MULTIDISCIPLINARY SCIENCE JOURNAL

RESEARCH ARTICLE
Published Online: January 9, 2024
https://doi.org/10.31893/multiscience.2024083

Irrigation planning for development of an effective cropping pattern using genetic algorithm

Sumant A. Choudhari[a] | **Manoj A. Kumbhalkar**[b] | **Mhalsakant M. Sardeshmukh**[c] | **Dattatraya V. Bhise**[b]

[a]Department of Civil Engineering, JSPM Narhe Technical Campus, Pune, India.
[b]Department of Mechanical Engineering, JSPM Narhe Technical Campus, Pune, India.
[c]Department of Electronics and Telecommunication Engineering, JSPM Narhe Technical Campus, Pune, India.

Abstract The majority of surface irrigation schemes are diverse in character, consisting of a diversity of crops and soils as well as a huge network of canals with varying qualities (design capacities, efficiencies, command area, length, duration of operation, etc.). The programmes in semiarid and arid locations are similarly related to limited water supplies and operate on a rotating water distribution system. As a result, managing irrigation in such settings is tough. It demands decisions on how much water and space should be allotted to different crops grown on different soils and in different areas or regions of the scheme (the allocation plan), based on water availability, benefit maximisation, varied needs, and the physical boundaries of the scheme. The current study focuses on the use of genetic algorithms (GA) in irrigation planning. In India, the GA technique is being used to create an effective farming plan for an irrigation project. Constraints include land and water limitations, as well as crop and storage limits. The model is run for various choices of population, generations, cross-over, and mutation probabilities to determine GA parameters. The results of GA are compared to those of linear programming. This case study is about a problem with linear constraints that was addressed using a genetic algorithm. The model's future use will be to address issues with non-linear constraints. Traditional nonlinear programming approaches become difficult and time-intensive in such instances. Future research is being conducted to improve the efficiency and usability of these artificial intelligence systems.

Keywords: energy, irrigation, cropping pattern, genetic algorithm, linear programming method

1. Introduction

The demand for water resources is constantly increasing due to explosive population growth, the advancement of civilization, and increased agricultural and industrial productivity. Water demand is expected to increase by 50% by the turn of the century, according to current estimates. However, water resources are limited in comparison to the world's ever-increasing demand (Jain et al., 2021). A review of several research projects over the last few decades has shown that the systems analysis approach has become widely accepted in the planning and management of water resources. However, the norm has been to maximise a single target at first, with the concept of multi-objective optimisation gradually gaining traction with resource planners and decision-makers. The current situation necessitates a scientific approach to water resource planning and management issues in order to meet future needs. So, water resource managers and planners should strive for the most efficient use of available resources (Katoch et al., 2021). Genetic algorithms are a class of computational models that use evolutionary principles to solve problems in water usage in agriculture. These algorithms make use of recombination operators to keep vital information intact while encoding a proposed solution to a specific problem on a basic chromosome-like data structure. Although genetic algorithms have been applied to a wide range of problems, they are most commonly regarded as function optimizers (Yijia Wang, 2022; Pereira et al., 2022). A population of (usually random) chromosomes is used to implement a genetic algorithm. Then, these structures are evaluated, and reproductive opportunities are assigned in such a way that the chromosomes that offer a better solution to the target problem have more chances to'reproduce' than the chromosomes that represent an inferior answer. A solution's 'goodness' is usually defined in terms of the current population (Avramidou et al., 2020; Enes Ayan et al., 2020; Namazzi et al., 2020; Mellouli et al., 2019). Growing agricultural product demand, rising water supply costs, and the stochastic nature of water supplies have all contributed to the need for an efficient and integrated management tool for an irrigation system.

Because irrigation water is limited, profit-driven irrigators prefer to divide available water among competing crops in order to maximise profits. Water allocation must be optimised across time, among crops, and among competing units of the same crop at the same time. To meet these requirements, optimal irrigated area design requires mathematical models and

 Received: September 17, 2023 | Accepted: November 20, 2023

innovative irrigation management approaches. Water scarcity, inefficient irrigation, and poor irrigation decisions all significantly limit agricultural production in arid and semi-arid countries. As a result, real-time, speedy, and accurate crop irrigation decision-making is required. A mathematical model abstracts a portion of the real world into a certain mathematical framework in order to achieve a specified purpose. Th+e goal of global optimisation in irrigation planning and agricultural production is to maximise crop productivity while limiting water supply within an irrigated area. Evolutionary algorithms (EAs) seek the optimal solution from a population of points rather than a single point. These tricks make them appealing for dealing with complex design issues. Genetic algorithms (GA) are well-known optimisation tools that are suited and beneficial for searching for feasible decision spaces and solving different difficulties related to natural resource planning, design, and management. Another intriguing property of GA is its capacity to tackle multi-objective optimisation problems, which has really popularised it. A genetic algorithm prefers to find the optimal solution from a population of points rather than from a single point. These benefits have increased their usefulness in dealing with difficult design issues. The optimal cropping pattern in this case study was discovered using the Genetic Algorithm artificial intelligence system. The problem model is developed using data from the Jayakwadi project on the Godavari River in Paithan, Aurangabad, Maharashtra. The problem is then solved using linear programming with sensitivity analysis, and the results obtained are compared with the genetic algorithm solved in MATLAB. This case study pertains to the problem based on the linear constraints solved by the genetic algorithm. The future scope of this model is to solve problems with non-linear constraints. In such cases, the traditional nonlinear programming models become complex and time-consuming.

The main objective of the study is to develop optimal policies in a genetic algorithm environment for a multipurpose reservoir in a river basin. The objective of this research is to show how some system analysis methods can be used to optimise the functioning of a water resources system in order to meet the objectives. With the shift in policy and development in the agricultural, industrial, and domestic sectors, any water resource system, whether already in operation or in the planning stages, should be able to meet the demand. Most of the eater resources system is operated with conventional approaches. Although system analysis in general and mathematical optimisation methods in particular have been found useful, As a result, it is critical to raise knowledge about the value of current methods for resolving water resource issues. The following are the sub-goals of this research:

- Maximize the relative yields of all crops.
- To reduce the escalating cost of supplying water for the fields.
- To optimize the water distribution in irrigation channels.
- The optimization model is used to study the performance of the Jayakwadi reservoir stage-I.
- Development of optimal operation policies through LINGO (Language for Interactive general optimization), giving a full range of policies available for decision makers.

Study related to optimization and Genetic Algorithm.

1.1. Related Work

Water is a critical resource for the sustainable production of agricultural products around the world, yet it is a limiting factor in most areas due to insufficient rainfall and a rising population. Irrigating crops enhances yields and productivity in agriculture; nevertheless, improper irrigation management can result in environmental issues such as a high water table, inadequate drainage, and hence salinization and pollution, in addition to poor irrigation water quality. This means that water management in agriculture is critical to the long-term viability of agricultural production. With the explosive population expansion, advancement of civilization, greater agricultural and industrial productivity, and other interconnected systems, the need for water resources is continually increasing. However, water resources are inadequate in comparison to the country's ever-increasing demands. The approach of systems analysis has been developed and generally accepted in the planning and management of water resources over the last few decades as a result of a number of research projects. The trend, however, has only been to optimize a single objective at the beginning, and gradually the concept of multi-objective optimization has caught the attention of resource planners and decision-makers. The prevailing circumstances call for a scientific approach to water resource planning and management problems so as to meet future needs. Optimal utilization of available resources should be the aim of water resource managers and planners. Real-life situations are frequently uncertain or ambiguous in a variety of ways. The future condition of the system may not be known due to a lack of information. The genetic algorithm provides a logical framework within which ambiguous concepts and phenomena can be investigated explicitly and thoroughly. The genetic diversity of cultivars grown is described along three distinct agro-ecological gradients in eastern Nepal. In order to analyze genetic diversity in 60 acid lime cultivars, 21 polymorphic ISSR markers were utilized. Popgene version 1.32 genetic diversity research found that the Terai zone has the largest proportion of polymorphic bands (PPB) and Nei's genetic diversity (H). The Nile Basin is one of just a few international river basins where potential disputes between riparian nations exist. The purpose of this article is to examine optimal scenarios for water resource management in the Eastern Nile. A hydro-economic optimization model based on the genetic algorithm was used to calculate the highest benefits for two scenarios. The results for Sudan suggest that the existence of GERD enhances hydropower generation in both management situations. The piecewise reorganization of chromosomal structure resulted in the development of a modified genetic algorithm, namely the piecewise genetic algorithm (PWGA). In order to increase the framework's computational efficiency, a URM-based groundwater model is additionally connected with PWGA. The data support the idea that GERD development benefits three Eastern Nile riparian countries: Ethiopia, Sudan, and Egypt (Munankarmi et al. 2018; Xingtan Zhang et al. 2018; Reem Digna et al. 2018; Villa et al. 2018; Ghasemi et al. 2016).

Under a likely climate change scenario, irrigation water usage is predicted to increase in the near future due to climate change and rising food and biofuel demand. Using multi-objective genetic algorithms, a new approach to sustainable management of pressured irrigation networks has been created. The suggested model was solved using a genetic algorithm (GA) in the vicinity of the Doroudzan Dam in Iran's southwest. Furthermore, for each weather situation, two irrigation techniques, full irrigation and deficit irrigation, were modelled. The researcher proposes a model for decision assistance in irrigation project planning based on on-farm irrigation scheduling and the basic genetic algorithm optimization (GA) approach (González Perea et al., 2016; Somayeh Sadati et al., 2014).

The suggested methodology is applied to a 394.6-hectare irrigation project in Delta, Utah. Our findings suggest that when the ideal area under corn and sugar beet reduces dramatically, the change in wheat-cultivated area is minimal. The optimization strategy was shown to be successful in the Doroudzan Dam area. The optimal plan for the 394.6-hectare irrigation project is as follows: Life cycle assessment (LCA) has been identified as a useful approach for evaluating the environmental implications of a product across its life cycle. In India, LCA is used in conjunction with the multi-objective genetic algorithm (MOGA) and data envelopment analysis (DEA) for irrigation planning (Azamathulla et al., 2008; Sheng-FengKuo et al., 2000; Khoshnevisan et al., 2015).

In 2004, Srinivasa Raju and Nagesh Kumar used a genetic algorithm to find the best cropping pattern and reservoir operation strategy for the Sri Ram Sagar Project (SRSP) on the Godavari River in Andhra Pradesh, India. They did this by looking at average inflows from the reservoir and trying to get the most net benefits.

Wardlaw and Sharif compared different evolutionary algorithm formulations for a four-reservoir, deterministic, finite-horizon issue. A nonlinear four-reservoir problem, one with extended temporal horizons, and a complex ten-reservoir problem were also considered. They came to the conclusion that using a genetic algorithm is more reliable. By evaluating two benchmark problems, Wu and Simpson (2001) used a messy genetic algorithm for optimal design and rehabilitation of a water distribution system. They discovered that the messy genetic algorithm requires fewer design trials than the other genetic algorithms.

To maximize relative yields, Nagesh Kumar et al. (2006) suggested a reservoir operating and crop water distribution model based on GA. For distinct planted regions, various conditions of input to reservoirs and rainfall, crop competition for water, and soil moisture dynamics were all taken into account at the same time.

Patil and Patil (2013) and Nicklow et al. (2003) devised a strategy for reducing sediment aggradation and deterioration. The controlling hydraulic and sediment constraints are solved using the simulation model HEC-6, while the overall control problem is solved using the genetic algorithm. The methodology is confirmed with a hypothetical and real-life case study, demonstrating its practical applicability as a sedimentation control decision-making tool.

Although GA has been successfully used to solve a variety of other optimization issues, it has rarely been used to solve an irrigation allocation problem. As a result, it is proposed in this work that GA be used to optimize irrigation allocation for multiple crops. For the identical problem, the outcomes from this model will be compared to the corresponding results from the LP optimization model.

2. The Methodology and Investigations

The genetic algorithm is used for the case study along with linear programming with sensitivity analysis. The term, component, and case of some system analysis methods can be used to optimise the functioning of a water resources system in order to meet the objectives (Choudhari et al., 2022).

2.1. Genetic Algorithm

In the genesis of species, Charles Darwin proposed the theory of natural evolution. Biological creatures evolve throughout generations based on the concept of natural selection, "survival of the fittest," to achieve astonishing tasks. The effectiveness of the albatross' exquisite forms, as well as the similarities between sharks and dolphins, are the clearest illustrations of random evolution triumphing over intelligence. As a result of how effectively it works in nature, simulating natural evolution and developing a way to address difficult search optimisation problems should be intriguing.

Individuals in a population struggle for virtual resources like food, housing, and so on. Individuals in the same species struggle for mates in order to reproduce. Poor performers have a lower chance of surviving as a result of this selection, while the most suited or "fit" individuals produce a high number of children. It's also worth noting that during reproduction, recombination of each ancestor's positive traits can result in "best-fit" kids who are more fit than their parents. Species evolve naturally through generations to become more and more adapted to their surroundings.

Holland expanded on this concept in his 1975 book, "Adaptation in Natural and Artificial Systems." He developed the first genetic algorithms by describing how to apply the principles of natural evolution to optimisation issues. Holland's idea has since been refined, and genetic algorithms (GAs) have emerged as a useful tool for solving search and optimisation issues. Genetic algorithms are based on genetic and evolutionary principles.

The power of mathematics rests in the transfer of technology. There are specific models and procedures that may be used to describe a wide range of phenomena and solve a large range of problems. GA is an example of mathematical technology transfer since it can address optimisation issues from a variety of sources by simulating evolution. GA is now used to handle complex optimisation problems such as timetabling. job shop scheduling, games playing.

2.1.1. Explanation of genetic algorithm terms

Genetic algorithms are search algorithms based on natural selection and natural genetic notions (Table 1). The Genetic Algorithm was created to imitate some of the processes seen in natural evolution, which are chromosome-based processes (organic devices for encoding the structure of living beings). The genetic algorithm differs from other search algorithms in that it searches a population of points and uses the coding of parameter sets instead of the parameter values themselves. It also makes use of objective function data without any gradient data.

The genetic algorithm's transition scheme is probabilistic, whereas previous approaches rely on gradient information. Genetic algorithms are utilised as general-purpose optimisation algorithms because of these characteristics. They also provide a way to search irregular spaces, and as a result, they're used in a wide range of function optimisation, parameter estimation, and machine learning applications.

Table 1 Genetic algorithm terms.

Genetic algorithms	Explanations
Chromosome (String, Individual)	Solution (Coding)
Genes (Bits)	Part of solution
Locus	Position of gene
Alleles	Value of gene
Phenotype	Decoded solution
Genotype	Encoded solution

2.1.2. Basic principle of GA

Figure 1 depicts the operating principle of a canonical GA. The formation of a population of solutions, the determination of the objective function and fitness function, and the use of genetic operators are the main processes. These aspects are briefly outlined below.

```
/* Algorithm GA */
Create a beginning population.
Initialize the population at random.
Repeat
Examine the function of the objective
Look for a fitness function
Make use of genetic operators
Reproduction
Crossover
Mutation
Until stopping criteria
```

Figure 1 A Simple Genetic Algorithm's working principle.

2.2. Components of Genetic Algorithms

An algorithm is a set of instructions for completing a task. A genetic algorithm is a problem-solving strategy that employs genetics as a problem-solving model. It's a search method for estimating solutions to optimisation and search problems. In essence, an optimisation problem appears to be quite straightforward. All viable solutions to a certain question are known in their own form. The search space is made up of all the solutions that fulfil these criteria. From all the various answers, the difficulty is to discover the one that fits the best, i.e., the one with the highest payoffs. The problem does not present a significant challenge if all of the answers can be rapidly enumerated. However, as the search space grows larger, enumeration becomes impractical since it would take far too long. To identify the best solution, you'll need to use a specific technique. One of these ways is through genetic algorithms. They all work in the same way in practice, adapting simple genetics to algorithmic mechanics.

GA manages a large number of potential options. A chromosome, which is essentially an abstract representation, is used to represent each solution. The initial, and probably not the most basic, step of a genetic algorithm is coding all possible answers onto a chromosome. In addition, a set of reproduction operators must be determined. Reproduction operators are used to perform mutations and recombination over issue solutions by applying them directly to the chromosomes. Appropriate representation and reproduction operators are vitally important, as the GA's behaviour is heavily reliant on them. Finding a representation that respects the structure of the search space and reproduction operators and is coherent and relevant according to the features of the problems can be quite difficult.

Selection should be able to compare each person in the population. A fitness function is used to make the selection. Each chromosome has a value linked to it that corresponds to the solution's fitness. The fitness should be based on a rating of the potential solution's quality. The solution that maximises the fitness function is the best. Genetic algorithms are used to solve problems involving maximisation of the fitness function. However, if the problem is to minimise a cost function, the adaptation is rather simple. Either the cost function can be converted to a fitness function, such as by inverting it, or the selection can be altered in some way.

Once reproduction and fitness functions have been specified, a genetic algorithm with the same fundamental structure is evolved. It all begins with the creation of a chromosomal population. This initial population must contain a wide range of genetic material. The gene pool should be as large as possible in order to generate any solution to the search space. The starting population is usually produced at random.

The genetic algorithm then goes through an iteration phase to evolve the population. The steps in each iteration are as follows:

1. Selection
2. Crossover
3. Mutation

2.2.1. Selection of Genetic Algorithms method

In nature, the person with the best survival skills will live for a longer period of time. As a result, it has a better probability of producing offspring using its genetic material. As a result, over time, the entire population will have more genes from outstanding individuals and fewer genes from inferior individuals. In other ways, the fittest lived while the unfit perished. Natural selection is the name given to this natural force.

A fraction of the existing population is chosen to breed a new generation throughout each succeeding generation. Individual solutions are chosen based on their fitness, with fitter solutions (as assessed by a fitness function) being more likely to be chosen.

Certain methods of selection rate the fitness of each answer and select the better options first. Because this process might be time-consuming, other approaches only rate a random sample of the population. The majority of functions are stochastic and designed to select a small percentage of less-suited solutions. This keeps the population's diversity high, preventing premature convergence on bad solutions. Roulette wheel selection and tournament selection are two popular and well-studied selection strategies.

Individuals are chosen for reproduction in a population based on their fitness levels. A probability rule states that the higher an individual's fitness, the more probable he or she will be chosen. A weighted roulette wheel, sorting algorithms, proportionate reproduction, and tournament selection are only a few of the ways accessible.

2.2.2. Crossover

Single-point crossover is the most common form. In single-point crossover, you pick a locus where the residual alleles from one parent are switched to the other. This is a complicated subject that is best comprehended graphically. As you can see, the offspring inherit one chromosomal segment from each parent. The randomly chosen crossover point determines the point at which the chromosome breaks.

Because there is only one crossover point, this method is known as single-point crossover. Occasionally, just offspring 1 or offspring 2 is produced, but more frequently, both offspring are produced and introduced into the new population. However, crossover does not always happen. No crossover occurs occasionally, based on a predetermined chance, and the parents are copied directly into the new population. The likelihood of crossover is normally between 60% and 70%, e.g.

2.2.3. Mutation

Now a fresh population of people is generated after selection and crossover. Some are directly replicated, while others are created by a crossover process.

Allow for a modest probability of mutation to ensure that the individuals are not all precisely the same. If an allele is selected for mutation, you can either change it by a modest amount or replace it with a new value by looping through all the alleles of all the individuals. The chances of a mutation are usually between one and two tenths of a percent.

Mutation is a straightforward process. You simply change the selected alleles according to your needs and carry on. Mutation, on the other hand, is essential for maintaining genetic diversity within a population. e.g.

2.3. Case Study

The Jayakwadi project is situated on the River Godavari in Aurangabad, Maharashtra, India. Its headworks are in Paithan village in Aurangabad district of Maharashtra, at 180 46’ N latitude and 75020’ E longitude. The location map of the Jayakwadi project is shown in Fig. 2, where the catchment area of the Jayakwadi project is demarcated. The climate of the area is subtropical and semi-arid. The average relative humidity for the period from July to September remains above 80%, whereas for April to June it is 65%. The evaporation loss for the project is 22.40 TMC per year. The average annual rainfall of the study area is 754.38 mm, out of which 680.72 mm falls from June to October. The cultivable command area (CCA) of the project (stage 1) is 1,83,640 ha. The suitable crop pattern and cultivation pattern are given in Tables 2 and 3, respectively.

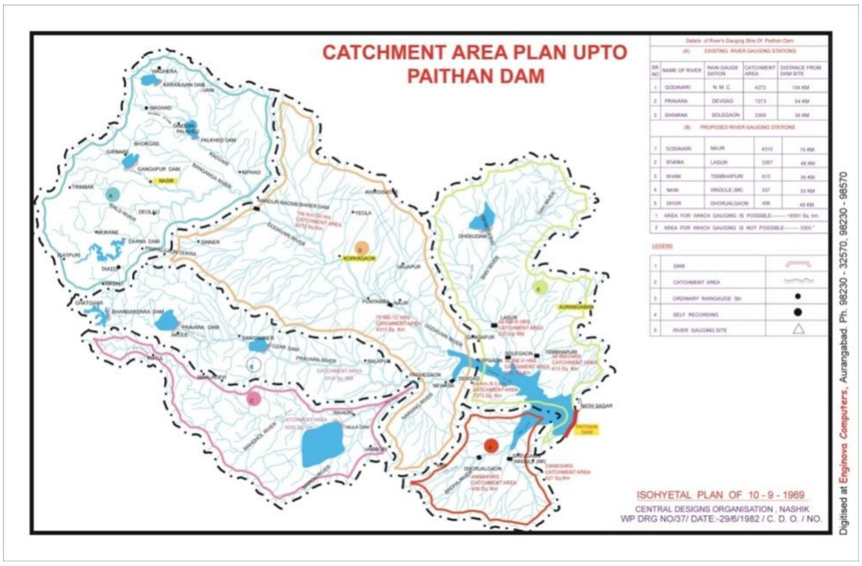

Figure 2 Catchment area of Jayakwadi project.

Table 2 Crop pattern.

Sr.No.	Crops	%	Paithan Left Bank Canal
1	Sugarcane	3	4,250
2	Other Perennials	1.5	2,125
3	Rice	5	7,082
4	L.S.Cotton	37.5	53,114
5	Rabi	51	72,236
6	H.W. Seasonals	2	2,333
	TOTAL:	100%	1,41,640 ha

Table 3 Cultivation pattern.

Sr.No.	Crop	Percentage
1	Rice	0.65
2	Wheat	5
3	Cane	0.26
4	Kharif Jawar	10.77
5	Rabi Jawar	43.7
6	Bajari	6.25
7	Maize	0.02
8	Other Kharif (Barli, Nachani, Wari, Sawa)	0.48
9	Gram	3.42
10	Other T.S. (Tobaco etc.)	0.01
11	Ground Nut	5.47
12	Other Oil seeds	1.66
13	Cotton	19.26
14	Pulses	3.68
	TOTAL:	100

2.4. Model formulation of crops

The objective of this study is to maximize revenue from the available constraints, i.e., from available land and water for irrigation. The crops grown in the command area are listed out and assigned with the variables of area in ha (Table 4), such as "X1" for sugarcane.

Table 4 List of crops with variables.

Sr.No.	Crop	Variable (ha)
1	Sugarcane (T.S.)	X_1
2	Gram (R)	X_2
3	Wheat (R)	X_3
4	Cotton (T.S.)	X_4
5	Paddy (R)	X_5
6	Banana (T.S.)	X_6
7	Hy. Jawar (R)	X_7
8	Ground Nut (R)	X_8
9	Hy. Jawar (K)	X_9
10	Chillies (T.S.)	X_{10}

It is important to optimize net revenues (NR) from the command area's various crops. By subtracting the production costs from the overall revenue realized from the crop on a unit area basis, the net benefit is determined. Costs for labor, fertilizer, water, crop output, and crop value are acquired from secondary sources for this purpose. Independent of the length of the crop season, net benefits from each of these crops are calculated through Eq. 1 separately.

$$N.R. = \sum_{i}^{10} NB_i A_i \tag{1}$$

Where N.R. is the net revenue from the crop, NBi is the net benefit from the cultivation of different crops in rupees, and Ai is the area of crop grown in the command area (ha).

Inflows, storage, release, and spills are all part of the reservoir's operating continuity. Eq. 2 Canal networks transport water from the reservoir to the farm fields in order to meet the needs for irrigation. The reservoir operation continuity equation can be written as

$$St+1 = St + It - Rt - Spillt \qquad t = 1, 2, ...12 \tag{2}$$

Where S_{t+1} = reservoir storage in the reservoir at the end of month t (Mm^3); I_t = inflows into the reservoir during the month t; R_t = releases from the reservoir during the month t (Mm^3); and Spillt stands for spill from the reservoir during the month t (Mm^3).

The cultivable command area (CCA) should not exceed the cropped area allotted for various crops in the command area during a given season. Based on the sum of monthly pan evaporation and the consumptive use coefficient, crop water needs (EvapoTranspiration, ET) are calculated with Eqs. 3 and 4. Effective rainfall can either completely or partially meet these needs.

$$\sum_{i} A \le CCA \tag{3}$$

i = 1, 4, 6, 9 for Kharif season
i = 2,3,4,5,6,7,8 and 10 for Rabi season

$$\sum_{i}^{10} D_i A_i \le TWAR \tag{4}$$

Where Di is the depth of water required depending upon the net irrigation for the base period (in m), Ai is the area of crop grown in the command area (ha), and TWAR is the total water available for irrigation for the entire season. The two cases for this constraint are considered in this study. Case-I is maximizing revenue, subjected to area constraints and water availability constraints, of the Jayakwadi project, considering the diversion of 350 Mm^3 from Jayakwadi stage I to stage II as per agreement. Case-II is maximizing revenue, subjected to area constraints and water availability constraints, of the Jayakwadi project, considering the diversion of 560 Mm^3 from Jayakwadi stage I to stage II as per agreement.

Reservoir storage volume S_t in any month t should be less than or equal to the storage capacity of the reservoir (Eq.5).

$$S_t \le SC \qquad \text{for } t = 1,2,3......12 \tag{5}$$

Given that the command area is in a location where agriculture plays a major role in the economy, planners must ensure that cash crops, in addition to food crops, are produced. The minimum and maximum allowed areas are determined by the population's needs for food in the command area. Information about this is based on the current cropping pattern, reports, conversations with irrigation and agricultural department officials, and the Command Area Development Authority (Eq. 6 and Eq. 7).

$$A \geq \min(A_i) \qquad i = 1, 2, \dots \dots \dots 10 \tag{6}$$

$$A \min \leq (A_i) \qquad i = 1, 2, \dots \dots \dots 10 \tag{7}$$

Where min (A_i) and max (A_i) are minimum and maximum values for crop area.

2.5. Determination of Genetic Algorithm parameters

The irrigation planning problem is solved using both genetic algorithms (GA) and linear programming (LP). In this case, the value of the fitness function is equal to the objective function. Since GA is dependent on various parameters such as population, generations, cross-over, and mutation probabilities, various combinations are tried. To conserve space, only a selected set of results is presented. Nineteen values of crossover probability, viz., from 0.1 to 1.0 with an interval of 0.05, and six values of mutation probabilities, viz., 0.01, 0.03, 0.05, 0.07, 0.1, and 0.12, are chosen with a population size of 100 and a maximum number of generations of 200. The maximum fitness function values are obtained for the above mutations and crossover probabilities. The results obtained are presented in terms of total fitness function values in the graphs below. It is observed from graphs that for a mutation probability value of 0.12 and for various crossover probabilities, each solution maintains its identity as being different from other sets of solutions. Among these, the maximum fitness function value of 4.488 million rupees is achieved for a crossover probability of 0.9 and a mutation probability of 0.12, and this combination is used for further analysis. The termination criterion is set to perform 200 generations of GA simulation, i.e., the program will terminate with the 200th generation. Efforts are also made to compare the solution of the Genetic Algorithm (GA) with the Linear Programming (LP) algorithm. Cropping patterns obtained by both methods are presented in the below model results. A graphic representation of the fitness function value against crossover probability for various mutation values is given in Figure 2 to figure 8.

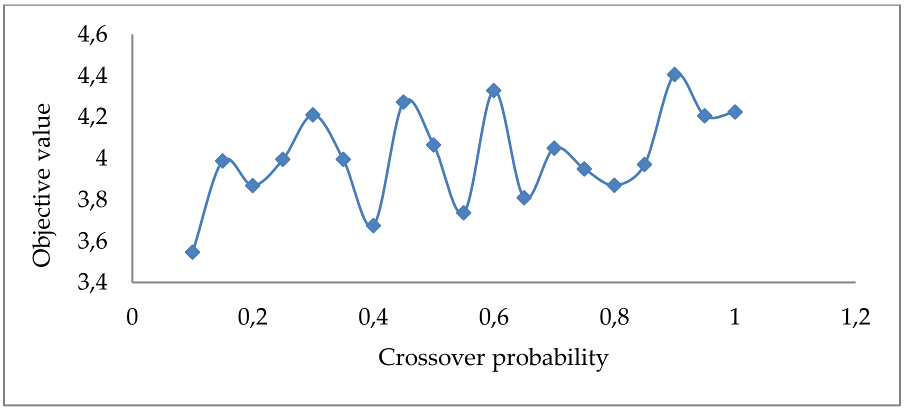

Figure 2 Mutation probability 0.01.

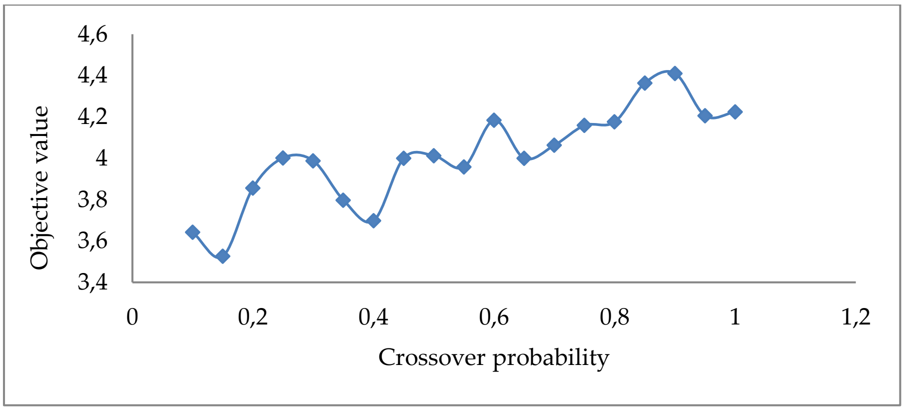

Figure 3 Mutation probability 0.03.

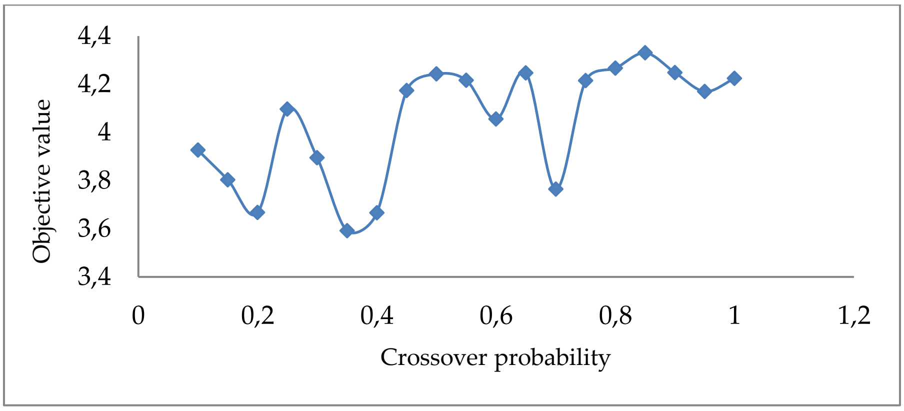

Figure 4 Mutation probability 0.05.

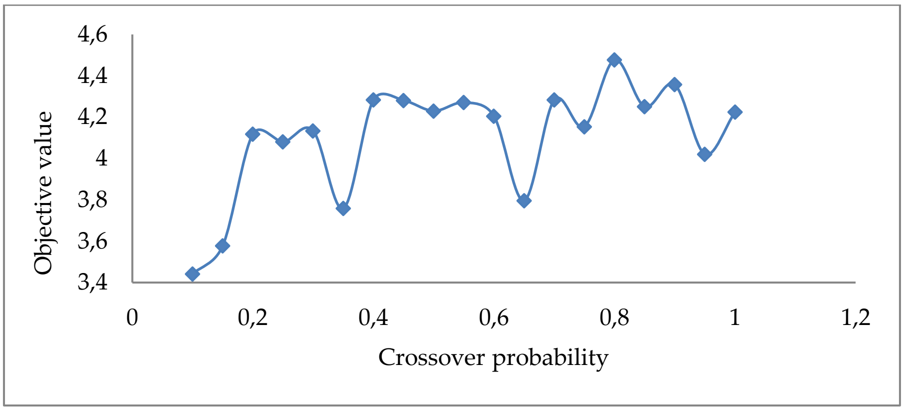

Figure 5 Mutation probability 0.07.

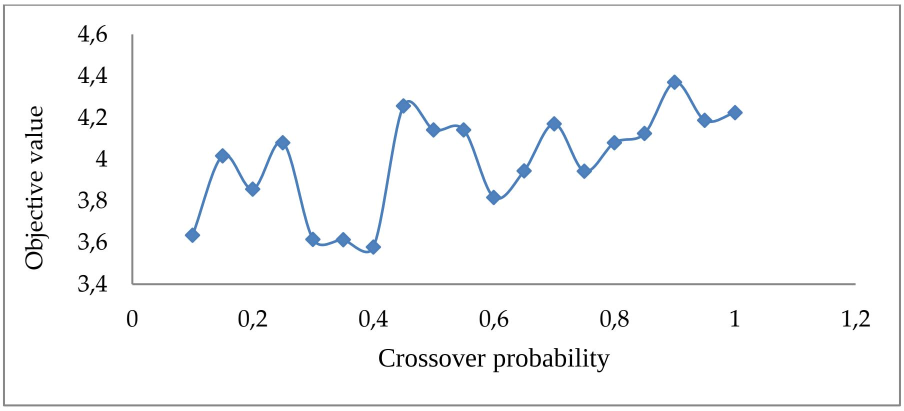

Figure 6 Mutation probability 0.1.

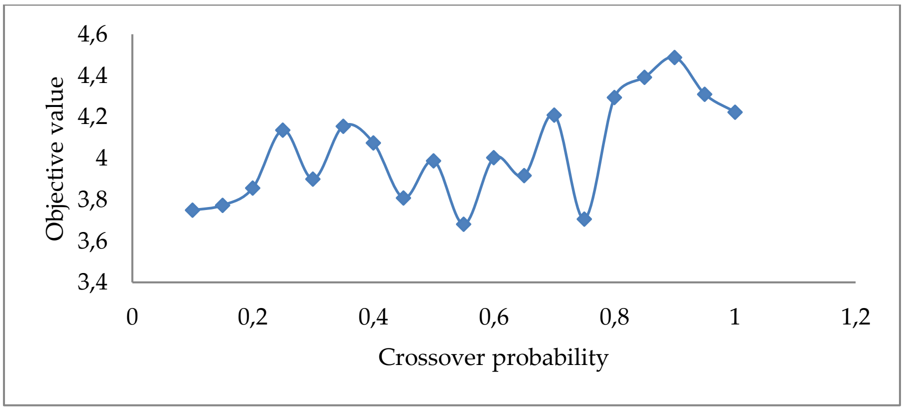

Figure 7 Mutation probability 0.12.

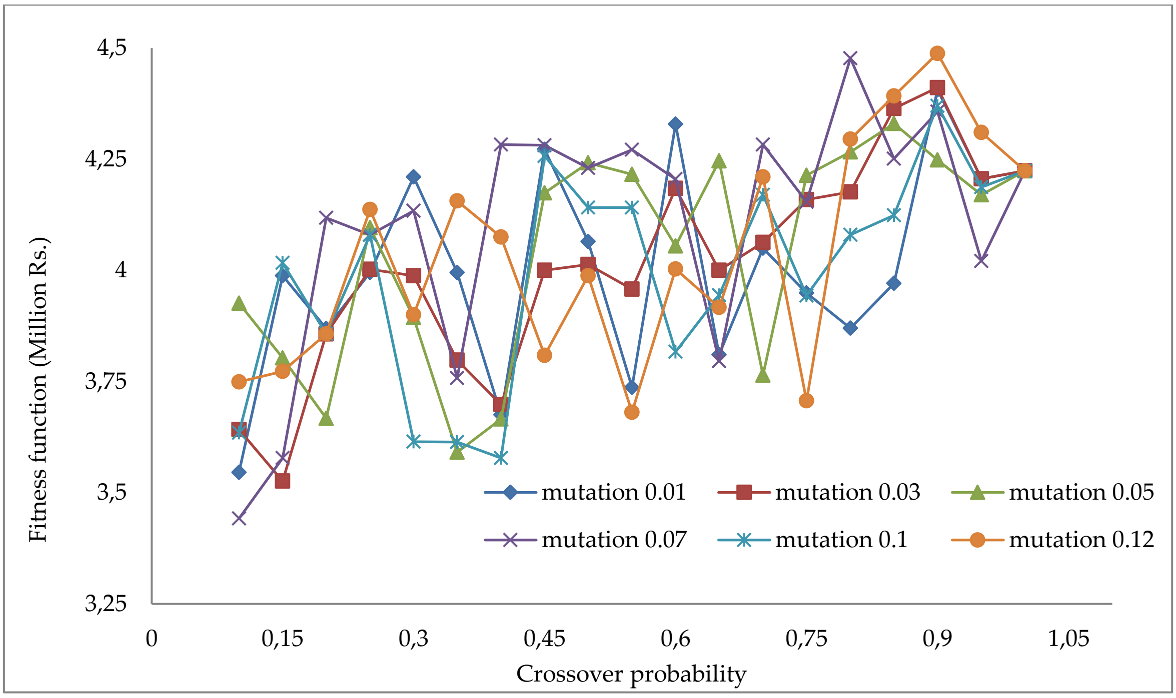

Figure 8 Comparison of fitness function values for various crossover and mutation probabilities.

3. Results and discussions

The objective of this study is to maximize revenue from the available constraints, i.e., from available land and water for irrigation. For this, the Jayakwadi project, Maharashtra, is taken as a case study. The water availability in Jayakwadi stage I depends on the diversion from the right bank canal to the Jayakwadi stage II project, i.e., Majalgaon dam. As per the project report, in an average rainfall year, the diversion of 350 Mm3 is assured from stage I to stage II. Also, when stage II is short of storage in a bad year, the maximum diversion of 560 Mm3 is assured. These two cases are considered for deciding the optimal cropping pattern and maximizing revenue from the Jayakwadi project. The model is formulated based on these two cases and solved using LINGO programming and genetic algorithms.

As per Jain et al. (2021), Telangana uses algorithms for harvests. Telangana has 49.61 lakh net cultivated acres. Crop planning considers Telangana's eight major crops: rice, maize, sugarcane, jowar, groundnut, cotton, sunflower, and chilli. Uses fertilizer adjustment equations to evaluate crop output and input fertilizers to maximize crop net return and decrease fertilizer use. Season and soil type affect crop yield and fertilizers. Major Telangana crops, crop variety, soil type, and season demonstrate fertilizer adjustment formulae. Crop planning boosts profits and cuts fertilizer use year after year. Rabi and Kharif crops are produced on distinct land since crop yield varies by season. Sugarcane uses one cropping area annually. The crop planning model features 15 option variables, including two area variables for each Rabi and Kharif crop (excluding sugarcane). (Jain et al., 2021) define the crop planning issue model and show how CSA, PSO, and a hybrid CSA-PSO algorithm may solve it.

3.1. CASE I: diversion of 350 Mm^3 from stage I to stage II

For the first case, the model is solved considering water availability of 100%, 90%, 80%, and 70%. Results are shown in Tables 5 and 6. A comparison of the results of LP and genetic algorithms is also discussed in Table 7. The comparison of results is also shown graphically in figures 9, 10, 11, and 12 for 100%, 90%, 80%, and 70%, respectively. From the results, it is seen that the optimized area for different crops and total revenue changes for 80% and 70% water availability. Therefore, even if there is a reduction of 10% in water availability, maximized revenue can be obtained from the project. The objective value for 100% and 90% water availability is Rs. 4.54 million and Rs. 4.52 million, respectively, by the linear programming method, and the objective value for 100% and 90% water availability is Rs. 4.48 million by the genetic algorithm. The deviation of 1.32% is observed from the results of GA with LINGO for 100% water availability. For a reduction in water availability of up to 30%, the objective value reduces to Rs. 4.36 million by LINGO, and the GA is 4.48 million.

3.1.1. Optimal Cropping Pattern for Varying Water Availability

The model formulated for Case I Considering diversion of 350 Mm^3 from Jayakwadi stage I to stage II is then solved in LINGO and results obtained are in Table 5.

Table 5 Optimal cropping pattern by Linear Programming case I.

Sr.No.	Variable	Crop	Area in ha (For Water Availability 100%)	Area in ha (For Water Availability 90%)	Area in ha (For Water Availability 80%)	Area in ha (For Water Availability 70%)
1	X_1	Sugarcane (T.S.)	4249.2	4249.2	4149.387	---
2	X_2	Gram (R)	7082	5785.066	---	---
3	X_3	Wheat (R)	35410.3	35410.3	35410.3	35410.3
4	X_4	Cotton (T.S.)	35410.3	35410.3	35410.3	35410.3
5	X_5	Paddy (R)	14164.1	14164.1	14164.1	14164.1
6	X_6	Banana (T.S.)	2124.6	---	---	---
7	X_7	Hy. Jawar (R)	21246.2	21246.2	21246.2	19822.4
8	X_8	Ground Nut (R)	4249.2	4249.2	---	---
9	X_9	Hy. Jawar (K)	16996.9	16996.9	16996.9	16996.9
10	X_{10}	Chillies (T.S.)	4249.2	4249.2	4249.2	4249.2
	Net cropped area (ha)		145180	141760.466	131626.387	126053.2
	Net revenue (Rs)		4542425	4523085	4465337	4363784
	Water used (ha.m)		67039.3	60335.37	53631.44	46927.51

3.1.2. Interpretation of the results by LINGO

The model is formulated for the Jayakwadi project on the Godavari River at Paithan in case I, i.e., considering a diversion of 350 Mm^3 as per the agreement made with the government of Maharashtra. The available water for the irrigation scheme is manipulated as 670.39 Mm^3. The model is then run in LINGO for the results using the linear method. The sensitivity analysis has also been carried out for the reduction of water by 10%, 20%, and 30%. The results obtained are tabulated in the above Table 5.

For the first condition, when the water availability is 100%, the maximum revenue obtained is 4.54 million rupees, and the net cropped area is 145180 Ha. All crops on the list get the maximum area, and none of the crops got eliminated as the water available was 100%. For the second condition, when the available water is 90%, the maximum revenue obtained is 4.52 million rupees, and the net cropped area is 141760.466 Ha. As the available water has been reduced for irrigation, the banana crop has been eliminated; all other crops remained unaffected and got the maximum area. For the third condition, when the available water is 80%, the maximum revenue obtained is 4.46 million rupees, and the net cropped area is 131626.387 Ha. As the available water has been reduced for irrigation, the Gram, Banana, and Ground Nut crops have been eliminated; all other crops remained unaffected and got the maximum area. For the fourth condition, when the available water is 70%, the maximum revenue obtained is 4.36 million rupees, and the net cropped area is 126053.2 Ha. As the available water has been reduced for irrigation, the sugarcane, gram, banana, and groundnut crops have been eliminated, and there is a slight reduction in the area of HY. Jawar (R), while all other crops remained unaffected and got the maximum area. The model made for Case I, which takes into account the 350 Mm^3 that was moved from Jayakwadi Stage I to Stage II, is then solved in GA. The results are shown in Table 6.

Table 6 Optimal cropping pattern by Genetic Algorithm case I.

Sr.No	Variable	Crop	Area in ha (For Water Availability 100%)	Area in ha (For Water Availability 90%)	Area in ha (For Water Availability 80%)	Area in ha (For Water Availability 70%)
1	X_1	Sugarcane (T.S.)	4249.2	4249.2	4249.2	4248.994
2	X_2	Gram (R)	0.881	0.881	0.712	---
3	X_3	Wheat (R)	35410.3	35410.3	35410.3	35409.09
4	X_4	Cotton (T.S.)	35410.3	35410.3	35410.3	35410.284
5	X_5	Paddy (R)	14164.1	14164.1	14164.1	14159.901
6	X_6	Banana (T.S.)	0.972	0.972	0.923	---
7	X_7	Hy. Jawar (R)	21246.2	21246.2	21246.193	21246.027
8	X_8	Ground Nut (R)	4249.2	4249.2	4249.199	4246.278
9	X_9	Hy. Jawar (K)	16996.9	16996.9	16996.9	16995.076
10	X_{10}	Chillies (T.S.)	0.968	0.968	0.823	0.919
	Net cropped area (ha)		131729.021	131729.021	131728.65	131716.569
	Net revenue (Rs)		4488267.481	4488267.481	4488265.968	4488147.622
	Water used (ha.m)		67039.3	60335.37	53631.44	46927.51

3.1.3. Interpretation of the results by GA

The model is then run in the GA for the results using the genetic algorithm method. The sensitivity analysis has also been carried out for the reduction of water to 10%, 20%, and 30%. The results obtained are tabulated in the above Table 6.

For the first condition, when the water availability is 100%, the maximum revenue obtained is 4.48 million rupees, and the net cropped area is 131729.021 Ha. All crops in the list get their respective areas, and none of the crops got eliminated as the water available was 100%.

For the second condition, when the available water is 90%, the maximum revenue obtained is 4.48 million rupees, and the net cropped area is 131729.021 Ha. Although the available water has been reduced for irrigation, none of the crops get affected and get the same areas as those with 100% water availability.

For the third condition, when the available water is 80%, the maximum revenue obtained is 4.48 million rupees, and the net cropped area is 131728.65 Ha. As the available water has been reduced for irrigation, a slight reduction in the areas of some crops, such as Gram, Banana, and Chilli, is observed; all other crops remained unaffected and got the maximum area.

For the fourth condition, when the available water is 70%, the maximum revenue obtained is 4.48 million rupees, and the net cropped area is 131716.569 Ha. As the available water has been reduced for irrigation, the Gram and Banana crops have been eliminated, and a slight change in the areas of sugarcane, wheat, and paddy has been observed. All other crops remained unaffected and got the maximum area.

3.1.4. Comparison of results of LINGO and GA for 70% water availability

The results obtained from LINGO and GA for 70% water availability are then compared with each other in Table 7 shown below.

The comparison of results obtained by LINGO and GA for water availability of 70% analyzed as the Linear method eliminates Sugarcane, Gram, Banana and Ground Nut and also reduces revenue to 4.36 million Rs and the net area cropped to 126053.2 Ha. Whereas GA eliminates only Gram and Banana and able to maintain revenue at 4.48 million Rs and net cropped area at 131729.021 Ha. Therefore, the GA is found out as more efficient tool to solve the model as compared to traditional Linear Programming method. The graphical comparison of varying water availability (from 100% to 70%) results are presented below in Figure 9 to Figure 12.

Table 7 Comparison of crop pattern by LINGO and GA case I.

Sr.No.	Variable	Crop	Area in ha (By LINGO)	Area in ha (By GA)
1	X_1	Sugarcane (T.S.)	---	4248.994
2	X_2	Gram (R)	---	---
3	X_3	Wheat (R)	35410.3	35409.09
4	X_4	Cotton (T.S.)	35410.3	35410.284
5	X_5	Paddy (R)	14164.1	14159.901
6	X_6	Banana (T.S.)	---	---
7	X_7	Hy. Jawar (R)	19822.4	21246.027
8	X_8	Ground Nut (R)	---	4246.278
9	X_9	Hy. Jawar (K)	16996.9	16995.076
10	X_{10}	Chillies (T.S.)	4249.2	0.919
	Net cropped area (ha)		126053.2	131729.021
	Net revenue (Rs)		4363784	4488267.481
	Water used (ha.m)		46927.51	67039.3

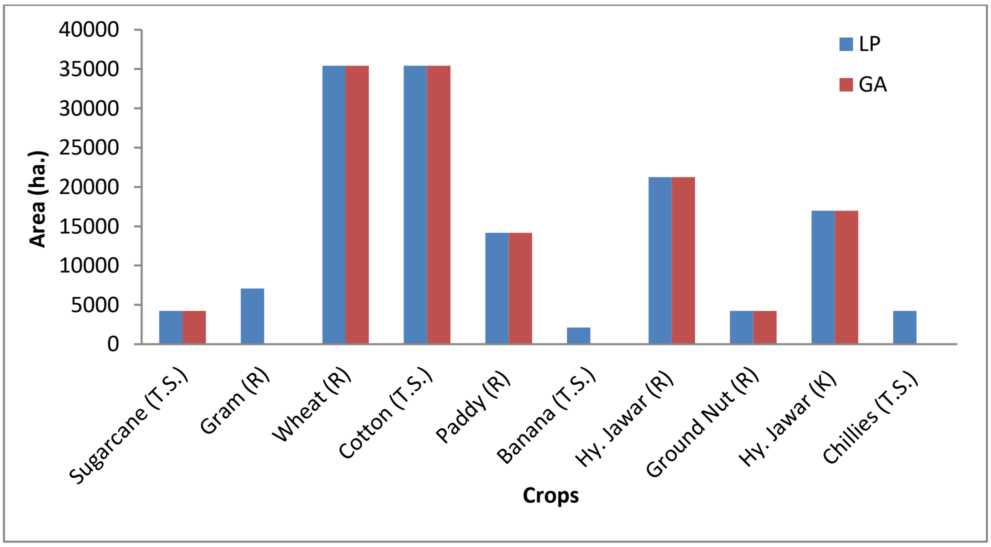

Figure 9 Cropping pattern for 100% water availability for case I.

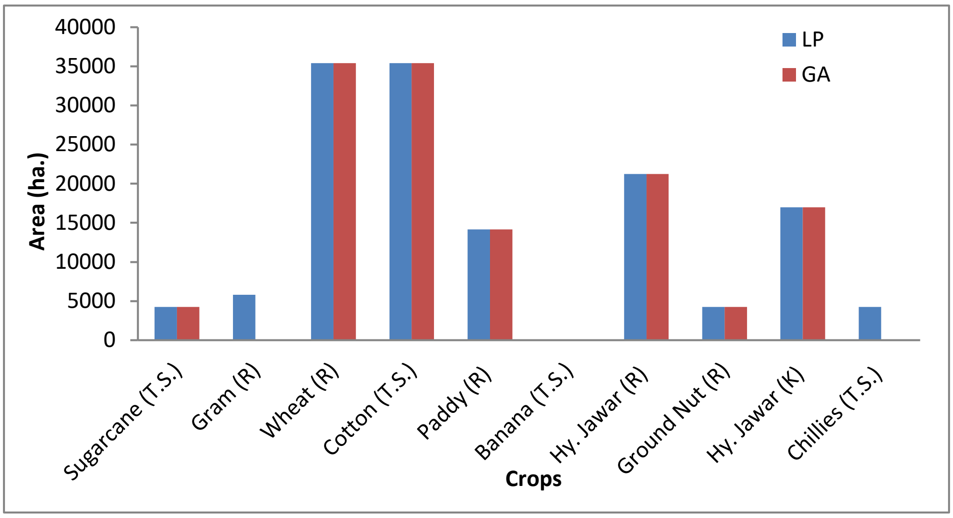

Figure 10 Cropping pattern for 90% water availability for case I.

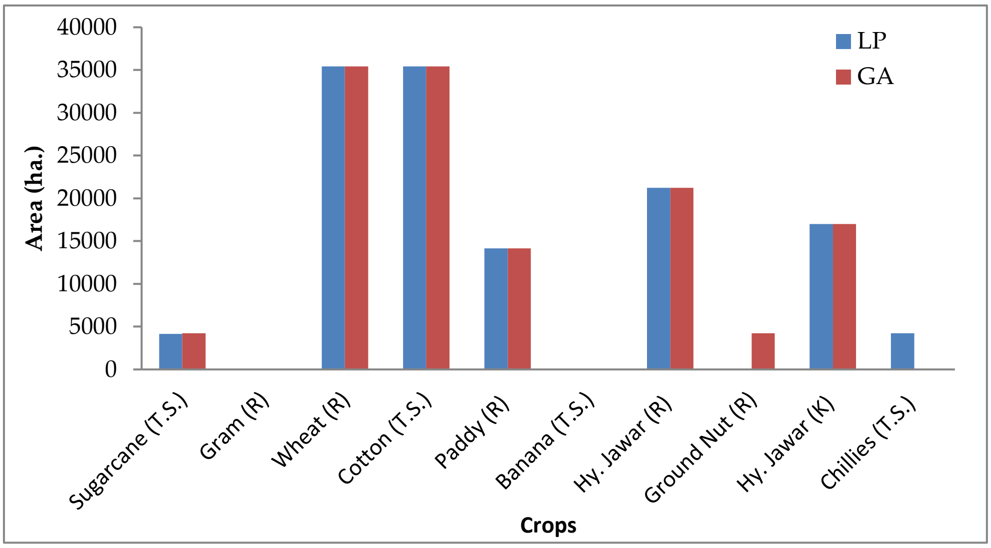

Figure 11 Cropping pattern for 80% water availability for case I.

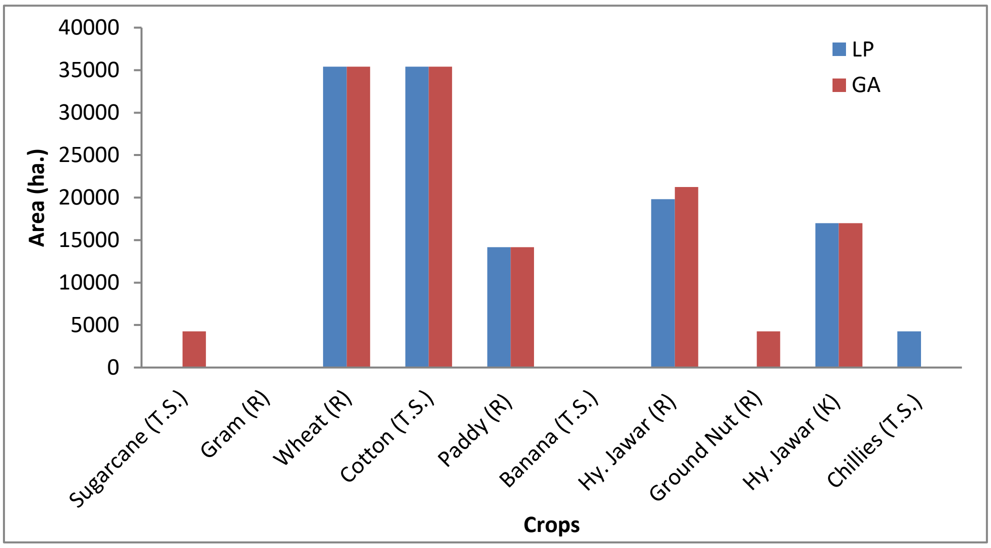

Figure 12 Cropping pattern for 70% water availability for case I.

3.2. CASE II: Diversion of 560 Mm^3 from stage I to stage II

For the second case, the model is solved considering water availability of 100%, 90%, 80%, and 70%. Results are shown in Tables 8 and 9. Also, a comparison of the results of LP and genetic algorithms is discussed in Table 10. The comparisons of results are also shown graphically in figures 13, 14, 15, and 16 for 100%, 90%, 80%, and 70%, respectively. From the results, it is seen that the optimized area for different crops and total revenue changes for 80% and 70% water availability. Therefore, even if there is a reduction of 10% in water availability, maximized revenue can be obtained from the project. The objective values for 100% and 90% water availability are Rs. 4.54 million and Rs. 4.27 million, respectively, by the linear programming method, and the objective values for 100% and 90% water availability are Rs. 4.48 million and 4.45 million by the genetic algorithm. The deviation of 1.32% is observed from the results of GA with LINGO for 100% water availability. For a reduction in water availability of up to 30%, the objective value reduces to Rs. 4.11 million by LINGO, and the GA is 4.35 million. For a reduction in water availability, sugarcane, gram and groundnut, banana, Hy. jawar, and chilies areas get affected in the optimal cropping plan.

3.2.1. Optimal Cropping Pattern for Varying Water Availability:

The model formulated for Case II Considering diversion of 560 Mm^3 from Jayakwadi stage I to stage II is then solved in LINGO and results obtained are tabulated in Table 8.

Table 8 Comparison of crop pattern by LINGO and GA case I.

Sr.No.	Variable	Crop	Area in ha (For Water Availability 100%)	Area in ha (For Water Availability 90%)	Area in ha (For Water Availability 80%)	Area in ha (For Water Availability 70%)
1	X_1	Sugarcane (T.S.)	---	---	---	---
2	X_2	Gram (R)	---	---	---	---
3	X_3	Wheat (R)	35410.3	35410.3	35410.3	35410.3
4	X_4	Cotton (T.S.)	35410.3	35410.3	35410.3	35410.3
5	X_5	Paddy (R)	14164.1	14164.1	14164.1	10801.95
6	X_6	Banana (T.S.)	---	---	---	---
7	X_7	Hy. Jawar (R)	18435.46	11246.29	4057.146	---
8	X_8	Ground Nut (R)	---	---	---	---
9	X_9	Hy. Jawar (K)	16996.9	16996.9	16996.9	16996.9
10	X_{10}	Chillies (T.S.)	4249.2	4249.2	4249.2	---
	Net cropped area (ha)		124666.26	117477.09	110287.946	98619.45
	Net revenue (Rs)		4349739	4276951	4204161	4117278
	Water used (ha.m)		46039.31	41435.37	36831.44	32227.51

3.2.2. Interpretation of the results by LINGO

The model is formulated for the Jayakwadi project on the Godavari River at Paithan for case II, i.e., considering a diversion of 560 Mm^3 as per the agreement made with the Government of Maharashtra. The available water for the irrigation scheme is manipulated as 460.39 Mm^3. The model is then run in LINGO for the results using the linear method. The sensitivity analysis has also been carried out for the reduction of water by 10%, 20%, and 30%. The results obtained are tabulated in the above Table 8. For the first condition, when the water availability is 100%, the maximum revenue obtained is 4.34 million rupees, and the net cropped area is 124666.26 Ha. As the available water is less for irrigation, the sugarcane, gram, banana, and groundnut crops have been eliminated, causing a slight change in the area of HY. Jawar is observed; all other crops remained unaffected and got the maximum area. For the second condition, when the available water is 90%, the maximum revenue obtained is 4.27 million rupees, and the net cropped area is 117477.09 Ha. As the available water is less for irrigation, the sugarcane, gram, banana, and groundnut crops have been eliminated, resulting in a reduction in the area of HY. Jawar is observed; all other crops remained unaffected and got the maximum area.

For the third condition, when the available water is 80%, the maximum revenue obtained is 4.20 million rupees, and the net cropped area is 110287.946 Ha. As the available water is less for irrigation, the sugarcane, gram, banana, and groundnut crops have been eliminated, and a reduction in the area of HY. Jawar is observed. All other crops remained unaffected and got maximum area. For the fourth condition, when the available water is 70%, the maximum revenue obtained is 4.11 million rupees, and the net cropped area is 98619.45 Ha. As the available water is less for irrigation, the sugarcane, gram, banana, groundnut, HY. jawar, and chilly crops have been eliminated. Paddy crop areas get slightly reduced; others remain unaffected. The model made for Case II, which takes into account the 560 Mm^3 that was moved from Jayakwadi stage I to stage II, is then solved in GA. The results are shown in Table 9.

Table 9 Optimal cropping pattern by Genetic Algorithm case II.

Sr.No.	Variable	Crop	Area in ha (For Water Availability 100%)	Area in ha (For Water Availability 90%)	Area in ha (For Water Availability 80%)	Area in ha (For Water Availability 70%)
1	X_1	Sugarcane (T.S.)	4249.2	4242.702	0.95	4247.126
2	X_2	Gram (R)	0.436	0.861	0.212	0.212
3	X_3	Wheat (R)	35410.3	35410.3	35410.3	35410.3
4	X_4	Cotton (T.S.)	35410.3	35410.3	35410.3	35410.3
5	X_5	Paddy (R)	14164.1	14164.1	14164.1	13954.634
6	X_6	Banana (T.S.)	0.492	0.342	0.658	0.663
7	X_7	Hy. Jawar (R)	21246.2	21246.2	21246.199	21239.261
8	X_8	Ground Nut (R)	4194.369	0.986	0.896	0.94
9	X_9	Hy. Jawar (K)	16996.9	16996.652	16996.739	0.722
10	X_{10}	Chillies (T.S.)	0.894	0.114	0.918	0.498
	Net cropped area (ha)		131673.191	127472.557	123231.06	110264.656
	Net revenue (Rs)		4487801.74	4452437.312	4363361.4	4358755.7
	Water used (ha.m)		46039.31	41435.37	36831.44	32227.51

3.2.3. Interpretation of the results by GA

The model is then run in the GA for the results using the genetic algorithm method. The sensitivity analysis has also been carried out for the reduction of water to 10%, 20%, and 30%. The results obtained are tabulated in the above Table 9. For the first condition, when the water availability is 100%, the maximum revenue obtained is 4.48 million rupees, and the net cropped area is 131673.191 Ha. All crops in the list get their respective areas, and none of the crops got eliminated as the water available was 100%.

For the second condition, when the available water is 90%, the maximum revenue obtained is 4.45 million rupees, and the net cropped area is 127472.557 Ha. The available water has been reduced for irrigation, and a reduction in areas of sugarcane and groundnut has been observed. All other crops on the list remain unaffected.

For the third condition, when the available water is 80%, the maximum revenue obtained is 4.36 million rupees, and the net cropped area is 131728.65 Ha. As the available water has been reduced for irrigation, reductions in the areas of sugarcane have been observed, and slight changes in other crops have also been noticed with respect to 90% results.

For the fourth condition, when the available water is 70%, the maximum revenue obtained is 4.35 million rupees, and the net cropped area is 110264.656 Ha. As the available water has been reduced for irrigation, the change in areas of sugarcane, paddy, and HY. jawar has been observed; all other crops have remained unaffected.

3.2.4. Comparison of results of LINGO and GA for 70% water availability

The results obtained from LINGO and GA for 70% water availability are then compared with each other in Table 10 shown below. The comparison of results obtained by LINGO and GA for water availability of 70% was analyzed as the linear method eliminates sugarcane, gram, banana, HY. jawar, groundnut, and chilly and also reduces revenue to 4.11 million rupees and the net area cropped to 98619.45 ha. Whereas GA eliminates none and is also able to maintain revenue at 4.35 million rupees and net cropped area at 110264.656 ha. So, the GA is found to be a more efficient tool to solve the model as compared to the traditional linear programming method. The graphical comparison of varying water availability (from 100% to 70%) results is presented below in Figure 13 to Figure 16.

Table 10 Comparison of crop pattern by LINGO and GA case II.

Sr.No.	Variable	Crop	Area in ha (By LINGO)	Area in ha (By GA)
1	X_1	Sugarcane (T.S.)	---	4248.994
2	X_2	Gram (R)	---	---
3	X_3	Wheat (R)	35410.3	35409.09
4	X_4	Cotton (T.S.)	35410.3	35410.284
5	X_5	Paddy (R)	14164.1	14159.901
6	X_6	Banana (T.S.)	---	---
7	X_7	Hy. Jawar (R)	19822.4	21246.027
8	X_8	Ground Nut (R)	---	4246.278
9	X_9	Hy. Jawar (K)	16996.9	16995.076
10	X_{10}	Chillies (T.S.)	4249.2	0.919
	Net cropped area (ha)		126053.2	131729.021
	Net revenue (Rs)		4363784	4488267.481
	Water used (ha.m)		46927.51	67039.3

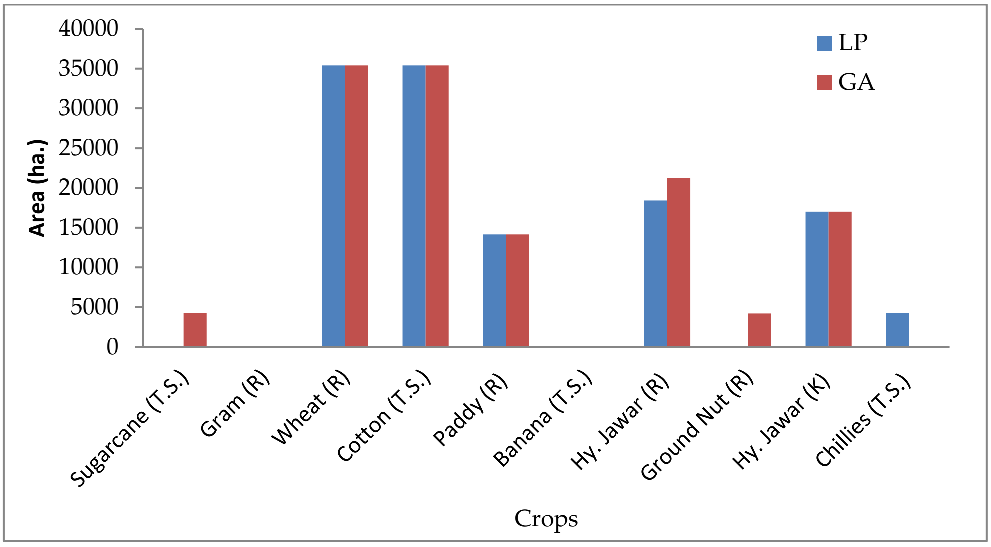

Figure 13 Cropping pattern for 100% water availability for case II.

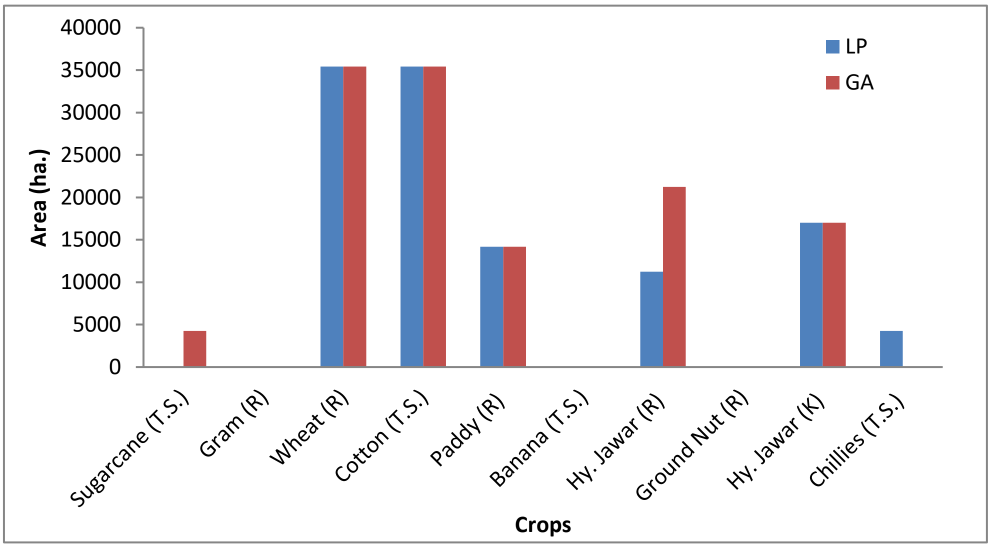

Figure 14 Cropping pattern for 90% water availability for case II.

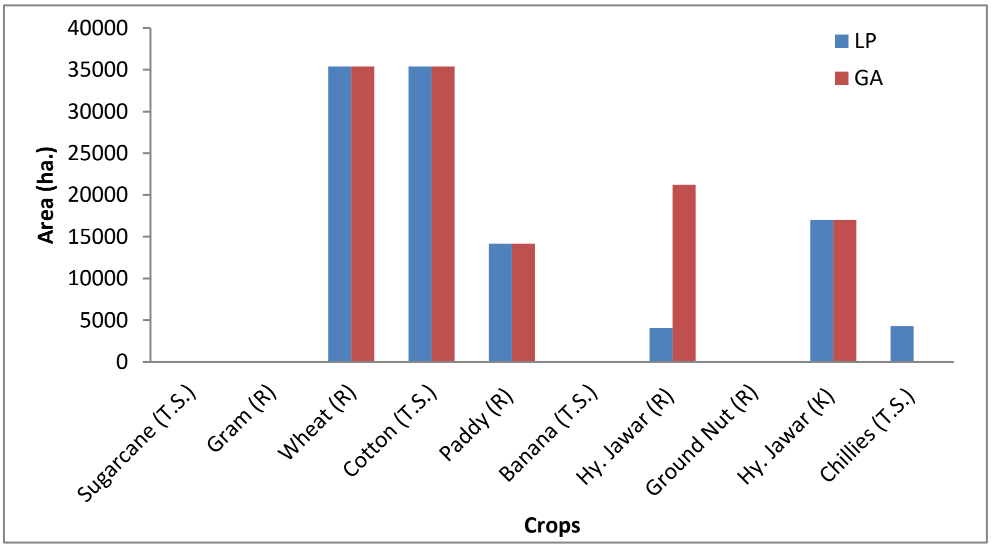

Figure 15 Cropping pattern for 80% water availability for case II.

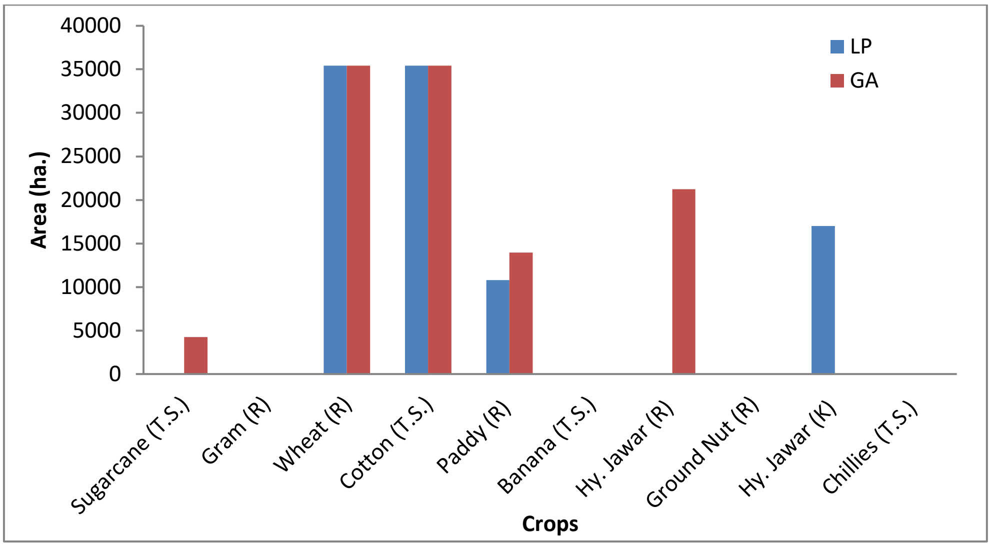

Figure 16 Cropping pattern for 70% water availability for case II.

4. Conclusions

In the present study, a GA-based model is developed for evolving an optimum cropping pattern for the Jayakwadi Project in Aurangabad, Maharashtra, India. The objective is to maximize net revenue with constraints such as continuity equations, land and water requirements, canal capacity, reservoir storage restrictions, and cropping pattern considerations. The results obtained from the GA model are compared with those obtained from the linear programming model. The observations from the study are as follows: The best GA parameters, such as the number of generations, population size, crossover probability, and mutation probability, are to be obtained to get the maximum net benefits from the formulated model. A number of operations were taken with varying crossover and mutation probabilities, and the parameters were then selected to give the maximum revenue value. Those parameters are identified as: number of generations = 200, population size = 100, crossover probability = 0.9, and mutation probability = 0.12.

- After running the formulated model for case-I by doing sensitivity analysis in LINGO and GA for varying water availability from 100% to 70%, the results obtained are then compared.
- For cases I and 100%, 90%, 80%, and 70% water availability, the maximum benefits obtained by the LP solution are 4.54, 4.52, 4.46, and 4.36 million rupees, respectively, whereas these are 4.48 million rupees by GA for all percentages. The net cropped area assigned by LP is 145180 Ha, 141760 Ha, 131626 Ha, and 126053 Ha, respectively, and by GA it is 131729 Ha, 131729 Ha, 131728 Ha, and 131716 Ha, respectively. The deviation observed in the results for benefit is 1.32%, 0.88%, 0.44%, and 2.68%, respectively, and that for net cropped area is 9.26%, 7.07%, 7.74%, and 4.29%, respectively. It is observed that solutions obtained by both GA and LP are reasonably close for 100% water availability, and for 90%, 80%, and 70% water availability, the benefits and cropped area assigned by GA have increased from the results of LP.
- After running the formulated model for case II by doing sensitivity analysis in LINGO and GA for varying water availability from 100% to 70%, the results obtained are then compared.
- For cases II and 100%, 90%, 80%, and 70% water availability, the maximum benefits obtained by the LP solution are 4.34, 4.27, 4.20, and 4.11 million rupees, respectively, whereas these are 4.48, 4.45, 4.36, and 4.35 million rupees, respectively, by GA. The net cropped area assigned by LP is 124666 ha, 117477 ha, 110287 ha, and 98619 ha, respectively, and by GA it is 131673 Ha, 127472 Ha, 123231 Ha, and 110264 Ha, respectively. The deviation observed in the results for benefit is 3.12%, 4.04%, 3.67%, and 5.52%, respectively, and that for net cropped area is 5.32%, 7.84%, 10.50%, and 10.56%, respectively. It is observed that benefits and cropped area allocation have increased by GA from the results of LP for all percentages of water availability.

Genetic algorithms are found to be an effective optimization tool for irrigation planning, and the results obtained are found to be more beneficial than LP results; hence, this technique can be used for other scheduling problems and for more complex systems involving non-linear optimization.

Ethical considerations

Not applicable

Conflict of Interest

All authors have no conflict of interest.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors

References

Mellouli, A., Mellouli, R., & Masmoudi, F. (2019). An Innovative Genetic Algorithm for a Multi-Objective Optimization of Two-Dimensional Cutting-Stock Problem. *Applied Artificial Intelligence, 33*(6). https://doi.org/10.1080/08839514.2019.1583857

Khoshnevisan, B., Bolandnazar, E., Shamshirband, S., Shariati, H. M., Anuar, N. B., & Kiah, M. L. M. (2015). Decreasing environmental impacts of cropping systems using life cycle assessment (LCA) and multi-objective genetic algorithm. *Journal of Cleaner Production, 86*, 67-77. https://doi.org/10.1016/j.jclepro.2014.08.062

Namazzi, C., Sserumaga, J. P., Mugerwa, S., Kyalo, M., Mutai, C., Mwesigwa, R., Djikeng, A., & Ghimire, S. (2020). Genetic Diversity and Population Structure of Brachiaria (syn. Urochloa) Ecotypes from Uganda. *Agronomy, 10*(8), 1193. https://doi.org/10.3390/agronomy10081193

Kumar, D. N., Raju, K. S., & Ashok, B. (2006). Optimal Reservoir Operation for Irrigation of Multiple Crops Using Genetic Algorithms. *Journal of Irrigation and Drainage Engineering, 132*(2). https://doi.org/10.1061/(ASCE)0733-9437(2006)132:2(123)

Ayan, E., Erbay, H., & Varçın, F. (2020). Crop pest classification with a genetic algorithm-based weighted ensemble of deep convolutional neural networks. *Computers and Electronics in Agriculture, 179*, 105809. https://doi.org/10.1016/j.compag.2020.105809

Avramidou, E. V., Koubouris, G. C., Petrakis, P. V., Lambrou, K. K., Metzidakis, I. T., & Doulis, A. G. (2020). Classification Binary Trees with SSR Allelic Sizes: Combining Regression Trees with Genetic Molecular Data in Order to Characterize Genetic Diversity between Cultivars of Olea europaea L. *Agronomy, 10*, 1662. https://doi.org/10.3390/agronomy10111662

Ghasemi, M. M., Karamouz, M., & Shui, L. T. (2016). Farm-based cropping pattern optimization and conjunctive use planning using piece-wise genetic algorithm (PWGA): a case study. *Earth Syst. Environ., 2*, 25. https://doi.org/10.1007/s40808-016-0076-z

Perea, R. G., Poyato, E. C., Montesinos, P., et al. (2016). Optimization of Irrigation Scheduling Using Soil Water Balance and Genetic Algorithms. *Water Resour Manage, 30*, 2815–2830. https://doi.org/10.1007/s11269-016-1325-7

Azamathulla, H. M., Wu, F. C., Ghani, A. A., Narulkar, S. M., Zakaria, N. A., & Chang, C. K. (2008). Comparison between genetic algorithm and linear programming approach for real time operation. *Journal of Hydro-environment Research, 2*(3), 172-181. https://doi.org/10.1016/j.jher.2008.10.001

Villa, I. R., Rodríguez, J. B. M., Molina, J. L., & Tarragó, J. C. P. (2018). Multiobjective Optimization Modeling Approach for Multipurpose Single Reservoir Operation. *Water, 10*(4), 427. https://doi.org/10.3390/w10040427

Raju, K. S., & Kumar, D. N. (2004). Irrigation Planning using Genetic Algorithms. *Water Resources Management, 18*(2), 163–176. https://doi.org/10.1023/B:WARM.0000024738.72486.b2

Katoch, S., Chauhan, S. S., & Kumar, V. (2021). A review on genetic algorithm: past, present, and future. *Multimed Tools Appl, 80*, 8091–8126. https://doi.org/10.1007/s11042-020-10139-6

Munankarmi, N. N., Rana, N., Bhattarai, T., Shrestha, R. L., Joshi, B. K., Baral, B., & Shrestha, S. (2018). Characterization of the Genetic Diversity of Acid Lime (Citrus aurantifolia (Christm.) Swingle) Cultivars of Eastern Nepal Using Inter-Simple Sequence Repeat Markers. *Plants, 7*(2), 46. https://doi.org/10.3390/plants7020046

Nicklow, J. W., Ozkurt, O., & Bringer, J. A. (2003). Control of Channel Bed Morphology in Large-Scale River Networks using a Genetic Algorithm. *Water Resources Management, 17*, 113–132. https://doi.org/10.1023/A:1023609806431

Digna, R. F., Castro-Gama, M. E., Van der Zaag, P., Mohamed, Y. A., Corzo, G., & Uhlenbrook, S. (2018). Optimal Operation of the Eastern Nile System Using Genetic Algorithm, and Benefits Distribution of Water Resources Development. *Water, 10*(7), 921. https://doi.org/10.3390/w10070921

Pereira, R. M. S., Lopes, S. O., Costa, M. F. P., Haie, N., & Fontes, F. A. C. C. (2022). Modelling of smart irrigation with replan and redistribution algorithms. *Journal of Sustainable Development of Energy, Water and Environment Systems, 10*(3), 1090409. https://doi.org/10.13044/j.sdewes.d9.0409

Choudhari, S. A., Kumbhalkar, M. A., Bhise, D. V., & Sardeshmukh, M. M. (2022). Optimal Reservoir Operation Policy Determination for Uncertainty Conditions. *3C Empresa, 11*(2), 277-295. https://doi.org/10.17993/3cemp.2022.110250.277-295

Kuo, S. F., Merkley, G. P., & Liu, C. W. (2000). Decision support for irrigation project planning using a genetic algorithm. *Agricultural Water Management, 45*(3), 243-266. https://doi.org/10.1016/S0378-3774(00)00081-0

Sadati, S. K., Speelman, S., Sabouhi, M., Gitizadeh, M., & Ghahraman, B. (2016). Optimal Irrigation Water Allocation Using a Genetic Algorithm under Various Weather Conditions. *Water, 6*(10), 3068-3084. https://doi.org/10.3390/w6103068

Jain, S., Ramesh, D., & Bhattacharya, D. (2021). A multi-objective algorithm for crop pattern optimization in agriculture. *Applied Soft Computing, 112*, 107772. https://doi.org/10.1016/j.asoc.2021.107772

Patil, U. G., & Patil, S. N. (2013). Need of Evaluation of the Present Status of Environmental Conditions of Completed River Valley Projects – Jayakwadi Project a Case Study. *International Journal of Recent Trends in Science and Technology, 6*, 23-31.

Wu, Z. Y., & Simpson, A. R. (2001). Competent genetic-evolutionary optimization of water distribution systems. *J. Comp. Civil Engin. ASCE, 15*, 89–101. https://doi.org/10.1061/(ASCE)0887-3801(2001)15:2(89)

Zhang, X., Chen, X., Liang, P., & Tang, H. (2018). Cataloguing Plant Genome Structural Variations. *Curr. Issues Mol. Biol., 27*(1), 181-194. https://doi.org/10.21775/cimb.027.181

Wang, Y. (2022). Technical Research on Optimization of Irrigation Canal System Considering Genetic Algorithm. *Mobile Information Systems, 2022*, 1-9. https://doi.org/10.1155/2022/8687532