50	50	40	40	65	65	65	65	45	45	45
Fallow land	60	60	60	50	50	70	70	70	70	55	55	55
water bodies	18	18	18	15	15	25	25	25	25	20	20	20

Initial run has been carried in WEAP model with above mentioned inputs and some of the results are given in Figures 9, 10 and 11 as follows:

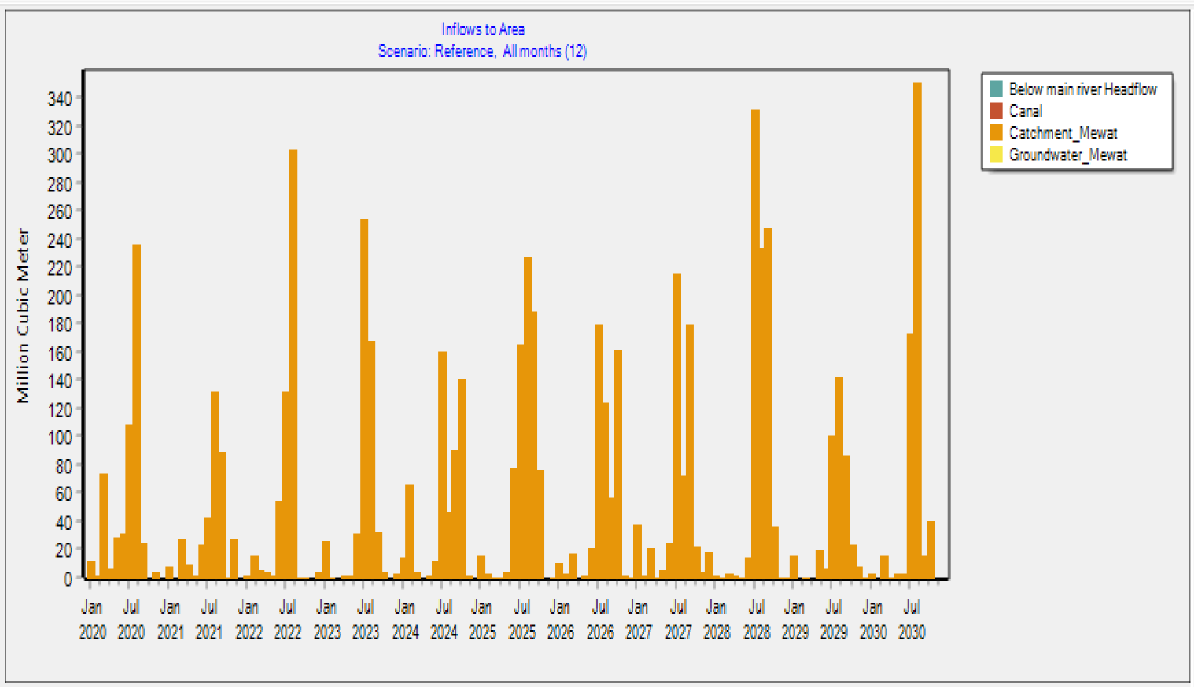

Fig 9. Monthly Inflows to area from 2020 to 2030

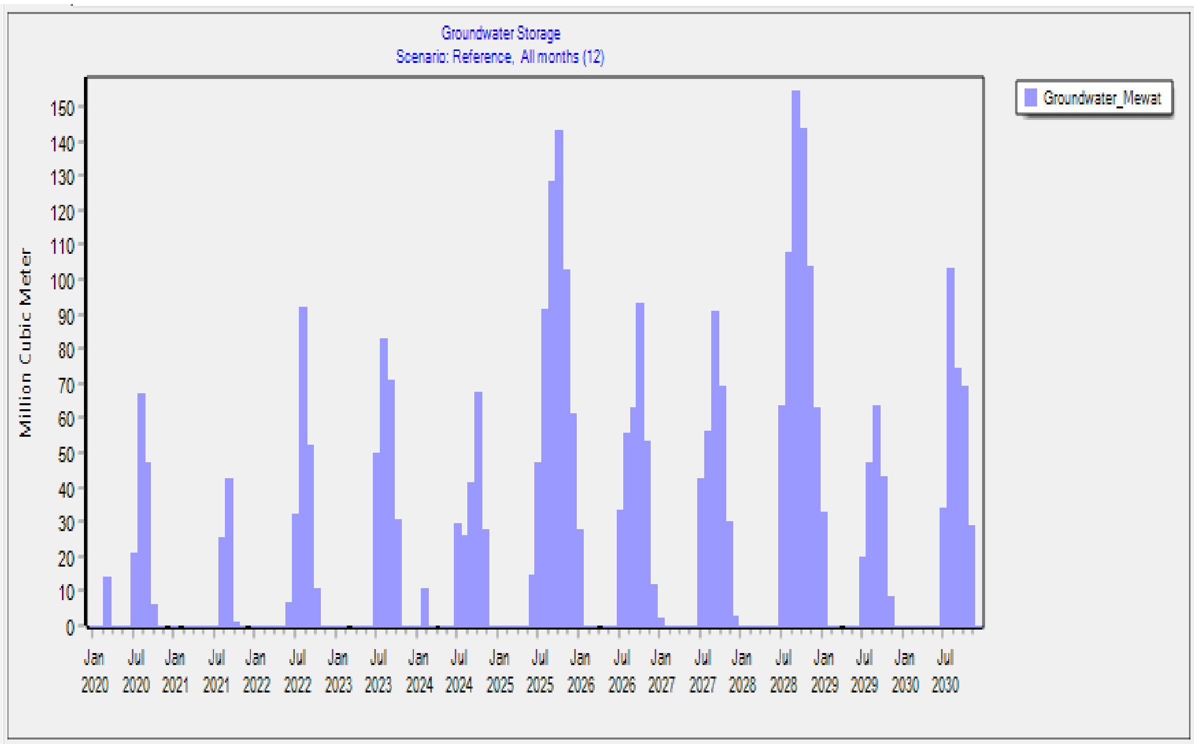

Fig 10. Monthly ground water storage from 2020 to 2030

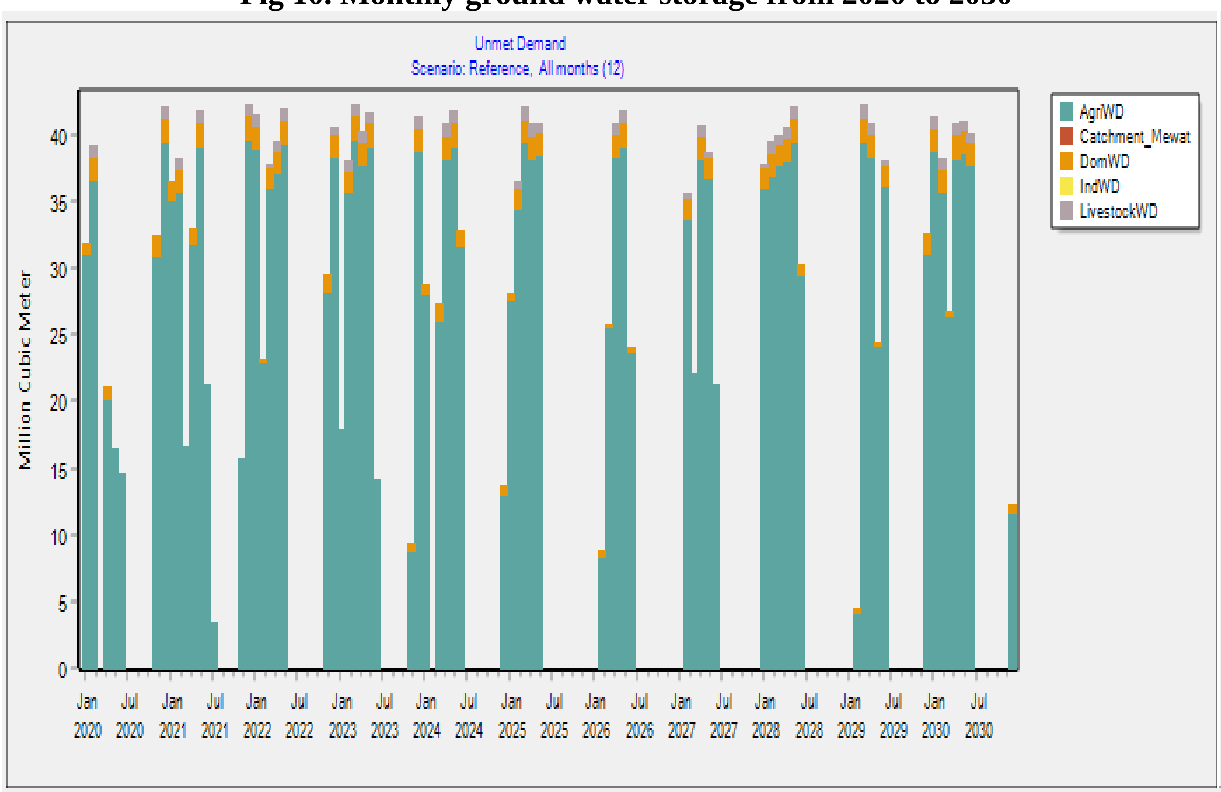

Fig 11. Monthly unmet demand from 2020 to 2030

5.1.1 Future scenarios

The following scenarios are considered for the optimization of farm income

a. Change of cropping pattern (crop diversity) considering food security

b. Change of cropping area with allowable limits

c. Availability of water (Normal, dry, very dry, wet and very wet)

d. Industrial and population growth

e. Climatic scenarios SSP245 and SSP370 from GCM models

5.2 LP Model

The Objective function considered for the optimization of farm income are

a. Maximizing the net profit from the crop cultivation
b. Minimizing the cost of the crop cultivation
c. Minimizing the water utilization

Subject to the constraints

a. Area for each crop and total area (Area of the crop can be varied from 0.9 to 1.1 times of the existing cropping area)

b. Surface and ground water availability (Surface water estimation from coefficient method or SCS Curve number method)

c. Crop water requirement for all the crops, water demand for domestic and industrial uses

d. Cost of the cultivation which includes labour cost, animal and machine power cost, seed cost, fertilizer and manure cost, pesticides, plant protection cost, tax to the revenue department, interest on loan, unforeseen expenditure

5.2.1 LP model formulation

The formulation of LP model for optimizing the net profit from farming practices with the objectives for optimal production cost and water use (Rani and Rao, 2012) is given as follows:

Objective function 1: Maximization of net profit

Total revenue for all the crops

$$T_R = \sum_{i=1}^{n} R_i Y_i A_i$$

Total production cost for all the crops

$$T_c = \sum_{i=1}^{n} C_i Y_i A_i$$

R_i – Revenue of the i^{th} crop per tonne; Y_i – Yield of the i^{th} crop per tonne per unit area; A_i – Area cultivated for the i^{th} crop in ha; C_i – Production cost for the i^{th} crop per tonne ; **n**=number of crops

$$\textbf{Maximize} \quad Z_1 = \sum_{i=1}^{n} R_i Y_i A_i - \sum_{i=1}^{n} C_i Y_i A_i$$

Objective function 2: Minimization of input cost

$$\textbf{Minimize} \; Z_2 = \sum_{i=1}^{n} A_i (CS_i + CF_i + CP_i + CH_i + CA_i + CR_i + CLR_i + GC_i + CU_i)$$

CS_i – Cost of the seed per unit area of the land for i^{th} crop; CF_i – Cost of the fertilizer per unit area of the land for i^{th} crop; CP_i – Cost of the pesticides per unit area of the land for i^{th} crop; CH_i – Cost of the labour per unit area of the land for i^{th} crop; CA_i – Cost of the animal and other labour per unit area of the land for i^{th} crop; CR_i – Cost towards interest on loan per unit area of the land for i^{th} crop; CLR_i – Cost on land revenue per unit area of the land for i^{th} crop; GC_i – Cost on gross input per unit area of the land for i^{th} crop; CU_i – Cost on unforeseen enpeditureper unit area of the land for i^{th} crop

Objective function 3: Minimization of water usage

$$\textbf{Minimize} \; Z_3 = \sum_{i=1}^{n} A_i (WK_i + WR_i)$$

WK_i **–** Water availability in Kharif season for the i^{th} crop; WR_i **–** Water availability in Rabi season for the i^{th} crop

Constraint on water availability

$$\sum_{i=1}^{n} \boldsymbol{W_i A_i + DR + IR \leq W_A}$$

$\boldsymbol{W_i A_i}$ **–** Total water requirement for all the crops; **DR –**Domestic requirement; **IR –** Industrial requirement**;** $\boldsymbol{W_A}$ **–** Water availability for both the seasons (surface water availability from SCS curve number method, ground water availability from pumping rate).

Constraint on land variability

$$\sum_{i=1}^{n} \boldsymbol{\lambda_i A_i \leq A_T}$$

$\boldsymbol{\lambda_i}$ – weight coefficient of the crop area; $\boldsymbol{A_T}$ – Total area for cultivation

Constraint on minimum yield requirement

$$\sum_{i=1}^{n} \boldsymbol{Y_i A_i \geq Y_{min}}$$

$\boldsymbol{Y_i A_i}$ – Minimum yield requirement of i^{th} crop for A_i; $\boldsymbol{Y_{min}}$ is minimum yield requirement for all the crops

Constraint on maximum yield requirement

$$\sum_{i=1}^{n} \boldsymbol{Y_i A_i \leq Y_{max}}$$

$\boldsymbol{Y_{max}}$ is maximum yield requirement for all the crops

Constraint on total availability of land for cultivation

$$\sum_{i=1}^{n} \boldsymbol{A_i \leq A_T}$$

Constraint on investment cost on land revenue

$$\sum_{i=1}^{n} \boldsymbol{CLR_i A_i \leq CLR}$$

Constraint on investment cost on unforeseen expenditure

$$\sum_{i=1}^{n} CU_i A_i \leq CU$$

Constraint on investment cost on gross input

$$\sum_{i=1}^{n} GC_i A_i \leq GC$$

Constraint on investment cost on seeds

$$\sum_{i=1}^{n} CS_i A_i \leq CS$$

Constraint on investment cost on fertilizers

$$\sum_{i=1}^{n} CF_i A_i \leq CF$$

Constraint on investment cost on pesticides

$$\sum_{i=1}^{n} CP_i A_i \leq CP$$

Constraint on investment cost on labour

$$\sum_{i=1}^{n} CH_i A_i \leq CH$$

Constraint on investment cost on animal and other labour

$$\sum_{i=1}^{n} CA_i A_i \leq CA$$

Constraint on investment cost on interest for loan

$$\sum_{i=1}^{n} CR_i A_i \leq CR$$

5.2.2. Input to the LP model

The input to the optimization model (LINGO) such as yield, market price and cost of cultivation for Kharif and Rabi crops are obtained from Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare for the year 2018-19 and literature and given in Tables 11 and 12 as follows:

Table 11 Yield and market price for Kharif crop

Sl.no	Crop	Yield (kg/ha)	Market Price (Rs/quintal) for 2020-21
1	Sorghum (Jwar)	1890	2640
2	Millet (Bajra)	2592	2150
3	Cotton	574	5515
4	Paddy	2337	1868
5	Fodder (sorghum)	35,000	500
6	Sugar Cane	70,000	362
7	Vegetable (Brinjal)	24700	2000

Table 12 Yield and market price for Rabi crop

Sl. No.	Crop	Yield (kg/ha)	Market Price (Rs/quintal) for 2020-21
1	Wheat	3903	1975
2	Mustard	2141	4650
3	Barley	3085	1600
4	Chickpea (chana)	1666	5100
5	Lentil (Masoor)	1,800	5100
6	Tomato	21,500	750
7	Vegetable (cauliflower)	16300	1300
8	Berseem Fodder	75000	500

The cost of cultivation for major Kharif and Rabi has been obtained from Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare for the year 2018-19 and given in Tables 13 and 14 as follows:

Table 13 Cost of cultivation for Kharif crop

Sl. No.	Crop	Cost of the seed per ha	Cost of the fertilizer per ha	Cost of the pesticides per ha	Cost of labour per ha
1	Sorghum (Jwar)	1121.43	2106.28	28.33	19966.53
2	Millet (Bajra)	1208.53	1881.83	144.07	11963.93
3	Cotton	3643.89	3452.07	2136.59	23970.43
4	Paddy	1690.13	4618.17	3865.07	20542.39
5	Sugar cane	4878.57	5205.79	4779.28	36818.87

Table 13 Cost of cultivation for Kharif crop (continued)

Sl. No.	Crop	Cost of animal and other labour per ha	Cost towards interest on loan per ha	Cost on land revenue per ha	Cost on gross input per ha
1	Sorghum (Jwar)	6357.50	490.58	0.00	47.74
2	Millet (Bajra)	7257.35	455.74	0.00	854.69
3	Cotton	7118.84	876.42	0.00	3244.44
4	Paddy	8101.42	1120.98	0.00	6052.91
5	Sugar cane	2950.99	3219.53	0.00	2712.03

Table 13 Cost of cultivation for Kharif crop (continued)

Sl. No.	Crop	Cost on unforeseen expenditure per ha	Fixed costs per ha	Cost of production Rs/Qtl
1	Sorghum (Jwar)	26.50	7125.65	2019.68
2	Millet (Bajra)	0.00	16408.69	1877.79
3	Cotton	15.23	29624.65	4908.46
4	Paddy	70.67	38647.26	1772.56
5	Sugar cane	118.96	97511.43	195.57

Table 14 Cost of cultivation for Rabi crop

Sl. No.	Crop	Cost of the seed per ha	Cost of the fertilizer per ha	Cost of the pesticides per ha	Cost of labour per ha
1	Wheat	2990.97	5113.84	1144.25	8724.59
2	Mustard	1250.19	3878.75	48.63	10596.21
3	Barley	3244.05	4109.47	231.78	23678.04
4	Chickpea (Chana)	1875.00	0.00	0.00	11445.24
5	Lentil (Masoor)	4960.63	1488.19	0.00	11484.01
6	Tomato	6000.00	10200.00	16580	58064.00

Table 14 Cost of cultivation for Kharif crop (continued)

Sl. No.	Crop	Cost of animal and other labour per ha	Cost towards interest on loan per ha	Cost on land revenue per ha	Cost on gross input per ha
1	Wheat	13875.55	932.18	0.00	4482.10
2	Mustard	9816.24	695.18	0.00	2596.81
3	Barley	8351.84	843.60	0.00	5786.15
4	Chickpea (Chana)	6915.71	451.80	0.00	58.95
5	Lentil (Masoor)	3897.64	446.19	0.00	1707.68
6	Tomato	5500.00	1280.6	0.0	1750.00

Table 14 Cost of cultivation for Kharif crop (continued)

Sl. No.	Crop	Cost on unforeseen expenditure per ha	Fixed costs per ha	Cost of production Rs/Qtl
1	Wheat	62.32	38084.68	1288.87
2	Mustard	66.51	34431.53	2987.48
3	Barley	51.00	18007.62	1342.45
4	Chickpea (Chana)	0.00	20840.96	2119.99
5	Lentil (Masoor)	19.69	7858.56	4835.62
6	Tomato	0.0	19656.53	553.63

Fixed cost includes rental value of owned land, rent paid for leased in land, depreciation on implements and farm building and Interest on fixed capital. The cost of cultivation for fodder (sorghum), Vegetable (brinjal) of Kharif crop and Vegetable (cauliflower), Berseem fodder of Rabi crop is being collected for the implementation of LP model for optimizing the benefits from the farming practices.

Chapter 6 Conclusion

Water shortage in meeting the demand in large scale basin as well as small scale micro-watershed is a major problem worldwide. The gap between demand and water supply is estimated to plan new water resources development and effective management of existing resources. WEAP and LINGO has been extensively used by various researchers, stakeholders and policymakers for the integrated water resources management due to its capability to build complex and integrated models of natural and man-made ecosystems. The model has been successfully applied to enormous number of catchments in simulating water demands of different sectors under different scenarios like climate change, population growth, demand management strategies etc.

The present study uses WEAP21 in combination with LINGO to optimize farmers' income by optimal land and water allocation with food security and diversified cropping pattern. The WEAP model has been set up for three blocks, Nuh, Nagina and Punhana of Nuh (Mewat) district with demand and supply nodes. The current population in Nuh, Nagina and Punhana of Nuh (Mewat) district is projected from data of 2011 census based on the report of the technical group on population projections constituted by National Commission on Population, May 2006 for the period from 2001-2026 and is observed an increase of 13.22 % by the end of 2020. The gridded data of rainfall, maximum and minimum temperature is obtained from IMD for the period from 1951 to 2019 and processed for Nuh, Nagina and Punhana. The extra-terrestrial radiation for the area is obtained from website. The daily evapotranspiration is estimated from gridded maximum and minimum temperature, extra-terrestrial radiation for the period from 1951 to 2019. The initial run of WEAP model has been carried out with crop area and water requirement for Kharif and Rabi season, livestock population and their water requirement, Urban and rural population and their water consumption, monthly crop coefficient for Kharif and Rabi crops, different landuses, effective precipitation for evapotranspiration from different state departments and literature. The LP model is formulated for optimizing the farmers' income with various input variables for current and various scenarios. The cost of cultivation, crop yield and market price for Kahrif and Rabi crops have been collected from Directorate of Economics and Statistics, Ministry of Agriculture and Farmer Welfare for the year 2018-19 for the implementation of LP model.

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