OPTIMIZATION OF MULTIPURPOSE RESERVOIR OPERATION USING EVOLUTIONARY ALGORITHMS

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**FACULTY OF ENGINEERING
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ABSTRACT

Today, the water resources are among the great human treasures. Optimal reservoir operation, due to the numerous needs, shortcomings and restrictions on the use of these resources is necessary. The main purpose of this study was presenting a model for an optimal operation of multi-purpose dams of water resources systems. In this study, a hybrid evolutionary algorithm model (HPSOGA) and linear programming (LP) has been developed for optimizing the operation of reservoirs with the objectives of maximizing hydroelectric power generation, meeting the water demand for agricultural purposes and predicting the cost and estimating amount of agriculture products.

An improved particle swarm algorithm (HPSOGA) is used to solve complex problems of water resources optimization. One of the main problems of this method is premature convergence and to improve this problem, the compound of the particle swarm algorithm and genetic algorithm were evaluated. The basis of this compound is in such a way that the advantages of the Particle Swarm Optimization (PSO) algorithm and Genetic Algorithm (GA) have been applied simultaneously. Two efficient operators of Genetic Algorithm, that is, mutation and crossover are used in the obtained algorithm, the mutation causes an increase in the diversity of the population and the intersection of information between the particles of the population. To evaluate the hybrid algorithm, optimization of hydro-power energy of Karun dams were considered.

Cases studied in this research were reservoirs of Karun I, Karun III and Karun IV. The three dams are located in a consecutive series of Karun River in Iran. In order to optimize, 41 years of the common statistical period were used. Then, the optimal output of the problem in the form of curves that represent the desired amount of discharge from the reservoir at a specified time interval were prepared and compared with the Lingo model. The regression analysis and artificial neural networks (ANN) were used to check the quality of the results.

By using the Weibull distribution, the base year which is consistent with the percent probability of agricultural needs was determined for downstream of the Karun III dam. To achieve the best cultivation pattern, initially the arable land was categorized into 6 classes and only 2100 hectares of agricultural irrigable land that had the best agricultural conditions were studied. The amount of water allocated to the mentioned land was about 6.240 MCM. Seventeen important agricultural products of the region were used for the modelling. The optimization problem was modelled with the aim of maximizing the ultimate value of agriculture in terms of the number of acres of each crop. The described model was resolved by linear programming and evolutionary algorithms in Microsoft Excel (Solver). The results showed full compliance of these two methods. To estimate and predict the cost of the different stages of farming, and the cost of fertilizers needed for agricultural products, the obtained results of cultivation pattern per acre multiplied to cost breakdown values in tables taken from the ministry of agriculture.

Comparing the results of the combination of the PSO and GA algorithms makes clear that the obtained algorithm increased flexibility and improving the ability of the PSO algorithm to create the population with high-speed convergence and it is very applicable to solve the problems of operation optimization of water resources. To compare the accuracy of the results, three criteria were used for RMSE, NRMSD and CV. In all the obtained results, i.e. optimum release, optimum storage and the produced energy, for all dams, the accuracy of HPSOGA was better than GA and GA accuracy was remarkably better than PSO. However, exceptionally, the accuracy of the GA algorithm was approximately 34% better than the HPSOGA algorithm for only the optimal storage capacity at Karun IV Dam. The overall results show that the optimal values have higher importance in the preparation of the rule curve, especially in periods of drought.

Keywords: Karun River, Optimization, Hydropower, Optimal Release, Cropping Pattern

ABSTRAK

Pada zaman moden ini, sumber air merupakan salah satu khazanah terpenting bagi umat manusia. Operasi optima tempat takungan air diperlukan bagi memenuhi pelbagai keperluan dan sekatan adalah diperlukan bagi mengawal sumber yang terhad ini. Tujuan utama bagi kajian ini adalah untuk memzahirkan sebuah model bagi satu sistem empangan pelbagai-fungsi yang beroperasi secara optima bagi satu sistem punca air. Di dalam kajian ini, satu model "hybrid evolutionary algorithm" (HPSOGA) dan "linear programme" (LP) telah dibangunkan bagi mencapai satu sistem operasi takungan air yang optima dengan bermatlamatkan untuk mendapatkan penghasilan kuasa hidroelektirk yang maksima bagi memenuhi permintaan agrikultur dan juga bagi mendapatkan satu jangkaan kos serta jumlah produk bagi industri agrikultur tersebut.

Bagi partikel algorithm (HPSOGA) yang telah dikembangkan, ia digunakan sebagai medium penyelesaian bagi masalah-masalah kompleks berkaitan dengan isu tahap optima bekalan air. Salah satu permasalahan berkaitan perkara ini adalah tentang isu penggabungan pra-matang, dan bagi menyelesaikan isu tersebut bahan gabungan bagi partikel algorithm dan genetiknya perlu dinilai. Asas bagi gabungan ini adalah di dalam bentuk kebaikan dari Particle Swarm Optimization (PSO) algorithm dan Genetic Algorithm (GA) yang digunakan secara sekali gus. Dua operator genetik algorithm yang berkesan dalam mendapatkan algorithm ialah "mutation (mutasi)" dan "crossover (persilangan)" di mana sistem mutasi akan menyebabkan kenaikan jumlah di dalam kepelbagaian populasi dan percambahan maklumat antara partikel-partikel populasi tersebut. Bagi menilai algorithm hibrid tersebut, tahap optima kuasa hidro bagi Empangan Karun harus dipertimbangkan.

Kajian kes bagi tujuan kajian ini akan difokuskan kepada empangan Karun I, III dan IV. Ketiga-tiga empangan ini terletak selari dengan Sungai Karun di Iran. Bagi

mendapatkan satu tahap optima, jangka masa statistik selama 41 tahun telah digunakan. Kemudian, hasil “output” optima bagi masalah tersebut yang dipamerkan di dalam bentuk lengkungan di mana ia mewakili jumlah yang ingin dilepaskan dari tangkungan tersebut, pada hentian masa yang spesifik disediakan dan dibandingkan dengan model Lingo.

Dalam menggunakan ‘pengagihan Weibull’, asas tahun yang memiliki konsistensi selari dengan peratusan keberangkalian keperluan agrikultur telah dikenalpasti bagi empangan Karun III. Bagi mencapai corak pertanian yang terbaik, pada asasnya tanah yang terlibat akan dikategorikan kepada enam kelas dan hanya 2100 hektar tanah agrikulur (Kelas Pertama) yang memiliki keadaan agrikultur terbaik akan dikaji. Jumlah air yang dibekalkan kepada tanah yang terlibat adalah sebanyak 6.240 MCM. 17 produk terpenting agrikultur di dalam satu kawasan adalah digunakan sebagai model. Optimasi permasalahan telah dicorakkan dengan matlamat memaksimakan nilai akhir agrikultur di dalam bentuk jumlah ekar tanah bagi setiap hasil tanaman. Model yang diterangkan adalah diselesaikan melalui suatu sistem ‘linear programming’ dan ‘evolutionary algorithm’ di dalam Microsoft Excel (Solver). Keputusan menunjukkan persetujuan yang positif di atas kedua-dua kaedah ini. Untuk mendapatkan jangkaan bagi langkah-langkah penanaman yang terlibat dan kos baja yang diperlukan bagi produk agrikultur, keputusan berkenaan corak pertanian dalam jumlah ekar yang diperolehi telah didarabkan dengan kos pecahan jumlah di dalam jadual yang diambil dari kementerian agrikultur.

Dalam membuat perbandingan antara keputusan gabungan PSO dan GA algorithm, adalah jelas bahawa algorithm yang diperolehi meningkat dari segi fleksibiliti dan juga meningkatkan kebolehan PSO algorithm dalam mencipta populasi gabungan kadar segera dan ini sangat membantu dalam menyelesaikan isu berkenaan operasi bekalan air secara optima. Untuk bandingkan ketepatan keputusan,terdapat tiga krateria yang digunakan RMSE,NRMSD dan CV. Daripada semua keputusan yang diperolehi, contoh

pembebasan optima, Penyimpanan Optima dan tenaga yang dibebaskan untuk semua Empangan , ketepatan HPSOGA lebih baik daripada GA dan Ketepatan GA jauh lebih baik jika dibandingkan dengan PSO. Walaubagaimanapun ketepatan algoritma GA sangat baik dengan anggaran 34% lebih baik daripada algoritma HPSOGA hanya untuk kapasiti simpanan optimal di Empangan karun IV. Keputusan keseluruhan menunjukkan bahawa jumlah optima memiliki kepentingan yang lebih tinggi dalam bentuk persediaan peraturan lengkungan, terutama di dalam musim kemarau.

Kata kunci: Sungai Karun, Pengoptimalan, Kuasa Hidro, Siaran Optimal, Corak Tanaman.

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LIST OF SYMBOLS AND ABBREVIATIONS

MILP	:	Mixed Integer Linear Programming
LP	:	Linear Programming
DP	:	Dynamic Programming
BLP	:	Binary Linear Programming
ILP	:	Integer Linear Programming
GAMS	:	General Algebraic Modeling System
AMPL	:	A Mathematical Programming Language
MINLP	:	Mixed Integer Nonlinear Programming
BINLP	:	Boolean integer nonlinear programming
CalSim	:	The California Simulation of Insurance Markets
OASIS	:	Operational Analysis and Simulation of Integrated Systems
MCM	:	Million Cubic Meters
CMS	:	Cubic Meter per Seconds
M	:	Meter
M^2	:	Square meters
M^3	:	Cubic meters
MCM	:	Million Cubic Meters
km^2	:	Square kilometer
Ha	:	Hectare
TOMAN	:	A super unit of the official currency of Iran (10 RIALS)
GRG	:	Generalized Reduced Gradient
FAO	:	Food and Agriculture Organization
MWN	:	The minimum required water (m3 per hectare)
APH	:	Average production per hectare (ton)

PVT	:	The product value per tonne (TOMAN)
MT	:	The minimum tonnage (ton)
MAL	:	Maximum available agricultural land (ha)
VPH	:	Value per hectare (10 Rials/ Toman)
MLN	:	The minimum land required for production (ha)
MWND	:	Minimum water required to provide the desired capacity (m3)
TAW	:	The total allocated water (MCM)
OPT	:	The optimal area of agricultural land for production (ha)
K 1	:	Karun I
K 3	:	Karun III
K 4	:	Karun IV
MOL	:	Maximum operation level
UG	:	Upper Gotvand dam
RMSE	:	Root Mean Square Error
NRMSD	:	Normalized Root Mean Square Deviation
CV	:	Coefficient of Variation

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CHAPTER 1: INTRODUCTION

1.1 Background

Water is the most important requirement for all living creatures after oxygen. Life and health of all beings including human, plants and animals, depends on water. Although 75 percent of Planet Earth is composed of water, only one percent is the usable fresh water. This insignificant amount is not spread on the earth uniformly. This limitation is one of the most significant challenges in countries with arid and semi-arid regions.

Variability of rainfall regimes and discrepancies in the discharge regime of the river with water needs and river flow in different years make it necessary to build storage systems to regulate the natural flow of rivers. One way to deal with the problems in water resources management and lack of appropriate temporal and spatial distribution, is the optimal use of reservoirs. Dams are designed and constructed in order to resolve such problems. Providing water for municipal, agricultural and industrial consumption is one of the main purposes for reservoir operation and planning. Moreover, because of water needs in the region, sometimes storage system includes a reservoir, and sometimes several in a row on the river or a network of reservoirs on the river and its tributaries are designed.

Surface reservoirs play an important role to reduce the damage caused by lack of water in the dry months or years by regulating river flow and water delivery from wet months to the dry months and also in some cases by regulating beyond the year.

Irrigation: In most countries, agricultural purposes have the highest water level consumption. Water stored in the reservoir has increased monthly and annual rate of discharge and subsequently irrigated acreage and gross income will be risen. On the other hand, water resource development costs have increased at a considerable rate and so any attempt at optimizing of the required reservoir volume due to the economic aspects of the plan will be a step forward on the path of economic development. Therefore, optimal operation and management of water resources, among giving proper response to the needs of this part, leads to reduced wastage of water and increases the level of production yield and gains sustaining development in agriculture.

Flood control: Flood control is another aims of constructing dams. Not only dams are known as main source in providing water, they also create high capacity for developing tourism industry.

Tourism: In most countries in the world, dams and their reservoirs are considered as the most important tourist attraction and attract numerous tourists annually.

Hydropower generation: One of the aims of constructing dams is hydroelectric energy. Nowadays, the hydropower and thermal energies have the highest share in producing the world electricity. Although, problems and limitations of producing electricity in thermal power sources due to technical issues, the imperatives of environmental criteria, resources constrains have caused that, by the time the general trend in the world of power generation, hydroelectric plants will be more preferred. The potential energy of water behind a dam, provide hydroelectric energy. In this case, energy of water depends on stored water of the dam and height difference between the water source and the withdrawal of water from the dam.

The next issue is the optimal operation of the reservoir, considering the objectives like drinking water needs, industrial, agricultural, hydroelectric purposes, flood control, tourism, etc. Variety of purposes of water resources management makes decision making complex and difficult. One of the principles of water resource management is implementation and correct operation of the dam reservoirs.

Efficient approaches and appropriate solutions must be considered for operating reservoirs as one of the most important components of water resources management.

Application of such approaches leads to create balance between available limited resources and high demand, optimization of water use in agriculture, municipal and industry and finally sustainable development in water resources management. Nowadays, water management and water protection are highly important in developing and developed countries. In order to system enhancement and equitable management of water resources, complaint to the prescribed principles and technical planning is necessary. Using practical planning techniques to optimize water resources, due to their simplicity and applicability are very important.

Application of optimization techniques to exploit the reservoirs is the main issue in the management and planning of water resources and, it has been highly considered by researchers in the past two decades.

Optimization techniques have been significant during the last few decades in management and operation of complex system reservoirs. Overall, management of the reservoir consists of two stages, Simulation and optimization processes.

In arid and semi-arid regions like most parts of Iran, water is the substantial limiting factor in agricultural development. Therefore, the essential issue in resolving the challenges in water management is maintaining a balance between supply and demand. According to the fact that the economic value of water is directly related to the crop cultivation pattern and their density and that this pattern undergoes many changes over the utilization years, by investigating these changes in all areas of the country the current water status in terms of pattern and density should be compared with the proposed status. Agricultural activities are the main indicators of development in countries like Iran. Whenever the allocation of resources is in non-optimal state at the level of producers and enterprises, one cannot expect the resources to be efficiently allocated at the macro level. In agriculture, it is very complicated to find an optimal cropping pattern with the aim of obtaining the maximum net profit by considering the constraints such as water resources, soil, regional needs, cost, etc. It is impossible to ensure that whether the proposed cropping pattern offers the maximum profitability by using common methods such as trial and error, because practically infinite number of cropping patterns should be tested. Mathematical programming is used for agricultural programming and determining the optimal crops cultivating pattern in an agricultural unit or in a certain region. The aim of linear programming is to maximize or minimize the objective function of the farm's manager regarding some of the constraints (available resources) and decision variables (activities) simultaneously.

1.2 Problem statement

Storage systems often lack the appropriate and academic utilization patterns in Iran. Therefore, investigating the methods and providing suitable models for the optimal utilization of such systems during normal operation and periods of intense drought had high priority. On the other hand, the limitation on the total amount of water and the fixed total amount of it, in contrast to increasing industrialization process and the subsequent process of increasing urban growth in demand in various fields, creates a set of factors related to each other and brings the issue of water crisis to the fore in the near future. So, efficient management and operation of the facilities have special importance.

Optimal operation of reservoirs requires management of storage to predict the output current for the future input current. Optimization is a fundamental concept to enhance the management and optimization of interactive efficiency of dam construction projects. One of the main priorities for water supply schemes is the appropriate operation of storage reservoirs. Moreover, codification of operation policy from constructed reservoirs is socially and economically important. Optimal design of storage reservoirs requires the regulation of operation based on the determination of the reservoir input and output values and determination of the relationship between them. Useful volume or reservoir storage capacity and output control for picking the accurate amount are calculated based on the indicators of storage system operation. Control the water output of a reservoir at any depth of water, is done by using a guide, tables and graphs. The tables and charts are used as operating instructions for the use of water in normal and stressful conditions, proper maintenance of water levels, operation at the time of the flood and partnership with other reservoirs.

There are different methods for the operation and storage of water in reservoir. All these methods determines the amount of current release at the specified time based on a simple storage system and release for a specified period, the analysis of measured data, and operation methods. In most reservoirs in the world, rule curve as the main pattern of operation, determine the amount of storage and release of water in storage reservoirs.

A rule curve describes how much storage reservoir at different times of the year should be in the reservoir so that the amount of needed water can always be supplied.

The study is going to answer the following questions:

1. How efficient is the rule curve of Karun dams for supplying required water by the purpose of minimizing the failure of supply?

2. How is the performance of the existing rule curve system in comparison with mathematical programming techniques such as linear programming?

1.3 Significance of the study

Iran is located in the arid and semi-arid region. Many areas of the country do not have enough water for agricultural activities so water is the main factor in most of the agricultural areas. Iran is located in the Middle East including 5% of the world population, just have access to only one percent of the world water. Average annual rainfall in Iran is 246 millimeters that means a quarter of the world average rainfall (Sadeghi, Moatamednia, & Behzadfar, 2011).

The total amount of rainfall in Iran is about 400 billion cubic meters. About 310 billion cubic meters (over 77%) rains in the mountainous areas and only 90 billion cubic meters rains on the plains ("Water Resources and Quality in Iran," 21/12/2016). About 286 billion cubic meters will be lost by evapotranspiration and approximately 114 billion cubic meters will remain in a year. Obviously, by the population increasing to 100 million in 1400, Iran will be in water deficit conditions. Non-uniform rainfall distribution in space and time are also the main problems in the water sector. So using the potential capacity and the hydro potential of the wet areas in order to supply water needs in arid areas is inevitable. To produce 65 million tons of agricultural products, about 85 billion cubic meters of water will be consumed. Even if there are enough agricultural land, but water resources of the country will not let the production increase enough, in accordance with the population growth.

Lack of enough water resources in Iran has been recognized as one of the key challenges in the water sector, with an increase in water demand due to the expansion of agricultural, industrial and urban activities. These challenges have been intensified.

The socioeconomic development of the regional society in the Karun River Basin, the case study, depends on the optimum development and management of the available water resources in the region. The river system is coming under increasing pressure to satisfy the demands of domestic, industrial, agricultural, environmental, navigation and hydroelectric power generation users, whilst at the same time maintain an adequate flow in the river systems both in terms of quantity and in terms of quality.

The hydraulic performance of the Karun and Dez Rivers demonstrate significant flood damaging potential to the adjacent fields and population, especially in the south reaches downstream of Ahwaz city. Short duration and high discharges are the characteristics of winter floods.

The fast development of multipurpose dams in the Karun and Dez rivers is placing additional pressure on the current operational dams and structures. The developed and under construction schemes are in significant need of management tools to be established to assist planning, evaluation, controlling and operating reservoirs in the system and to size the flood control and conservation storage requirements for each scheme.

Without immediate actions to be taken to manage and control the water resources of the river system, the combination of abstraction and flood events will inevitably lead to further water shortage and contaminated water quality, which will impact further on all water users and waterside residents.

This study has two innovations for optimizing the reservoir operation:

- Planning for present and future using regression analysis and artificial neural networks (in situations of data insufficiency or data generation for the future)
- Integrated and optimal resource management, from planning to operation. (Connecting the optimizer model to optimal water allocation for agricultural land and estimate the amount of agricultural products and predict the cost before implementation.

1.4 Objective of Research

The main objectives of this study are as follows:

1. Maximize the hydroelectric power generation in Karun dams (or minimize shortage of hydro power supply)
2. Optimize water supply (Determine the optimal release of the dam for domestic, agricultural and industrial purposes)
3. Minimize shortage of agricultural water supply (Identify the optimal cropping patterns for downstream of Karun 3 dam)
4. Predict costs and quantities of agricultural products in the obtained optimal cropping pattern

In other words, the main purpose of the study was to achieve an optimal operation program of the water system consisting of Karun I, Karun III, and Karun IV dams for the determined purpose in the operation.

1.5 Scope of the study

For the following five reasons, the study area was considered in the Karun Basin:

1. The problem should include more than two reservoirs in series.

2. Reservoirs must meet the objectives of producing a hydroelectric power plant, water supply and providing downstream agricultural needs.

3. Agricultural information at downstream of reservoirs should be accessible.

4. All dams should have long input data (at least 30 years)

5. The data must be accurate and complete.

The purpose of this study is to examine the “maximum potential” scenario, taking into account the requirements of water for industrial and domestic demand, for irrigation and hydropower. It is assumed that raw data (such as soil surveys and land maps showing irrigable potential) will be available.

The principal work activities of this component are as follows:

1. Collect all required hydro-meteorological data;
2. Collect data on existing reservoirs;
3. Review all main potential developments for hydropower, water supply and irrigation.

1.6 Thesis outlines

The first chapter briefly discussed some generalities about the problem and different methods of solving the problem, and the importance and purpose of the study.

Chapter 2 presents a review of related literature about different methods of optimizing operation of reservoirs. Chapter 2 consists of four sections. The first section contains generalities about optimal reservoir operation problems and then discusses about optimization process and methods. In the second part, a statistical overview of the published papers in field of optimal reservoir operation is presented. In the third part, a linear programming method and its related literature in details are discussed. In the fourth part, a complete description of new optimization algorithms, including background of research, process optimization, and advantages and disadvantages of each methods have been presented.

The third chapter, explains the whole study area, and after that the methods and tools used in the study (Lingo for linear programming and Genetic Algorithm and Particle Swarm Optimization and HPSOGA as a hybrid model consisting of these two methods for evolutionary algorithms).

In the fourth chapter, the results and discussions obtained from linear programming and HPSOGA algorithms and existing conditions are discussed.

Chapter five consists of overall conclusion of the study and suggestions.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

A multi-objective task, which involves water supply, flood control, energy generation, and environmental concerns, is called reservoir operation. In order to achieve almost all goals and most ideal possible performance of the reservoir, we need to analyze and operates the system optimally by considering the variations in inflow and demands. Decisions need to be made about releases and storage volumes over a period of time. The truth is none of the algorithms are capable of satisfying all these aspects of reservoir operation issues. Mathematical programming and Evolutionary algorithms are very famous as optimization methods, which have used to solve the optimal reservoir operation so far. Thus, researchers focus on optimization of reservoir operation more than ever.

Researchers have applied several mathematical programming techniques, such as Linear Programming (LP) (Needham, Watkins, Lund, & Nanda, 2000), Dynamic Programming (DP) (C. Cheng, Wang, Chau, & Wu, 2014; Hall, Butcher, & Esogbue, 1968; Li, Wei, Li, Wang, & Yeh, 2014; Zhao, Zhao, & Yang, 2012),and Stochastic Dynamic Programming (SDP) (P. Liu, Zhao, Li, & Shen, 2012; Saadat & Asghari, 2017; Shokri, Haddad, & Mariño, 2012; Stedinger, Sule, & Loucks, 1984) to solve different kinds of reservoir-operation problems optimally. During the last decades, A number of approximate algorithms are developed, which are trying to combine basic principles of evolutionary methods to find a method for efficient search in feasible regions. Evolutionary algorithms (EAs) like Genetic Algorithm (GA) (Ahmed & Sarma, 2005) (Ashofteh, Haddad, & Loáiciga, 2015; Fallah-Mehdipour, Haddad, & Mariño, 2012; Ngoc, Hiramatsu, & Harada, 2014), Differential Evolution (Reddy & Kumar, 2007; Schardong & Simonovic, 2015), Ant Colony Optimization (ACO) (A. Dariane & Moradi, 2010; Kumar & Reddy, 2006; Moeini & Afshar, 2013),, Simulated Annealing (SA) (Teegavarapu & Simonovic, 2002), Particle Swarm Optimization (PSO) (A.M. Baltar &

D.G. Fontane, 2008) (Fallah-Mehdipour, Haddad, & Mariño, 2011; Ostadrahimi, Mariño, & Afshar, 2012; Rahimi, Qaderi, & Abasiyan, 2013), A Hybrid Cellular Automat-Harmony Search Approach (M. Afshar, Azizipour, Oghbaeea, & Kim, 2017), and Artificial Neural Networks (ANN) (Wei & Hsu, 2008) are some samples of these methods (F. Othman, Sadeghian, & Heydari, 2012). A comprehensive survey of these methods can be found in (W. Yeh, 1985), (Labadie, 2004), (Wurbs, 1993) and (M. H. Afshar & Shahidi, 2009). It is extensively recognized that there is no single algorithm available to resolve all reservoir-operation problems, since every problem has its own distinctive physical and operational typicality'(W. W. G. Yeh, 1985).

Evolutionary methods are suitable for solving nonlinear optimization problems with large number of complicated variable decisions. The main advantage of these techniques is achieving a global optimum instead of local optimum. Usually, they are not trapped in local optima.

In summary, it can be said that various researchers have tried to optimize the operation of reservoirs using different methods or tools. However, the following two points are considered less than others:

1- Not paying attention to integrated management

2. Failure of the model for cases where data is not complete or there is no data at all (like modeling for future)

In this chapter the general principles of reservoir operation modelling has been introduced then linear programming (LP) and evolutionary algorithms (EA) are discussed thoroughly.

In section related to evolutionary optimization algorithms, the algorithms have been introduced briefly alongside the optimization process, previous research and strengths and weaknesses of each algorithm. Then multi objective optimization techniques have been introduced and after that the general principles, the optimal cropping pattern application and studies done in this field were discussed. In the end the statistical review of the published papers on the operation of the reservoir is given.

2.2 Principles of reservoir operation modelling

2.2.1 Governing relations in general reservoir operation problems

Governing relations in a multi-reservoir system which are going to be presented in following paragraphs are general and they are common in both deterministic and dynamic stochastic models.

Continuity equation:

In fact, Continuity equation is one of the physics laws available in the system and is based on the rule of Conservation of Mass (Equation 2.1):

$$S^{x}_{l,t+1} = S^{x}_{kt} + q^{x}_{t} - r^{x}_{klt} - eva^{x}_{klt} + \sum d_{t}{}^{xx'} \tag{2.1}$$

Which $S^{x}_{l,t+1}$ is the volume of water in the reservoir x at the end of the period, eva^{x}_{klt} is the evaporation from mean level of the reservoir, and r^{x}_{klt} is outcome belongs to reservoir x in t period. $\sum d_{t}{}^{xx'}$ is sum of flows which transfer from upstream reservoirs x' to reservoir x. q^{x}_{t} intermediate inflow into the reservoir upstream region in period t. in the reservoirs which have no other reservoirs upstream, q^{x}_{t} is as the only flow into the reservoir but in downstream reservoir, q^{x}_{t} is equal to total interway flows, it means that discharge from the sub-region is between considered reservoir and upstream reservoir. Furthermore, it is possible to enter return flows to the system in the format of this parameter. Figure **2.1** shows a simple two-reservoir system with signs.

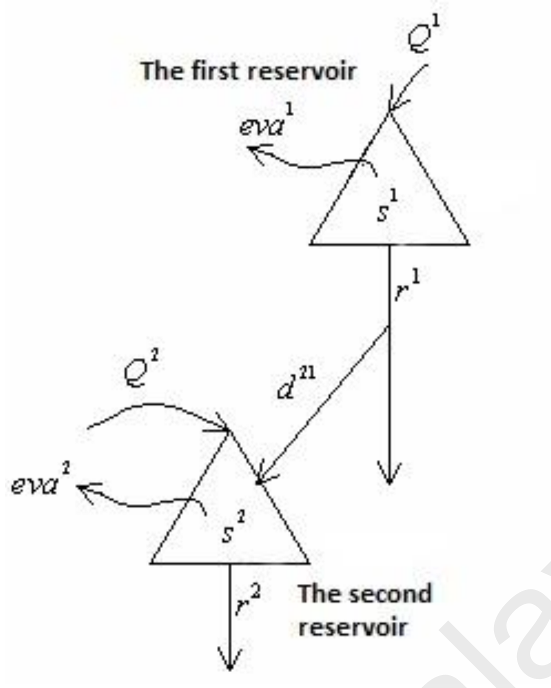

Figure 2.1: The relationship between two reservoirs in a multi – reservoir system.

Capacity limits:

Reservoir storage in each period should be within the active storage range (Equation (2.2) :

$$S^{x}_{min,t} \leq S^{x}_{kt} \leq S^{x}_{max,t} \tag{2.2}$$

Minimum capacity storage of the system in normal situation is equal to dead storage (a volume which is designed for sediments) but if reservoir is being used for producing electric-water energy or entertainment, it is necessary to consider more minimum capacity storage and the balance of the reservoir shouldn't be less than a specific level. In this case, the minimum storage volume of the reservoir would be more than dead storage.

Each reservoir has a fixed maximum capacity that would be indicate by K, at each time interval, the present volume cannot exceed the amount of capacity (Equation (2.3) :

$$St \leq K \tag{2.3}$$

Figure 2.2 shows different parts of a storage reservoir.

Reservoir outflow limitation:

It is possible to have limitations in each period for outflow from each reservoir Equation (2.4) :

$$R_{min,t}^{x} \leq R_{klt}^{x} \leq R_{max,t}^{x} \tag{2.4}$$

The minimum outflow of the reservoir is considered for cases such as certain needed discharge, minimum flow to protect environment and aquatic, and boating in multi reservoir systems. In addition, maximum output of the reservoir may be in the direction of turbines, rivers, downstream installments capacities and so on.

Evaporation calculation

In every reservoir operational program, the amount of loss from the reservoir as a result of evaporation should be considered. Usually, infiltration is unlike evaporation, negligible. Values of evaporation and rainfall related to the lake of the dam are expressed based on height, which according to the level of lake, their volumes are determined for the reservoir. For this purpose, first, a simple linear regression is generated between storage and reservoir level and then, its volume of the reservoir in each period is calculated based on pure evaporation height. Mean storage level based on the beginning and end of the period storage, is calculated by following Equation (2.5) :

$$A_{kt}^{x} = a_1^{x} + a_2^{x}\,(S_{kt}^{x} + S_{klt}^{x})/2 \tag{2.5}$$

Where $\mathrm{A_{kt}^{x}}$ is mean reservoir x level in t period and corresponds to storage volume at the beginning of t period $\mathrm{S_{kt}^{x}}$, and storage volume at the end of t period or beginning of t+1 period, is $\mathrm{S_{klt}^{x}}$. $\mathrm{a_1^{x}}$ and $\mathrm{a_2^{x}}$ Are regression coefficients.

Evaporation volume from reservoir level during the t period equals to Equation (2.6) :

$$eva_{klt}^{x} = A_{kt}^{x} * (evap_{t}^{x} - rain_{t}^{x}) \qquad (2.6)$$

Where $\mathrm{eva}_{\mathrm{klt}}^{\mathrm{x}}$, is the evaporation volume from surface of reservoir x in the t period. In this equation, resultant of evaporation and rainfall are incorporated into the formula so $\mathrm{eva}_{\mathrm{klt}}^{\mathrm{x}}$ can be negative and it means in that period, rainfall was more than evaporation.

Equations described above are the most important, essential and basic equations, relationships to model any reservoir at any desired time interval. The primary objective of every reservoir is to supply water to downstream over the time and space. The other objectives may include reservoir volume management for recreational purposes, flood control and the release of water management for the production of hydroelectric energy.

Reservoirs have been constructed to change the natural flow of rivers. Reservoir capacity and release policy defines the extent so that surface flow of water can be stored until it will be released in future. Using of reservoirs for the temporary storage often leads to complete loss of water because of evaporation and residual, reservoirs bring changes in regional climate, area and the river system. They also may cause displacement of people and their habitats. The benefits of building a new reservoir include water supply of downstream, hydro power production, navigation, recreation, and etc., the benefits obtained from the reservoirs may be significant, but the cost should also not be forgotten. Comparison between benefit and cost is always a challenge because it is difficult to express them in a standard mode.

A storage volume of the reservoir is divided into three major and main usages:

- Active Storage, which is used to supply the water of downstream regularly, recreational development in the area, hydropower, etc.

- Dead Storage, which is needed to collect the required sediment

• Flood storage, which is preserved in the reservoir to prevent damage downstream during flood

These three storages are demonstrated in Figure 2.2, separately. Distribution of flood storage capacity and active storage may have changed over the year. For instance, it is not essential to consider flood capacity in certain months of the year that have no experience of flooding.

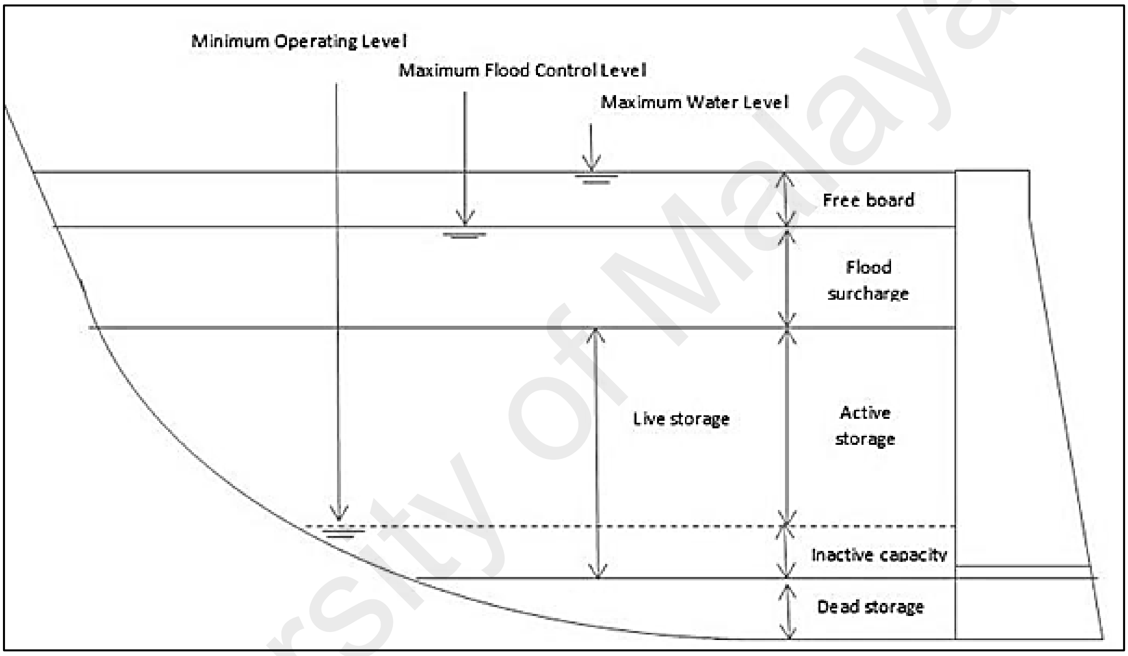

Figure 2.2: Allocating the capacity of reservoir to different volumes (Faridah Othman, Sadeghian, Heydari, & Rezaei, 2012)

These entire capacities can often be modelled separately and then added together to determine the total capacity.

2.2.2 The general structure of reservoir operation problem

The general structure of a base model that constitutes the base of most of optimization models for the operation of reservoirs is as follows:

$$\text{Min } Z: \sum \text{loss } t\ (Rt\ , Dt\ , St) \tag{2.7}$$

Subject to:

$$S_{t+1}=S_t - I_t - R_t - E_t - I_t \qquad (t=1, 2... n) \qquad (2.8)$$

$$S_{tmin}\leq S_t\leq Cap \qquad (t=1, 2... n) \qquad (2.9)$$

$$0\leq R_t\leq R_{maxt} \qquad (t=1, 2... n) \qquad (2.10)$$

$$S_t, E_t, L_t, R_t\geq 0 \qquad (2.11)$$

Where: (Equations above), Z: objective function, Loss t: the cost of operation in month t, which depends on the outlet need and the reservoir storage capacity in month t, R_t: release from reservoir in month t, D_t: water demand in month t, St: the storage capacity of reservoir in month t, N: number of intervals for programming, S_{min}: minimum volume water storage in reservoir, Cap: total volume capacity of water in reservoir, R_{maxt}: maximum release from reservoir in the duration of t, E_t: amount of evaporation from reservoir in month t, L_t: amount of water leaking from reservoir in month t and It: amount of inflow into the reservoir in month t. (Karamouz, Szidarovszky, & Zahraie, 2003).

In the objective function of this model, the total loss in the operation period is minimized. Different types of loss functions have been proposed for the optimization of reservoir operation models which are mostly based on a function of water deficit to meet the demand and the difference between the current storage and the design storage of water of the reservoir in every month. The loss of failing to meet the demands is calculated by comparing the total released water with the total needs of the system.

2.2.3 Reservoir operation as a decision-making process

The storage capacity needed to fulfill a given set of purposes depends on the policy used to operate the reservoirs. Given the major capital investments needed to build a reservoir, the environmental and social impacts of reservoirs, there is a strong incentive to find efficient operating policies that minimize the storage needed to satisfy the water needs and maximize the benefits provided by existing reservoirs. This pressure has increased in recent years due to a greater environmental and social awareness and to the restricted financial conditions that most nations are enduring. Proposals to construct new reservoirs to meet the always increasing water and energy demands and to reluctant politicians and an averse society. Water resource managers are thus being forced to review the operating policies of existing reservoir systems to find ways to further improve their performance.

Estimating reservoir-operating policies that maximize benefits provided by the operation of reservoirs and minimize their adverse impacts is not an easy task. Operating reservoirs is a complex decision-making process that involves a large number of variables, considerable risk and uncertainty, and often multiple conflicting objectives. Reservoirs may be built to satisfy a single purpose, but multipurpose reservoirs are often preferable because of the increased benefits derived from them.

In addition, the reservoir construction and operational costs can be distributed over a number of activities. While some of the reservoir purposes may be fairly compatible, like low flow augmentation for navigation and for pollution dilution, others may not be entirely compatible. For example, for power generation the reservoir should be as full as possible to increase the head, whereas for flood protection the reservoir should be empty to provide for maximum storage of floodwaters. In this case, no objective can be fully satisfied and a balance between them must be achieved.

Reservoirs are often integrated into systems of reservoirs and other control structures. If operated in a coordinated way, the reservoirs can provide larger benefits than the sum of the benefits yielded by the independent operation of each reservoir. This is especially true if the hydrological regime varies widely throughout the system and if the reservoir system is supposed to satisfy a number of different purposes. Water demands may be met from other sources thus saving thus saving water stored in the system reservoirs. Also, the operational benefits can be maximized by selecting the most appropriate set of reservoirs to satisfy each system objectives. For example, high-head reservoirs can be used to produce energy while reservoirs with high evaporation rates can be used for flood protection and low-head reservoirs can be used to satisfy water supply demands. As the size of the system increases, the operation becomes very difficult because of the large number of variables to be handled. System operators have to coordinate all the water demands with the water availability, and find the most efficient way to satisfy, all system objectives, if possible. They have to pay attention to all legal contracts, agreements and traditions that establish the priorities for the water use. Often, these priorities are not well established and are subject to dispute. This situation becomes even more complex if the reservoir system crosses administrative or international borders. Finally, all the operational decisions have to be made under the uncertainty of future hydrological conditions. System operators must continually evaluate the trade-offs between short and long-term uses of water without knowing with certainty the future availability of water. They may manage reservoir storage space to reduce the risk of flooding, knowing that a greater emphasis on flood protection may reduce their ability to satisfy for water or energy demands.

Given the typical scale of reservoir operation problems and the interdependence of all the factors involved, enormous benefits can be obtained from the reservoir if the correct operating policy is implemented for successful application of optimization models. One possible use of optimization models is in real-time operation of reservoir systems. In this situation, an optimization model is run at each decision time to determine the best operating decisions. These decisions are computed by solving a multi-period stochastic optimization problem that maximizes the expected future operational benefits subject to all operating constraints. However, despite the undeniable potential of this approach and the amount of research done by the academic community, these types of optimization models still play a minor role in determining reservoir releases. The following reasons may explain this lack of success.

Agreements on water resources management are difficult to achieve. The interests of each water user are often incompatible. Each user defends its position with vigor and only yields his rights with great reluctance. Long and intense negotiations are usually needed before a consensus is reached, and often the disputes have to be settled by the judicial system. The agreements or court decisions are usually stated as fixed rules that can be understood by all interested parties. If an optimization model is to be used to support real-time reservoir operations, all the interested parties have to accept the model and its results. This means that all have to accept each one of the mathematical equations that constitute the model, and agree on which technique should be used to solve the optimization problem. Since this discussion requires some technical and scientific knowledge, that some of the individuals involved in the decision process may not have, it may be very difficult to achieve an agreement. Some individuals may even refuse consensus.

Furthermore, the mathematical programming techniques available to solve optimization problems are only applicable if the size of the problem is not excessive, or if all the mathematical equations that constitute the model satisfy some specific set of conditions. These conditions require simplifications and approximations that prevent a detailed description of all the physical, hydrological and institutional characteristics of a reservoir system, as well as of all the needs and objectives of the various water users. If these simplifications are so severe that the optimization model does not capture the important characteristics of the reservoir system, the model results are not useful for real-time operation..

2.3 Methods for solving optimal reservoir operation

Operation of reservoirs is one of the most important and complicated issues in usage of dams that the designers have had challenges with for a long time. One of the most important solutions is choosing the best study method as well as utilizing the best engineering techniques. By using these methods and techniques, not only the operational method is studied, but also the capacity of reservoir is estimated. The most important methods in determining the capacity of reservoir are: critical period method (mass curve, sequent peak method, working table), optimization methods or system engineering techniques (linear programming, dynamic programming) and simulation methods. Optimization is a method that should result in the best answer to a problem based on given purpose and limitations defined as mathematical functions. In this method, the design parameters such as the height of the dam could be estimated using mathematical models.

The general trend of the reservoir studies is depicted in Figure 2.3. As it can be seen in this figure, having defined the possible options and calculated the reservoir function, the capacity of the reservoir and type of operation should also be defined.

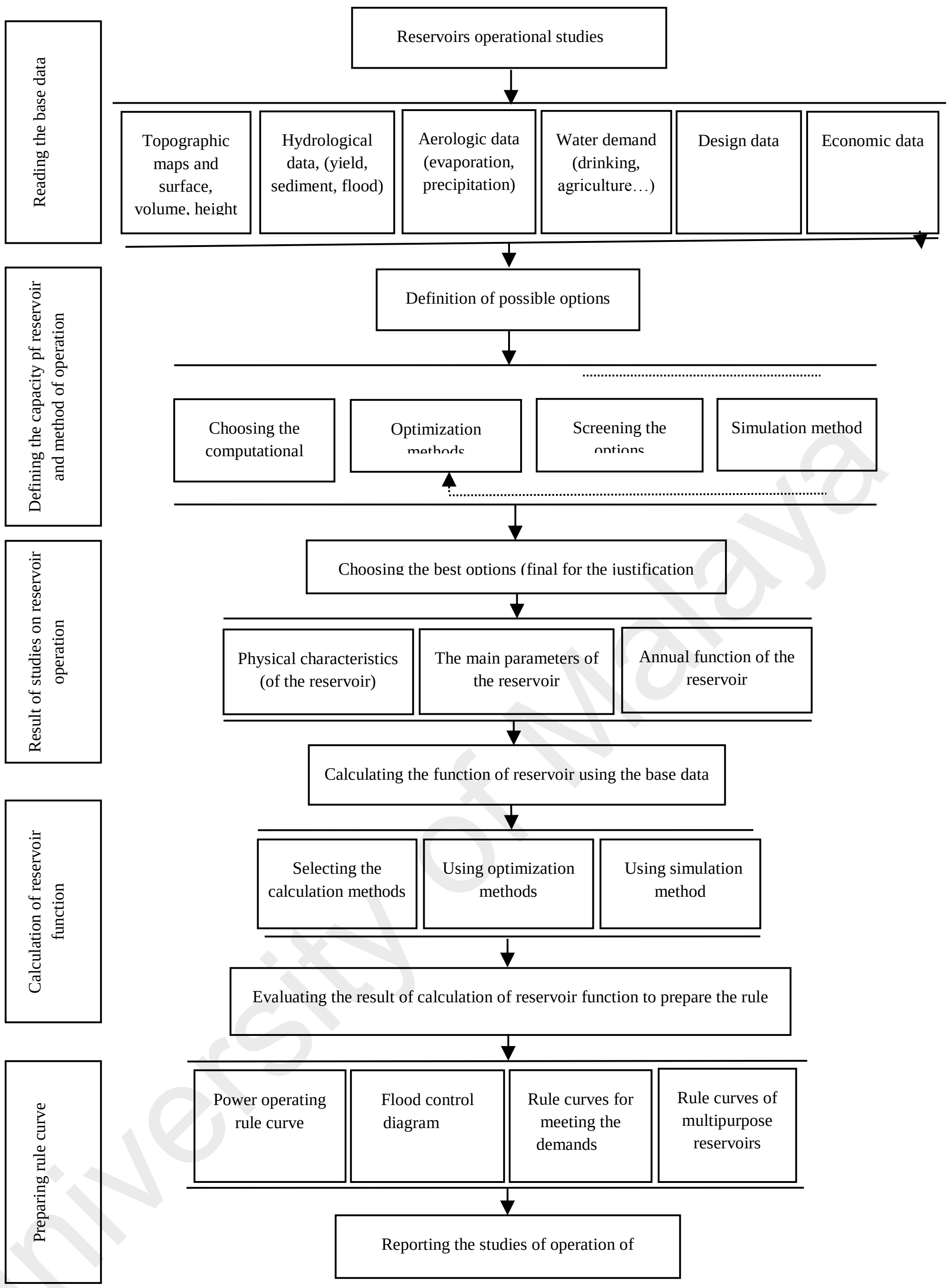

Figure 2.3: Operational studies of reservoirs (Faridah Othman et al., 2012)

2.3.1 Simulation models

Simulation model should predict the reaction of the system relative to a specific policy as if already the behavior of the system relative to different scenarios is determined (W. W. G. Yeh, 1985).

Input data for each simulation model can be divided into three parts: constant data, design data, and raw input flows. Constant data are system parameters, which physical and economical characteristics and relationships of them are defined and are not variable just like design parameters. Design data are in fact decision variables, which are determined during modelling process such as reservoir capacities and power plants. Input flow is also given to the system as artificial statistics or historical data (Jacoby & Loucks, 1972).

Simulation models can provide system efficiency and performance in different mixtures of reservoirs, power plants, values of storage volume, desired outputs, etc. and in this way have a good flexibility. Thus to choose the best mixture of them there is no good and effective tool. The reason is clear. Each time for a specific state of possible mixtures, simulation model shows the option by an operation policy and effectiveness. Now, if it is necessary to check many options, there should be necessary modifications for each option. This task is impossible in large systems, which have so many options.

Jacoby and Loucks (1972) studied this subject in Delaware area in the USA. This study consisted of 35 reservoirs, which only 6 reservoirs had determined capacity and the capacity of the rest of the reservoirs should be determined optimally. Regardless of variables related to operational policies, needed water and electric – water power plant and just 2 storage capacity options for each reservoir, the number of generated states would be 229 and if using of simulation is assumed, the number of simulations should be equal to that number. In this case, with 1 minute for each execution, more than 10 years is needed to perform all the possibilities.

2.3.2 Optimization models

As mentioned earlier, simulation models usually cannot obtain the best option. On the other hand, optimization models can produce the best possible mixture through assuming a special goal such as maximize revenue or minimize damage besides describing a physical and real phenomenon by logical mathematical equations. Also, due to some imposed assumptions in the computer program, in optimization models the resulted answer is not necessarily real optimal, but it is much closer to the real outcome which justifies the application of optimization for this purpose. Thus, it should be noted that in addition to these optimization models, there are more limitations, which make some difficulties in the application of them. Some of these problems may be due to limitations existing in the solutions. Thus, with all these problems, unique characteristics of optimization models, has made their application in water resources and particularly the planning and operation of reservoirs, very attractive. Today, the target of studies scientists and researchers in water resources management has focused on toward this direction. Using applied mathematics, they try to solve above-mentioned problems. The number of articles, which are published in magazines and journals, supports this idea.

Many studies that have been done on the optimization show that it is not possible to use a general method to solve all the problems of water resources.

Optimization Process

The optimization process of this study is presented in Figure 2.4, and it consists of seven vital steps.

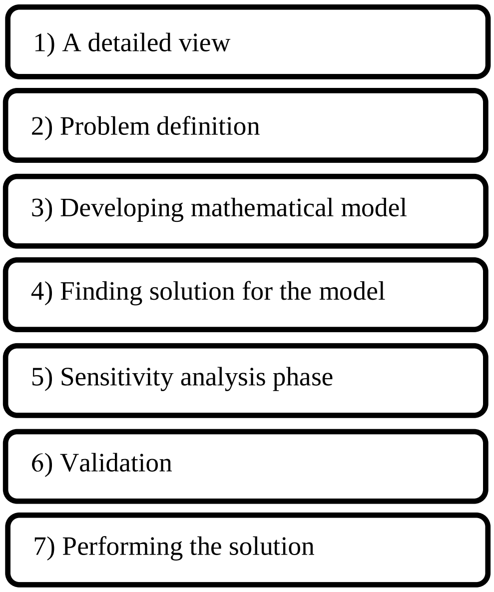

Figure 2.4: Schematic representation of optimization process

1. The first step in this process is expanding a clear understanding of the problem with a detailed view of the real world. To this end, a number of primitive solutions to achieve objectives must be defined that consider different aspects of the problem. Also, some doubts should be in the minds of decision makers as to which opinion to achieve the goal is the best.

2. Problem definition phase is a phase in which a precise and clear statement of the problem based on observations must be made and be gained in identification phase and transparency step of the problem. The mentioned problem definition should define purpose, the influence of the initial solutions, assumptions, barriers, limitations and possible available information on sources and markers involved in the problem. Experience shows that the erroneous definition of the problem leads to failure of analysis.

3. When we define the problem, the next step is developing a mathematical model. The mathematical model is the mathematical performance of the system or real problem and is able to perform different aspects of the problem in interpretable form. At first, it may be that qualitative model structure itself, including unofficial descriptive approach. From this unofficial qualitative model, an official model may develop. (Part 3 contains some applied models in order to optimize reservoir operations of dams.)

4. After formulating and developing the model, it is turn to find a solution for the model. Usually the optimal solution for the model with evaluation outcome sequence is found. This sequence of operation starts from a primitive solution that is as input of the model and the generation of the developed solution as output. The developed output is resubmitted as a new input and the process is repeated under the certain circumstances.

5. Another important phase of this study is a sensitivity analysis phase. Performing the sensitivity analysis allows us to determine the necessary accuracy of input data and understanding the decision variables that have the highest influence on the solution. The sensitivity analysis allows the analyst to see how sensitive the preferred option of changing assumptions and data is. In sensitivity analysis, analyst modifies the suppositions or data to enhance the considered option and convert it into optimal choice. Amount of measured default modification is determining the power of the model.

6. A solution should be tested. Often the solution is tested in a short or long term. The proposed solution must be validated against the actual performance observation while the test is being made, and it should be independent of how an optimal solution is obtained.

7. The final phase is performing the solution. This is the step of using optimal outputs for decision-making process. Usually, analyst converts his mathematical findings as a series of understandable and applicable decisions. It may be necessary to train decision-makers to help them apply the findings to attain the required changes from the current situation to the desired situation. In addition, they need to be supported until they learn the mechanism of maintenance and upgrading the solution.

2.4 Linear Programming

In order to solve optimal reservoir operation problem, researchers are trying to use some techniques in relation with programming and management for a long time. Most of practical and applied problems can be modeled as a linear programming problem regarding all intrinsic complexities. The mentioned reason and presence of different solving software of linear programming problems have caused that linear programming to be used as one of the most practical methods in the field of dam operation for years. In this research, we introduce optimal operation problems of reservoirs by using linear programming techniques and discuss about them. Also, objective and multi objective models were introduced by using some questions. Finally, some popular methods in the field of modeling such problems are introduced.

2.4.1 LP literature review

Charles Revelle in 1969 decided to act for design and reservoir management by linear programming and using the Linear Decision Rule (LDR). In this linear decision making method, reservoir outflow in whole operation period was calculated as the difference between the storage of the reservoir at the beginning of the period and decision parameter by solving linear programming (Revelle, Joeres, & Kirby, 1969). In 1970, Loucks applied the linear model with its probable limitation and its deterministic equivalent for solving the system of reservoirs (Loucks, 1970)

Cai and his collaborators in 2001, used genetic algorithm with linear programming in complex problems of water reservoir. The gained results have been reported very satisfactory (Cai, McKinney, & Lasdon, 2001). in 2005, Reis et al. used combination of Genetic Algorithm (GA) and Linear Programming (LP) method designed and solved planning and decision-making for reservoirs of water systems (Reis, Walters, Savic, & Chaudhry, 2005). In 2006, Reise and his associates performed a combination method using genetic algorithm (GA) and linear programming (LP) in order to achieve operational decisions for a system reservoir that is applied during optimization term. This method identifies a part of decision variables named Cost Reducing Factors (CRFs) by Genetic Algorithm (GA) and operational variables by Linear Programming (LP) (Reis, Bessler, Walters, & Savic, 2006).

2.4.2 Linear programming

Classical optimization models are linear, nonlinear or dynamic models. Optimization problems are often divided into linear and nonlinear models. This division is due to the variable relations. It means that if the relation among all variables is linear, then the problem is called linear, otherwise it is called nonlinear. Due to the simplicity of linear programming structure, and applicability of these models as a primitive appropriate model in water resources management systems, the possibility of solving problem with large number of variables, with no need for assumptions and primary values, researchers tend to use this kind of programming in their researches. Another advantage of mathematical programming are different solutions (like simplex method, interior point method), the possibility of converting nonlinear problem to linear one, and the possibility of instant calculation of the final optimal solution.

Maximize $c_1x_1+c_2x_2+\ldots+c_nx_n$ (2.12)

Subject to

$x_1, x_2,\ldots, x_n \geq 0$ (2.13)

$a_{11}x_1+a_{12}x_2+\ldots+a_{1n}x_n \leq b_1$ (2.14)

$a_{21}x_1+a_{22}x_2+\ldots+a_{2n}x_n \leq b_2$ (2.15)

$a_{m1}x_1+a_{m2}x_2+\ldots+a_{mn}x_n \leq b_m$ (2.16)

In such cases, the objective function is minimized. In the last formulation, we assume maximization, as minimization problems can be rewritten into maximization problems by multiplying the objective function by –1.

The best method for solving constrained optimization model depends on the specified mathematical form of the objective function and equations. There is not any comprehensive method for efficient solving of all the optimization models.

Thus, every mathematical programming model in its best way is only an approximate description of the actual water resources system. The obtained answer is only optimized to the prepared model but not to the real problem.

2.4.3 Methods for solving linear programming problems

Essentially, there are two popular methods for a LP model. These models are Simplex method and its variants and Interior point method (Robere, 2012). These two methods describe practicable solution term, which can be defined as a confined space with constraints and variable bounds. Then the optimal point (best method for solution) of the solution space is found.

Main objective of the graphical method shows acceptable solutions and research limitations. The method has practical value in solving small problems with two decision variables and only few constrains (Turban & Meredith, 1994).

Simplex is an algebraic method. The flowchart in Figure 2.5 demonstrates the solution steps briefly. Details of the simplex can be found in operations research concepts and cases (Hillier & Lieberman, 2005).

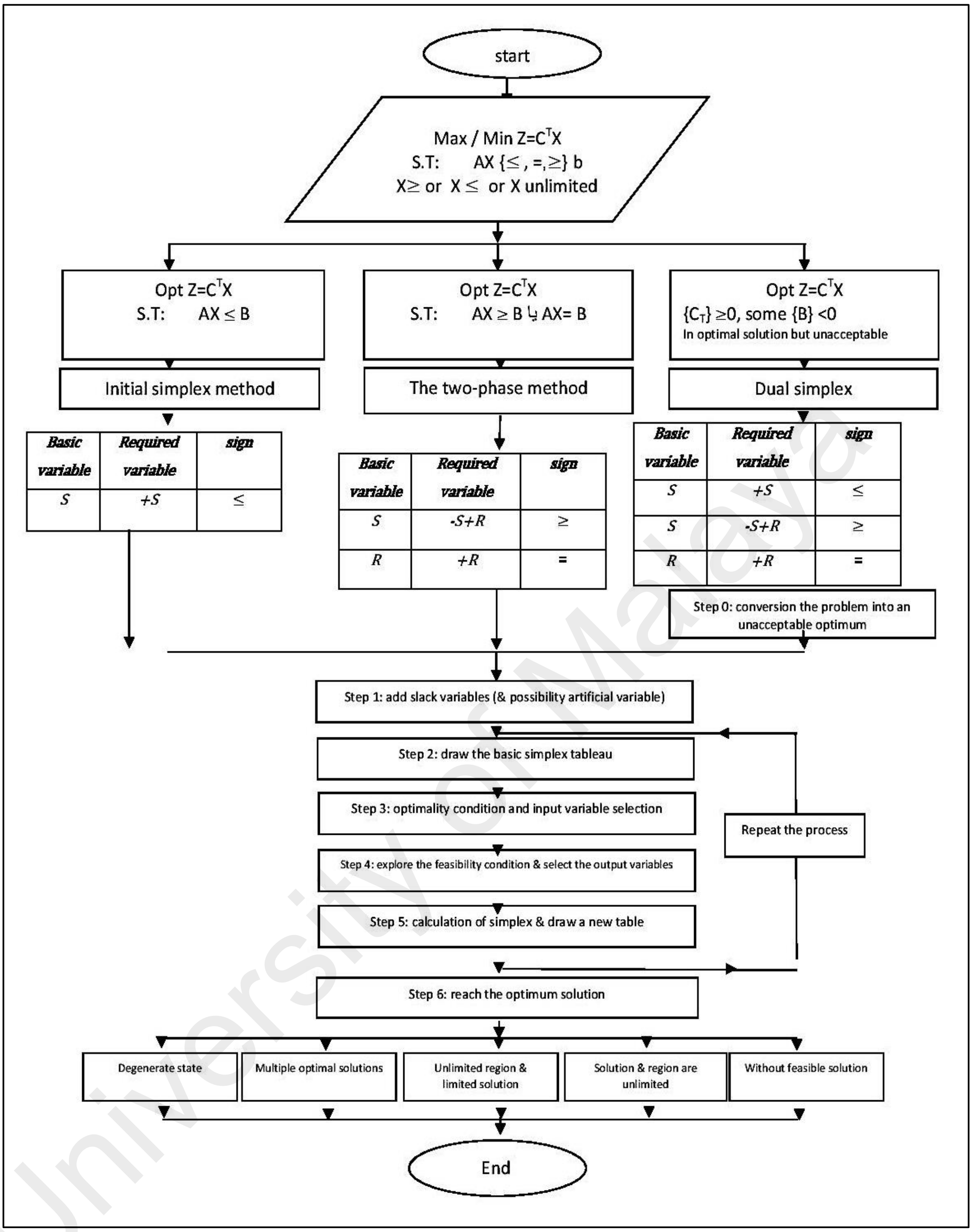

Figure 2.5: Steps to solve linear programming problems by using the simplex method

The interior point method is particularly efficient for solving large- scale problems. For small LP models, the interior point algorithm requires a relatively wide computing, then after repetition may only an approximation of the optimal solution be obtained. In contrast, the simplex method requires only a few instant repetitions to find optimal solution. For large LP models, the interior point method is very efficient, but it provides only one approximate solution. The comparison between these two methods have been discussed thoroughly in a study by Illés, T. and T. Terlaky (Illés & Terlaky, 2002).

In solving large-scale linear programming problems, we often encounter specially structured coefficient matrices. The most common structure is as follows:

$$\begin{pmatrix} A_{0,1} & A_{0,2} & \cdots & A_{0,k-1} & A_{0,k} \\ A_{1,1} & & & & \\ & A_{2,2} & & & \\ & & \ddots & A_{k-1,k-1} & \\ & & & & A_{k,k} \end{pmatrix} \tag{2.17}$$

Where are Ai,j ($0 \leq i \leq k$, $1 \leq j \leq k$) given matrices. When applying the simplex method in such cases, we can take advantage of the special structure, and in each simplex step (moving to a neighboring vertex) we are able to preserve this special structure.

Another special method is the decomposition technique, where the optimal solution of the large problem can be formulated by using a sequence of the solutions of much smaller problems, the sizes of each are determined by the sizes of the blocks Ai, (i = 1, 2, …, k). The most popular decomposition technique is the Dantzig–Wolf method, a discussion of which can be found in almost all texts of optimization. The classical text of Dantzig (1963) is a good source for further reading (Dantzig, 1963; Dantzig & Cottle, 1963; Wolfe, 1963)

If the objective function and one or more constraints are nonlinear, then the problem becomes one of nonlinear programming. In the case of only two variables, they can be solved by the graphical approach; however, the feasible decision space may not have vertices, and even if it does, the optimal solution might not be a vertex. In such cases, the curves of the objective function with different values have to be compared. This procedure is shown next.

2.4.4 Introducing popular optimization models

Nowadays, many optimization models of operation research, including linear model, nonlinear model and integer model can be easily analyzed by using computer software. Among them, some software like GAMS ،GINO ،LINDO ،LINGO ،QSB and TORA can be mentioned. There are many commercial software packages in the market to solve the mathematical models. The solving software package is generally a solver engine, which contains one or more algorithms for solving a specific class or a number of different levels of mathematical models, like simplex and interior point algorithm for solving LP model. Below is a brief introduction to some of the most popular models.

EXCEL SOLVER: Excel solver is a powerful tool for optimization problems. This solver can solve most of optimization problems like linear, nonlinear and integer programming. This tool was first created by Frontline Systems, Inc (Fylstra, Lasdon, Watson, & Waren, 1998). Excel solver uses Generalized Reduced Gradient (GRG2) algorithm in order to optimize nonlinear problems and also uses simplex algorithm for solving linear programming (Del Castillo, Montgomery, & McCarville, 1996; Kemmer & Keller, 2010).

LINDO: LINDO performs a robust solution for linear, nonlinear (convex and non - convex), quadratic, limited degree and integer optimization of probabilities. Demo version can solve models with 300 variables and 150 constrains (including 30 integer numbers) (LINDO Systems, 2013).

LINGO: LINGO is considered as a simple and also robust tool for solving linear and nonlinear programming (Xie & Xue, 2005). One of the major advantages of this tool is formulizing big problems briefly and analyzes problems. LINDO and LINGO software were designed by LINDO Systems, Inc. Company in order to solve optimization problems in university, industry and business. The mentioned products come with books operation research: applications and algorithms (1994) (Winston & Goldberg, 1994) and an introduction to mathematical programming: applications and algorithms (2003) written by professor Winston (Winston, Venkataramanan, & Goldberg, 2003). After GAMS, LINGO is the most robust software of operation research. Among the advantages of LINGO in comparison with LINDO or GAMS is its power in modeling problems that are modeled by LINDO, without the need to specify the type of model by the user. While, LINDO and GAMS don`t have such capability. Another important capability of LINGO is having a very robust, simple and complete Help. LINGO is a comprehensive language in order to facilitate all optimization models. Another specification of this software is having different mathematical functions, statistics and probability, ability to read data from files and other worksheets and high ability in analyzing model.

GAMS: General Algebraic Modeling System (GAMS) model is a professional software in solving mathematical optimization problems (Brooke, Kendrick, Meeraus, Raman, & Rasenthal, 1998). This software has a program for modeling with high capability in order to obtain optimal value of variables in objective function of a programming problem. GAMS is used for solving problems like linear programming (LP), nonlinear programming (NLP) and multiple integer programming (MIP) and multiple integer linear programming (MINLP) etc. One important specification of GAMS is that writing its model is independent from the solution. Therefore, we can solve the model with different methods (linear, nonlinear and integer) by only making changes in SOLVER. Interpreting the model of mathematical language to GAMS language is often transparent because GAMS use common English words.

MATLAB: MATLAB programming is undoubtedly one of the most robust computing programs in the field of mathematics, engineering and technology. There are many methods for solving linear programming problems. Among them, the simplex method has specific importance and efficiency for solving problems with average size. There are also some ways for solving large problems (equations with many variables). All the mentioned methods are in optimization toolbox of MATLAB and these features are used to solve, linear programming problems. We can simply write the specific functions and programs by using codes and functions of MATLAB. If the number is high, we can make a toolbox with them by assigning a subtype. In fact, MATLAB is a simple programming language with very developed characteristics. Also, this software is easier to use than the other computer languages (Venkataraman, 2009).

MPL: (Mathematical programming language), product of Maximal Software company, is a modeling system that allows developers to model efficient optimization formulation. MPL is able to solve problems with millions of variables and constrains. MPL works with optimization engines like CPLEX and XPRESS and many other robust industrial solvers. Trial versions are just used up to 300 constrains for a limited time.

Win QSB: (Quantitative Systems for Business) is a Windows-based decision-making tool. Win QSB is an educational tool that includes a number of modules that almost covers all basic methods of operation research and management science. The size of optimization problems can be worked with Win QSB is almost similar to LINGO and Solver or any other trial version. The model is flexible in almost any field and can analyze all models and parameters. The control chart of this software, in addition to charting, gives users other tools such as Pareto analysis charts, histograms, graph and efficiency of the process, analysis of data distribution and the corresponding computations.

2.5 Evolutionary Optimization Algorithms

Operation of the reservoir is one of the key issues among different water resources issues. An operation policy includes a set of laws which determines the amount of water that must be stored or released under different conditions of operation (Wurbs, 1993). Determining a proper utilization plan of water resources systems, in a way that a good performance would be gained from the system in all conditions, is called optimization. As a result, application of optimization method is required in order to determine the operation schedule of the reservoirs. Optimal Management of dam reservoirs can be very complex in the real world. Increasing complexity in engineering issues and having a systematic view to the management, particularly in water resources engineering reduced efficiency of classic methods. In recent decades, massive efforts have been done in order to develop and introduce algorithms that are more appropriate.

Meta heuristic algorithms are one of these methods, which have been used recently in many scientific studies. One difference between Meta heuristic algorithms and classic algorithm is to provide the set of answers at each step (Meta heuristic algorithms) instead of producing an Answer (classic methods). In this case, if the problem has only one optimal answer, it is expected that all answers of Meta heuristic algorithm will be congruent. Since many problems of water engineering only need good answers and somehow close to the optimal solution, therefore, the heuristic algorithms that guarantee such answers were considered.

Evolutionary algorithms are techniques that are based on random searches and are inspired by natural biological evolution. These algorithms work on the possible solutions that have superior characteristics. Evolutionary algorithms have no need for other knowledge and there is no restriction in defining the objective function. These algorithms are based on populations rather than individuals working for a single solution. Hence, the search can be done in parallel with each of the individuals. In the case of several optimal solutions (Pareto front) evolutionary algorithms are inherently efficient. Aforementioned reasons, range of applicability, ease of use and ability to achieve a global optimum solution make these algorithms the best among methods of solving complex optimization problems.

In almost all evolutionary algorithms, first a set of randomly generated solutions and a merit function is calculated, compared and ranked. Then the individuals with the best solution are chosen to improve the population in next step by mimicking natural processes such as mating, mutation and foraging. This is done until some of the individuals reach the optimum and the termination conditions are met (Figure 2.6).

2.5.1 Overall view of an evolutionary algorithm

- Creation of a random population
- Comparison and ranking between solutions
- Creating a new generation inspired by nature, e.g. mutation or crossover.
- Repeating stage two of the process.

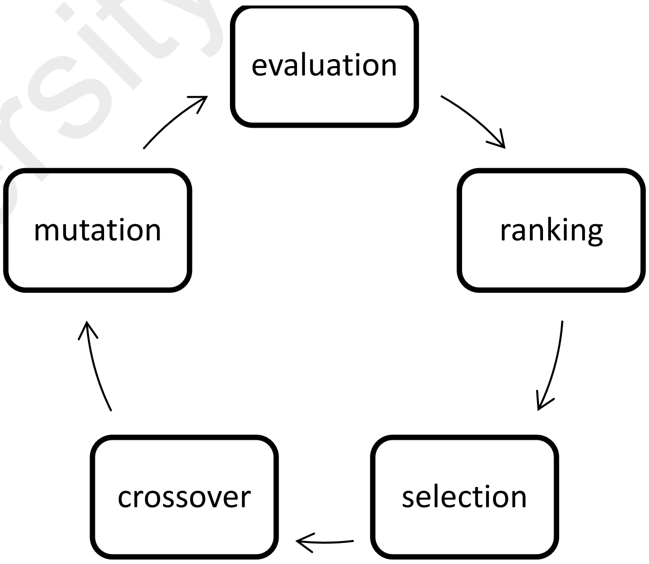

Figure 2.6: Procedure of an evolutionary algorithm

2.5.2 Genetic Algorithm (GA)

Using meta-heuristic algorithms became prevalent when first Genetic Algorithm was introduced by Golderg in 1989 (Goldberg, 1990). Genetic algorithm is one of heuristic algorithm that is considered in the field of water resources. East and Hall in 1994 (Esat & Hall, 1994) used this algorithm to model the four-reservoir system and discussed the high capability of this algorithm in modeling water resources systems. Another research, loucks and Oliveira in 1997 (Oliveira & Loucks, 1997), showed the ability of Genetic Algorithm in dealing with multi-objective reservoir systems. Wardlaw and Sharif also used a genetic algorithm to optimize a four-reservoir system, and showed that this method can provide valid and acceptable answers (Wardlaw & Sharif, 1999). A year later, this work was improved by Sharif and Wardlaw (Sharif & Wardlaw, 2000). Also, for a system of 10 reservoirs genetic algorithm was used which was designed by Murray and Yakowitz and were used by Vardla and Sharif. Accuracy of results of genetic algorithm for this problem is very acceptable (Murray & Yakowitz, 1979). In addition, Cai et al used a combination of genetic algorithm and linear programming in their study to solve nonlinear models of water management (Cai et al., 2001). Yuan et al also used a Genetic Algorithm as a method of combination with the chaotic optimization method and called it Hybrid Chaotic Genetic Algorithm. This method is used for finding optimal schedule of a hydroelectric system with consecutive power plants on the horizon 24-hours with intervals of one hour (Yuan, Yuan, & Zhang, 2002). Chang et al used Genetic Algorithm to find the rule curve of monthly optimization in a multi-objective of the single dam system in Taiwan (F.-J. Chang, Chen, & Chang, 2005).

In 2005, Ahmad and Sarma (Ahmed & Sarma, 2005) compared the results of Genetic algorithm and stochastic dynamic programming in optimizing multi-objective reservoir system and suggested that this algorithm gives more acceptable results in obtaining operation policies in reservoir systems.

Jian-Xia al in 2005 (Jian-Xia, Qiang, & Yi-Min, 2005), compared the binary-coded and real-coded Genetic Algorithms and found that real-coded Genetic algorithm results more earlier and reliable. This research also evaluated the algorithm components such as selection, crossover and mutation and suggests the best way of ordering them. In 2008, Cheng et al (C.-T. Cheng, Wang, Xu, & Chau, 2008) compounded the chaos algorithm and genetic algorithm to introduce a novel Chaos Genetic Algorithm CGA and applied it for the monthly operation of a hydropower reservoir. They concluded that this method results better in benchmark optimization problems.

Dariane and Momtahen applied linear operation policy and linear plot by doing reform bars in the genetic algorithm operators in the multi-reservoir systems(A. B. Dariane & Momtahen, 2009).

Wang et al in 2011 (Wang, Chang, & Chang, 2011) proposed a Multi-tier Interactive Genetic Algorithm to deal with large-scale systems with high dimensional variables in which the system is decomposed to small sub-systems and the optimal solution is found using the interaction of these sub-systems.

Considering several objectives together as approaching the problems, researchers tried to improve metaheuristic algorithms to be able to derive trade-offs between objectives. This led to advent of Multi-Objective Evolutionary Algorithm (MOEAs). Some proposed EAs by researchers are Non-dominated Sorting Genetic Algorithm (NSGA) (Srinivas & Deb, 1994), Niched Pareto Genetic Algorithm (NPGA) (Horn, Nafpliotis, & Goldberg, 1994) that has received good recognition. Cieniawski et al in 1995 (Cieniawski, Eheart, & Ranjithan, 1995) used Genetic Algorithm in a multipurpose problem of locating a network of groundwater monitoring wells and finally tried to obtain trade-off curves. They showed that GAs are able to find a large portion of Pareto Frontier but not all. Deb et al in 2002 (Deb, Pratap, Agarwal, & Meyarivan, 2002) introduced non-dominated sorting-based multi-objective algorithm which was called non-dominated sorting genetic algorithm II (NSGA-II), which was tested through benchmark problems and showed much better performance in deriving Pareto Frontiers. Schardong et al in 2012 (Schardong, Simonovic, & Vasan, 2012) used Multi-objective Differential Evolution to achieve optimal operation of a multipurpose multi-reservoir system and compared it with the results of NSGA-II. The objectives included minimization of demand shortage, maximization of water quality and minimization of pumping cost.

2.5.3 Particle Swarm Optimization (PSO)

Particle Swarm Optimization is one of the population-based random search algorithm, presented for the first time by Kennedy and Eberhart (Kennedy & Eberhart, 1997). Particle Swarm Optimization algorithm (Eberhart & Shi, 1998, 2001) is based on the simulation of the movements of birds and fish in a swarm behavior. Like other evolutionary techniques, this algorithm consists of a population of potential solutions, which tries to explore the search space. The main difference between this method and other methods is that each particle has a velocity vector, which helps the particle to change the direction and improve its position in entire search space.

Kumar and Reddy used proposed particle swarm algorithm as elitism mutation of influx particles to solve the famous problem of Larson four reservoirs. Then, they compared results of different methods with those of this method and reported that this method has many advantages over all other methods tested. (Nagesh Kumar & Janga Reddy, 2007).

In recent years, several single-objective water systems have been modeled using Particle Swarm Optimization algorithm. For example, Montalvo et al in 2008 (Montalvo, Izquierdo, Pérez, & Tung, 2008) used this algorithm in two cases: water distribution network and water supply tunnel system in New York. Their objective was to compare the previous results with the ones obtained by PSO. Shourian et al used the combination of particle swarm algorithm and MODSIM for the design and operation of the Sirvan reservoir system (Shourian, Mousavi, & Tahershamsi, 2008). Cheng et al in 2009 (C.-t. Cheng, Liao, Tang, & Zhao, 2009) compared DP and PSO algorithm applied in obtaining sample load curve of hydropower plant. Results showed that PSO is applicable in such problems.

In recent years, several reforms have been applied to PSO algorithm. Most of these changes have improved the applicability of the algorithm and some other has caused PSO to act better in some specific sort of problems. For example FPSO (Fuzzy PSO) and binary PSO, which was introduced by Kennedy and Eberhart in 1997 (Kennedy & Eberhart, 1997). In binary variation, every particle represents its position in binary values which are 0 or 1. In Fuzzy PSO algorithm velocity vector is presented in fuzzy mode (H. Liu, Abraham, & Zhang, 2007; Shi & Eberhart, 2001).

Zhang et al used combination of article swarm and genetic algorithms to optimize energy in a multi-reservoir system (Zhang, Wu, Cheng, & Zhang, 2011). In 2013 Afshar (M. Afshar, 2013) proposed a constrained version of PSO in three variations called Partially Constrained PSO one (PCPSO1), Partially Constrained PSO two (PCPSO2) and Fully Constrained PSO (FCPSO). It showed that PCPSO1 might violate the feasible search area. Therefore, PCPSO2 is introduced by a modification of the storage volume bounds to remove the flaws of first algorithm and hence enhanced to FCPSO version of the PSO. Results obtained from two benchmark problems were compared with other algorithms and showed the superiority of proposed version.

In most cases in which there are several objectives to handle with simultaneously, MOPSO can be used to deal with such problems. In 2007 Reddy and Kumar (Nagesh Kumar & Janga Reddy, 2007) studied on elitist-mutated particle swarm optimization (EMPSO) technique to obtain operation policies applied in multipurpose reservoir system. They used elitist-mutation technique to improve the performance of standard

PSO. At the end they discussed that EMPSO yields better solution compared to Genetic Algorithm with less function evaluation. In 2007 these researchers also (Reddy & Nagesh Kumar, 2007) offered EM-MOPSO which they discussed that it gives more efficient results and good convergence in reaching a true Pareto Front. To facilitate its application in reservoir problem they used a decision-making approach and showed its competency in obtaining results.

In 2008 Baltar and Fontane (Alexandre M Baltar & Darrell G Fontane, 2008) used MOPSO (Multi-Objective Particle Swarm Optimization) to solve a multipurpose problem. It was applied to a problem of four objectives. They concluded that PSO resulted in very encouraging results compared to other evolutionary algorithms. In 2011 Ostadrahimi et al (Ostadrahimi et al., 2012) employed a new approach called MSPSO (Multi-Swarm Particle Swarm Optimization) accompanying HEC-ResPRM simulation model to estimate the parameters of the rule curves in a multi-reservoir system. In this research the simulation model evaluates the objective function for each set of the population made through a new mechanism named multi-swarm PSO algorithm.

2.6 Principles of Cropping Patterns

2.6.1 Cropping Pattern Definition and Advantages

The optimal use of natural and human resources is an important economic and social objectives that in this case, fundamental and sweeping changes in the structure of agriculture, the extensive involvement of staff and favorable management factors of production, are necessary to develop the agricultural sector in the country. In this communication, design and adjust the cropping pattern to determine the amount of cultivated area and the right combination of products, is utmost important and should be done in such a way that in addition to the optimal use of existing capacities and access, regional and national needs are considered.

There are many definitions for cropping pattern, which it seems the most comprehensive definition is: "cropping pattern refers to determining an agriculture system with an economic advantage based on state macro politics, local knowledge of farmers and optimal operation of regional potential observing ecological principles of products along with preserving the environment." In addition, cultivation combination means "The proportion of dedicating fields of an area to various agricultural and garden products."

The definition shows that in many regions of the state, growing agricultural and horticultural crops or operation of fields and forests suits regional potential. Climatic restrictions, negative balance sheet of valleys water and the need of production stability make us to move in a way to improve underground water and increase water consumption efficiency.

In fact, the most important finding of crops pattern and cultivation combinations can be outlined as follows.

- Improving water efficiency coefficient for agriculture products and scientific use and optimal operation from other production institutions.

- Modifying operation system of natural resources and controlling instability factors of these resources and effort for maintenance and development.
- Promoting efficiency and paying attention to economics, security and political values of water in its acquisition, presentation, maintenance and consumption.
- Increasing water acquisition rate, minimizing natural and unnatural water wastes.

2.6.2 Performing Cropping Pattern Consideration

- Performing appropriate cropping pattern guarantees food security and production stability.
- Performing appropriate cropping pattern is necessary for protecting basic resources and increasing efficiency production factors.
- Performing appropriate cropping pattern requires coordination and cooperation of power ministries, agriculture and commercial institutions.
- Accessing stable production in agriculture is in lieu of appropriate operation and efficiency of basic resources.
- We can guarantee production stability and food security with performing appropriate cropping pattern.
- We should consume water along with the optimal cropping pattern.
- Paying attention to state climatic conditions, guarantees performing appropriate cropping pattern and production stability.
- With collecting required rules and terms, basis of performing appropriate cropping pattern is provided.
- Performing appropriate cropping pattern requires common intrinsic county planning.
- Performing optimal cropping pattern causes to preserve natural resources.
- With performing an optimal cropping pattern, we reduce adverse effects of drought.

2.6.3 Previous Studies of Cropping Pattern

The complexity of water resource problems leads to increase the application of systems analysis approaches. Optimization makes it possible to model a process mathematically along with its constraints. After that, the model could be optimized utilizing optimization techniques.

Aside from the optimum cropping pattern, the policy makers, employers and managers in the agricultural sector are very interested to be informed about the amount of agricultural inputs (such as fertilizers) before the agricultural activities commence. This knowledge helps them to know the funding requirements as well as storing, maintaining and managing the agricultural process.

Most of the resources, restrictions, aims and sensitivities of these kinds of matter that can be compiled with developing models based on linear programming are considered and determined an optimal cropping pattern. Here are examples of some studies that have been conducted on determining an optimal cropping pattern especially with the help of computer software and programming models. Bayat (1999) determined the optimum cultivation pattern in terms of integrative use of surface and groundwater resources in Borazjan plain. The results showed that the programming efficiency of implementing the optimum pattern will be increased respectively 33% and 21% for utilizations of 6 and less than 6 hectares and utilizations of more than 6 hectares compared to their current pattern. Also, several studies were done in and outside of Iran by using the application of mathematical programming techniques in relation to the present study, which are briefly referred to some of them. Matanga and Mariño (1979) have done a test in which irrigation programming was with respect to the agricultural pattern and with the help of dynamic linear programming. These researchers aimed to maximize gross interest for different products, with respect to water availability limitations in different periods, system capacity, task force and other possible resources. Lamers and Bruentrup (1996) estimated the economic profitability of five options on fodder crops in West Africa by using linear programming. Based on these results, the proposed model includes a set of options in which, the economic benefit is at the highest level possible. The results show that the use of forage for livestock feed has the most profitable and the burning forage is involved minimum benefit for farmers. Omoregie and Thomson (2001) have studied the competition in oilseeds production using linear programming method in Nigeria. In their study, oilseed production is limited by the constraints of land and oil extraction plants. They concluded that the Middle Belt region is the most economical area in grain production than other areas because of its central location, and it has the highest shadow value per hectare. On the contrary, the West has the least shadow price per hectare of land. The results of this study are concerned that transportation costs as the main factor in reducing the profitability of oilseed production. D. Singh, Jaiswal, Reddy, Singh, and Bhandarkar (2001) used linear programming to optimize cropping pattern in Pakistan. Maximizing the net income was the objective function. Total available water and land during different seasons, the minimum area under wheat and rice for local food requirements, farmers' socio-economic conditions, and preference to grow a particular crop in a specific area were constraints. Based on the results, wheat was found to be the most profitable crops. Doppler, Salman, Al-Karablieh, and Wolff (2002) provided the optimal pattern of water and cultivation together for the Jordan valley using the approach of MOTAD risky planning. Based on the results, it was found that even if the risky considerations are included in the model, the share of cereals would be increased due to the lack of cereals' price fluctuations in the risky pattern. Francisco and Ali (2006) analyzed the interaction and dynamic effects between various production technologies, activities and constraints among vegetable growers in Manila Taiwan. In this study, the minimum variance pattern was used for incorporating the risk. Other researchers such as

(Lakshminarayana & Rajagopalan, 1977; Low, 1974; Sahoo, Lohani, & Sahu, 2006; D. Singh et al., 2001) have used linear programming to determine the cropping pattern.

In recent years, researchers have used different approaches to management and obtain the optimal irrigation plan (Hoesein & Limantara, 2010; Noory, Liaghat, Parsinejad, & Haddad, 2011; Regulwar & Gurav, 2011). They also frequently have used mathematical programming techniques such as Linear Programming (Igwe, Onyenweaku, & Nwaru, 2011; Scarpari & de Beauclair, 2010), Chance constrained linear programming (Jothiprakash, Arunkumar, & Ashok Rajan, 2011), Fuzzy Dynamic Programming (Safavi & Alijanian, 2010) and evolutionary algorithms such as genetic algorithms (Pandey, Ostrowski, & Pandey, 2012) ,Pareto based evolutionary algorithms (Márquez et al., 2011) and strategies of differential evolution (Otieno & Adeyemo, 2010) to get the optimum cropping pattern. The purpose of many of the studies has been the efficient use of land (Barakade, Tonape, & Lokhande, 2011), reduced water consumption (Boustani & Mohammadi, 2010), increasing farm income (A. Singh, 2015) improve soil fertility, sustainable productivity (Ali, Awan, Ahmad, Saleem, & Akhtar, 2012) and maximizing the net profit of the agricultural sector and ensuring the efficient allocation of the scarce water resources and arable farmland among the competing crops (Alabdulkader, Al-Amoud, & Awad, 2012). In some studies, the impact of various factors in conflict with crop patterns is investigated. Among them can be mentioned such as the impact of water pricing strategies (Doppler et al., 2002), the impact of climate change (Kaur, 2011), the effects of organic manure and Fertilizer (Bodruzzaman, Meisner, Sadat, & Hossain, 2010; Islam et al., 2011), and risk management (Mandal, 2010) .

CHAPTER 3: METHODOLOGY

3.1 Introduction

The operation of multi-purpose, multi-reservoir systems is a complex decision-making problem. At each decision time, the operator has to decide how much water to release from the system, and how much to keep in storage for future use. The operator also has to decide which reservoirs will be used to meet the chosen system release. In addition, if the amount of water released is not sufficient to meet all demands, the operator has to allocate the water shortage among the various water uses. All these decisions have to be made under the uncertainty of future hydrological conditions and water demands.

Typically, reservoir systems are operated through a nested or hierarchical approach consisting of a number of interconnected decision levels. Each decision level has different concerns from long-term system goals to short-term operational objectives. The decision process starts at the long-term level, and a sequence of decisions with shorter horizons is made until reservoir release decisions are actually evolved. The decisions taken at the lower levels depend on the decisions taken at the upper levels. Some nested approaches have feedback loops that convey the output of the lower decision levels to the upper levels for iterating and updating.

The nested approach is a convenient form of decomposition of large and complex problem into smaller and simpler problems. This approach also has the advantage of separating the different types of decisions. General policy decisions, like the agreement on long-term contracts, concerning the firm power and water supply capabilities of the system, are made at the long-term decision level. Medium-term operation is concerned with the operation of the system for the next season, which may be of several weeks or months. The system operator is usually concerned about determining the best way to satisfy the targets established at the long-term decision level. The purpose of short-term operation is to provide a plan in the immediate future, usually the next day or hours. The decisions at this level have to be much more detailed and technicalities such as daily schedules of water and power use, efficiency curves versus output of power generating units and losses in transmission lines have to be considered.

At all decision levels, the system managers and operators attempt to choose the set of decisions that maximizes the expected benefits generated by the system operation during the horizon designated for that decision level. Alternatively, they can seek to minimize the cost of achieving targets specified at upper decision levels. In either case, the decisions have to satisfy all constraints on the system operation that arise from the water availability, physical characteristics of the system and from legal contracts and agreements accepted by the system owners, managers and users. The system manager or operator usually has available a number of decision-aid tools. Typical tools are sets of charts and tables specifying a pre-defined operating policy, computer simulation models that estimate the impact of alternative decisions and computer optimization models that determine the set of releases that maximize or minimize some specified objective function.

Predefined operating rules are by far the most common decision aid tool in reservoir operations. These rules are used to specify medium to long-term operating policies. They indicate the actions to be taken by the system operator based on a small number of variables that describe the state of the system. They are usually defined by sets of tables and/or charts that are easy to read and understand. The detail of these pre-defined rules varies widely. Some rules only specify some long-term target releases or storage levels and leave considerable freedom to the operator to exercise his/her judgement on the short-term decisions. Others are more complete and provide more indications on what to do for any hydrological situation, and are therefore more amenable to be used for medium-term decisions.

Predefined rules were originally designed without reference to a computer, but they are increasingly being incorporated into computer models. Optimization routines are now being used to determine the set of releases that minimizes the deviations from the targets specified by the rules, while satisfying all constraints on the system operation. These optimization routines can be included in simulation models to define reservoir releases in these simulations or they can be used alone to define actual reservoir releases to be made at every decision period.

However, included in the optimization models there are several pre specified rules that define target pool levels or specify the economic value of hydro-energy in storage. The distinction between simulation and optimization models is based only on the purpose for which the model is to be used. Simulation models are run numerous times to evaluate alternative policies under different hydrological scenarios. Based on the output of the several model runs, the system manager or operator is able to make a more informed decision. Optimization models are usually run once to determine the set of releases that maximizes the specified system objectives, although they sometimes are run more than once for sensitivity analysis.

The distinction between a simulation and an optimization model based on the mathematical techniques included in the models, is not so clear. A simulation model may have optimization routine to compute the releases that maximize the system objectives. Likewise, an optimization model must have embodied some kind of a simulation model that simulates the system behavior. Simulation models are a fundamental tool in water resources management. They allow a detailed representation of the system, which make their results easy to explain and accept, and enable the study of the impact of streamflow stochasticity. Simulation models are used at all levels of the decision-making process. In the long-term decision level, they are used to assess different long-term operating policies and to decide upon the firm energy and water supply values. At the medium to short-term levels, they are used to assess the performance of alternative release decisions for different hydrological scenarios. Numerous simulation models have been designed and are routinely being used as decision-aid tools.

Unlike simulation models, optimization models are usually run only once to determine the policy that maximizes the specified operational objectives given the state of the system, hydrological forecasts and operation constraints. The system manager or the operator is not required to follow exactly the model recommendations since some particular features of the system may not have been included in the model. But if the model is to be of any help, the final release decision should be guided by the model results. Optimization models may be used at all levels of the decision process. At a planning stage, optimization models can be used to determine the long-term operational goals, such as the firm supply of energy or water, so that contracts can be drawn. In real-time operation, they can be used to compute the reservoir releases for every operational period. In this case, the optimization model is run each time a decision has to be made and its results are taken into consideration before implementing any release decision. At the end of the operational period, the variables representing the system state and hydrological forecasts are updated, and the model is run again for the next operational period.

The following flowchart shows the methodology of the problem, classified by main objectives. Output, calibration and validation methods are also shown in the Figure 3.1.

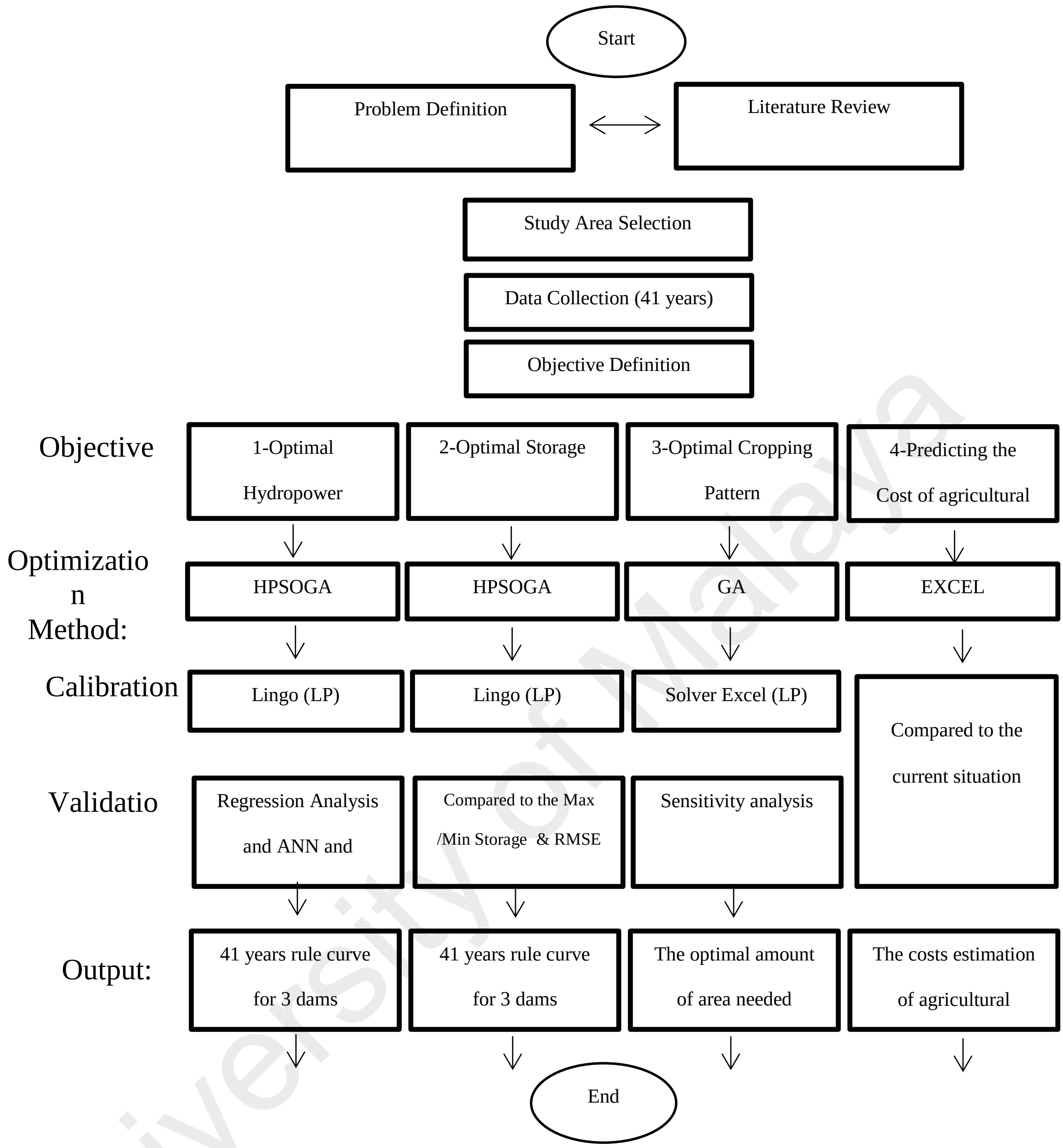

Figure 3.1: Summary of applied methodology in this study

3.2 The Study Area

3.2.1 Karun and Dez catchment

The Karun and Dez catchment area is located in the Khuzestan Province. The Khuzestan Province is located between latitudes 29-58' to 32-58' N and longitudes 47-42' to 50-39' E in the southwestern corner of Iran. It is bordered by the Lorestan, Isfahan, Ilam, Chaharmahal and Kohgiluye provinces. Khuzestan is bordered on the South by the Persian Gulf and on the west by Iraq. Its area is over 66,532 km^2.

Khuzestan has 15 counties: Ahwaz, Abadan, Andimeshk, Izeh, Bagh Malek, Mahshahr, Behbahan, Khoramshahr, Dezful, Dasht, Azadegan, Ramhormoz, Shadegan, Shushtar and Masjed Soleyman. Furthermore, the province has 28 towns, 35 rural districts, and 113 villages. The provincial center is Ahwaz.

Khuzestan is the center of almost half of the oil and gas industries of Iran as well as one of the major regions for steel and cement production. Khuzestan is a land of vast plains and high altitudes. It has the greatest number of Hydroelectric Dams, such as Dez, Shahid-Abbaspoor, Maroon, Karkheh and Godar Landar, in the whole country.

Six major rivers (Karun, Dez, Karkheh, Zohreh, Maroon, Jarrahi) make the land of Khuzestan one the most fertile lands in Iran and thus agriculture is one of the main activities in Khuzestan. It is one of the few provinces in Iran, which has access to free international waterways through the Strait of Hormuz.

The study area covers the catchment of Karun and Dez river basin with a total catchment area of 58,180 square km^2.

The area is divided to 30 watersheds in 2 main basins. Those watersheds contribute water inflows into main rivers. The following map (Figure 3.2) illustrates the watersheds and their connectivity with the main rivers.

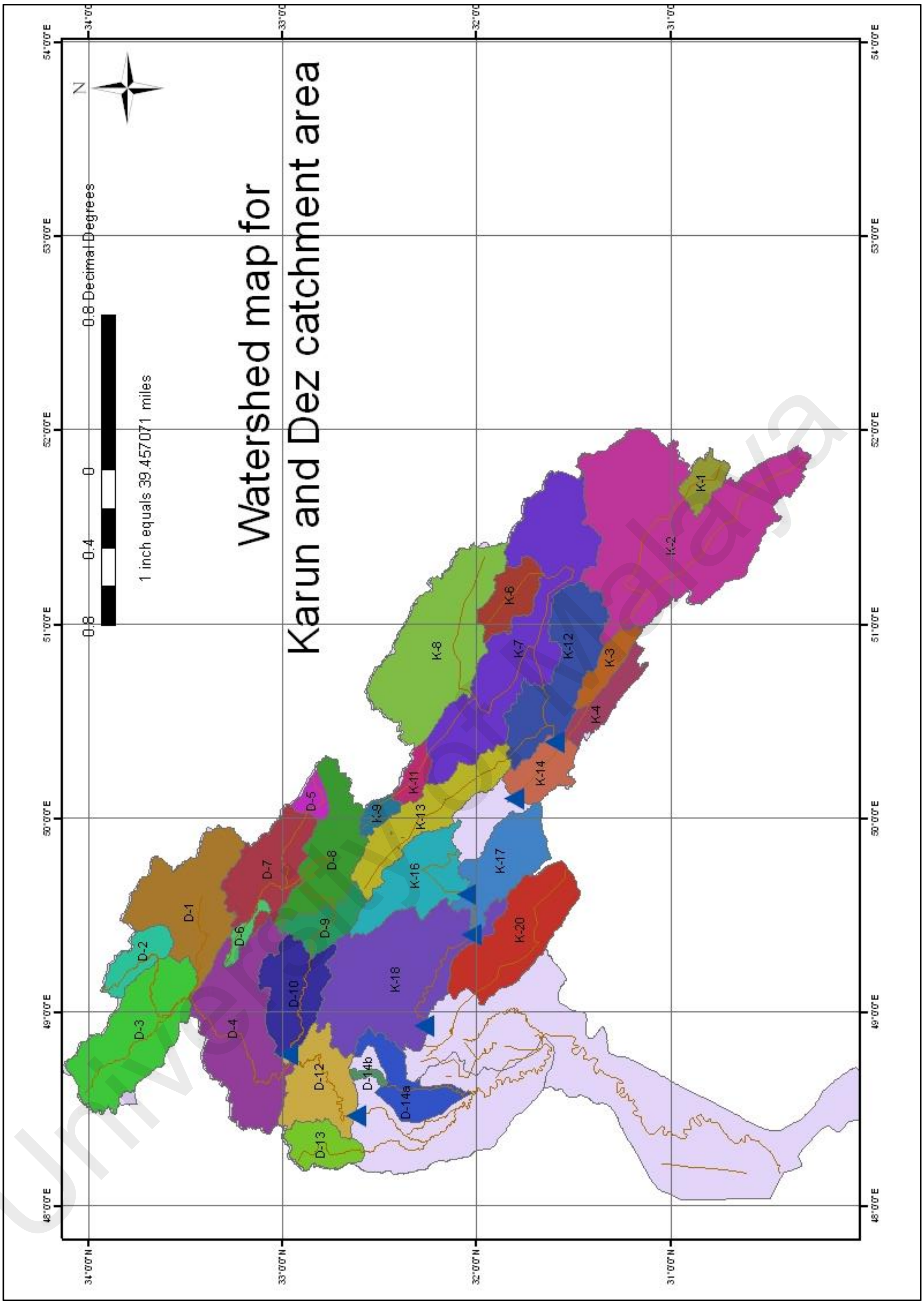

Figure 3.2: Watershed map for Karun and Dez catchment area

As we can see in Figure 3.3 there are 8 reservoirs. Some of the reservoirs are under construction.

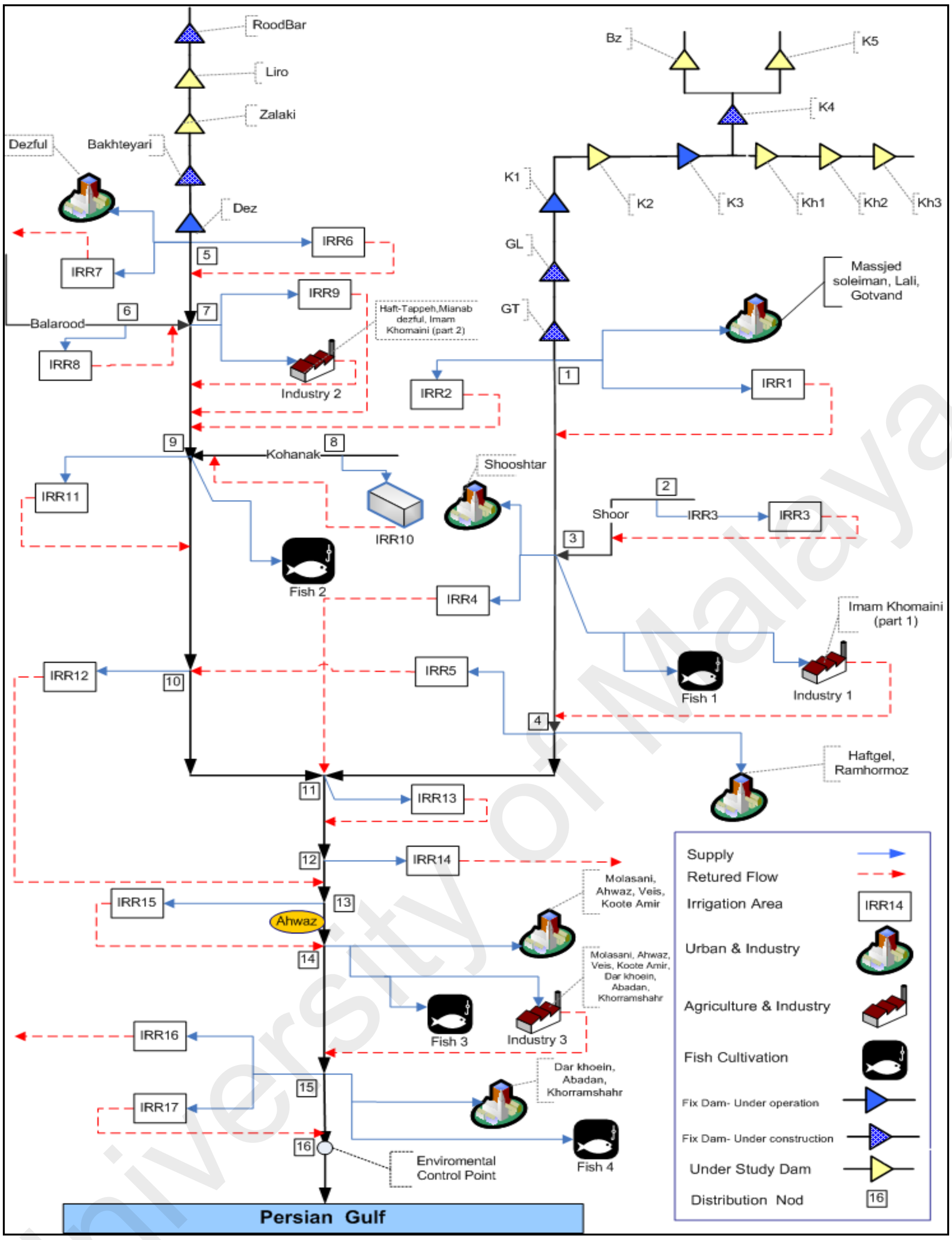

Figure 3.3: Schematic picture of Dez and Karun Reservoirs System and consumption areas

3.2.2 Flood control in the current situation

The Khuzestan flood plain conditions significantly changed since the Dez, Karun I, Karun III and Karun IV dams came into operation. The dams are operated with three key objectives (Water supply, Hydropower generation, and flood control) flood control being one of the most important of them. Some dams such as Karun II are currently under construction. A greater part of the regional flood problem will be alleviated after these dams come into operation. The determination of the attenuation by the existing dams of the downstream floods is the main objective of the reservoir flood control simulation.

Karun IV, Karun III, and Karun I at the Karun catchment has been considered in the study of implementation of downstream flood mitigation plans. It must be mentioned that the Godar-E-Lander dam, which has 200 MCM reservoir volume and negligible fluctuations in the reservoir level (6 m fluctuation between Normal Water Level (NWL) and Minimum Operation Level (MOL)), does not have any effect on Karun river floods. This dam is run off-river and operated for hydropower. For this reason, this dam was not considered in the flood control simulation and the downstream flood computation.

The safety capacity of the Karun River at different locations are as follows:

Karun River has 5000 m^3/s of maximum capacity at Ahwaz. The Karun maximum discharge at Faarsiat is approximately 2500 m^3/s after the water diversion into the Shadegan estuary. There is no evidence of flood damage from the Dez River down to the BaamDezh area for discharges smaller than 2500 m^3/s. The flow naturally diverts to the waterway for discharges greater than 1500 m^3/s. The Karun estimated river capacity between Mollasani and Vais is 6000 m^3/s.

Dams Characteristics

The physical characteristics of the reservoirs and dams and their flood control rules affect the downstream flood magnitude. Figure 3.4 depicts the river system considered in the flood mitigation studies. The relevant features of the dams are shown in Table 3.1.

Table 3.1: Relevant features of dams under study

Name of Dam	Normal water level (masl)	Minimum operation level (masl)	Maximum permissible level (masl)	Crest level (masl)
Karun IV	1025	996	1028	1032
Karun III	845	800	848	850
Karun I	530	500	532	542

The spillway rating curves and volume-area-elevation curves for each of the dams of the study are shown in Figure 3.5 to Figure 3.10. The normal and maximum operating levels determine the reservoirs flood control volume, which is an essential flood control parameter. The maximum level has been calculated from the gate height in normal conditions or from the allowable rising level in a flood situation.

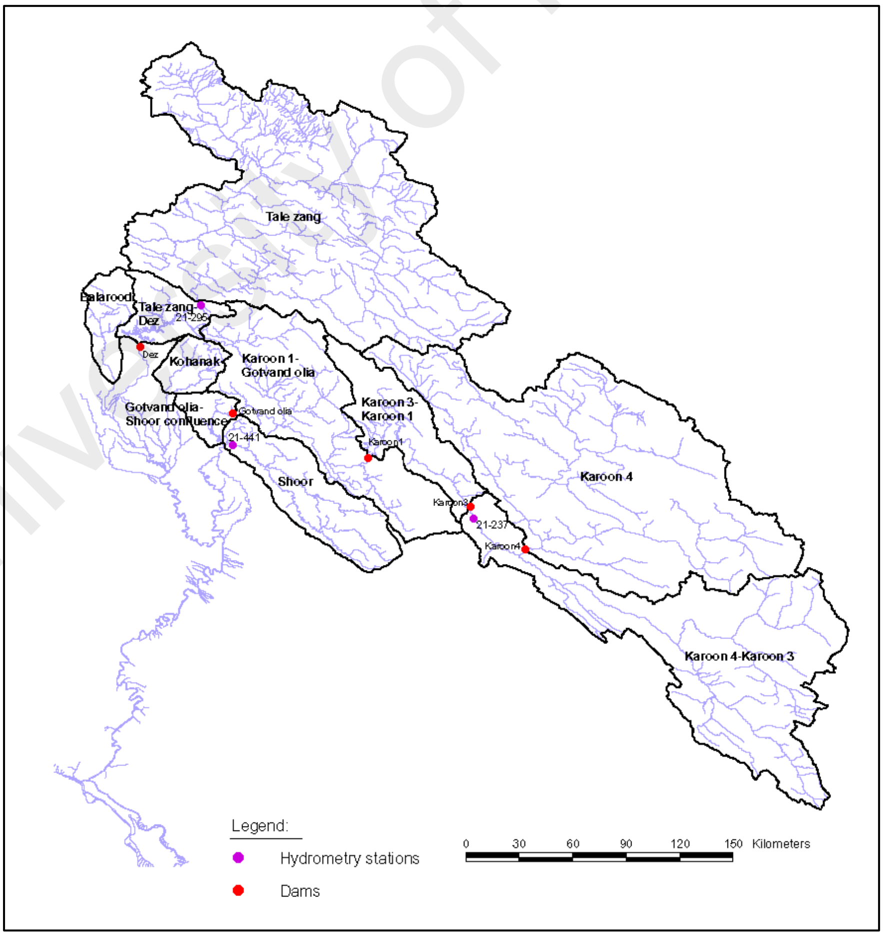

Figure 3.4: Dams and Sub-catchments considered in the flood study

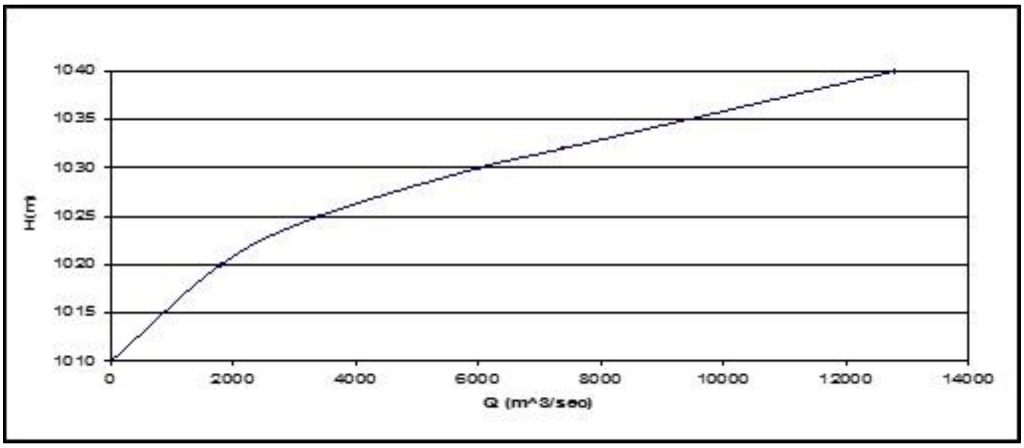

Figure 3.5: Rating curve for Karun IV spillway

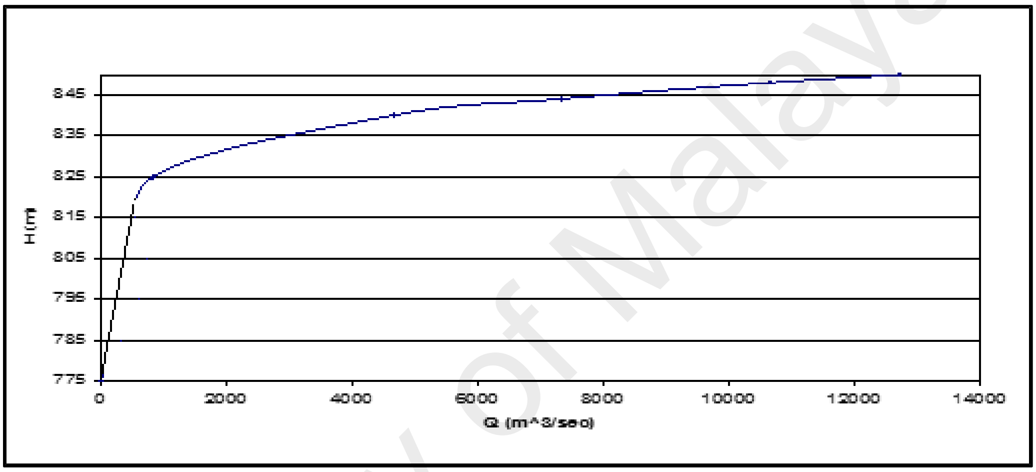

Figure 3.6: Rating curve for Karun III spillway

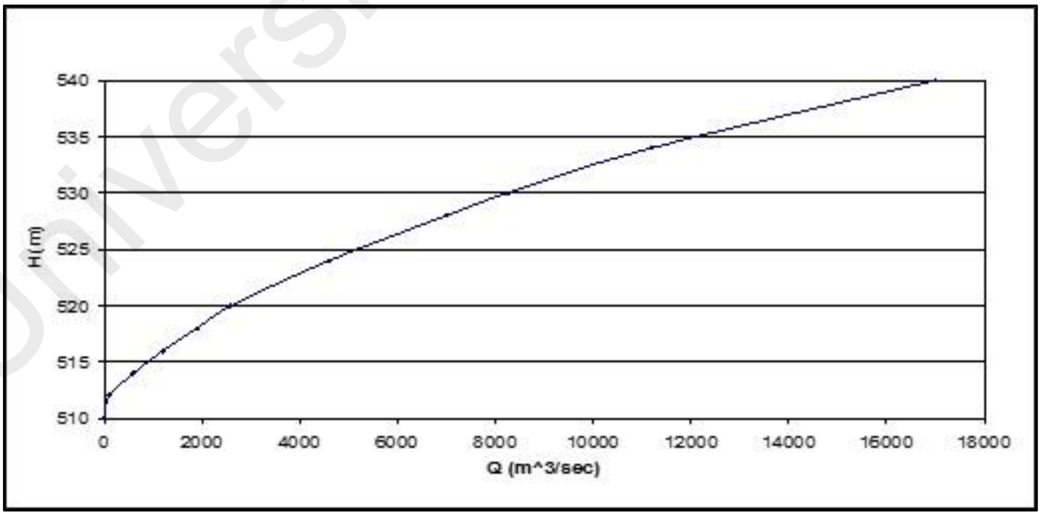

Figure 3.7: Rating curve for Karun I spillway

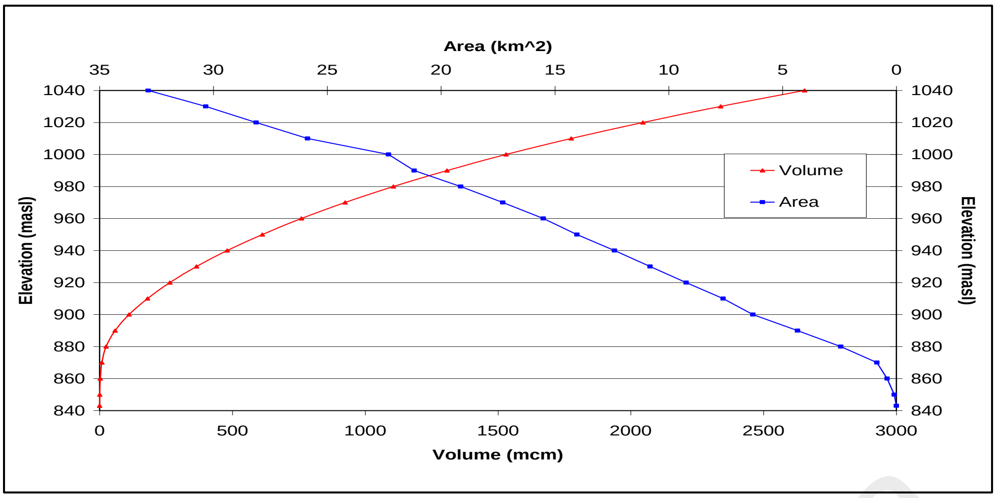

Figure 3.8: Area-Volume-Elevation relationship for Karun IV reservoir

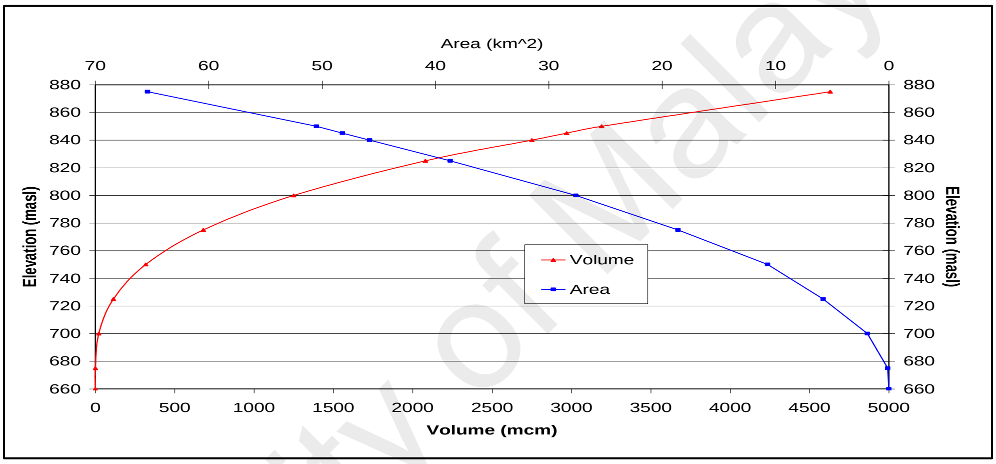

Figure 3.9: Area-Volume-Elevation relationship for Karun III reservoir

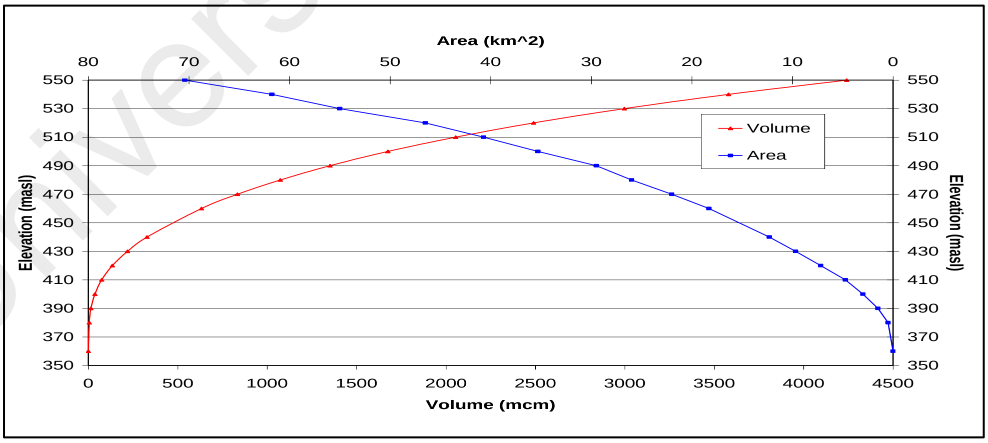

Figure 3.10: Area-Volume-Elevation relationship for Karun I reservoir

3.2.3 Hydropower in the current situation

Water resource system planners have always regarded Karun river system very important for the Iran's largest hydropower potential. Topography of the river basin before entering the Khuzestan plain has created very suitable sites for the construction of reservoir dams for hydroelectric energy production (Sadeghian, Heydari, Niroobakhsh, & Othman, 2016).

This power planning study is being carried out as part of the River Karun Catchment Study, with particular focus on the sequence and timing of the commissioning of the Karun River hydropower cascade schemes. This initial run of the power planning study does not incorporate the results of the cascade simulation for optimum flood capture and other water uses. Based on the results of this power planning study the cascade modelling will need to be revised and optimized.

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3.3 Methods

In the present study, the system consists of three dams (Figure 3.11) with the aim of producing hydroelectric energy, supplying downstream needs and controlling floodwater. Also in this study, three different algorithms for solving two different approaches have been used. The three main mentioned algorithms are as follows: Genetic Algorithm, Particle Swarm Optimization algorithm and the Linear Programming algorithm. The two approaches are single-objective optimization by using compromise programming and multi-objective optimization using Non-Dominated sorting Genetic Algorithm (NSGA-II). In addition, the model of water loss through evaporation has been considered in this study. The uncertainty in the model has been considered as three reservoir inflow scenarios.

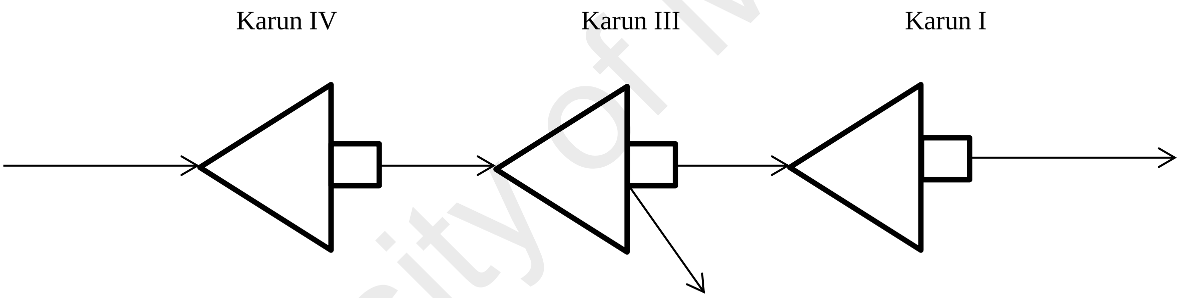


Figure 3.11: Schematic view of a multi-reservoir system of Karun

The objectives of this model include agricultural water supply, drinking water and power plant water supply and also the economic purposes. Due to the shortage of water in Iran as well as the priority of water supply for agricultural, drinking and power purposes, the economic outlook is the secondary concern. There are other purposes such as, flood control and recreational views, which are of particular importance due to their contrast in optimal allocation for agriculture, drinking purposes, etc. based on the amount of water level and storage behind the dam. The above-mentioned objectives along with the management of the catchment for the benefit all of the stakeholders, increase the importance of challenges presented later in preparing this model. In general, the three purposes used in this model are agricultural water supply, energy production and flood control in certain months of the year. The model is optimized by evolutionary algorithms and the balance between the objectives is shown in Pareto curves.

3.3.1 Description of the optimization problem

In this study, the intended objectives consist of downstream supply, hydroelectric energy production and flood control (especially in certain months of the year, i.e., March, April, May, June, July and August). The reservoir's output from hydroelectric turbine and reservoir storage volume in each period is taken as the variables of the problem. Each of the three functions is defined by minimizing the sum of squared distances from each goal amount of water in a year as described below.

The first objective function is related to providing downstream water (Equation (3.1)). This function is defined by minimizing the subtraction of the goal amount of water, which is

$$Minimize\ Z_1 = \sum_{j=1}^{3}\sum_{t=1}^{T}\left(\frac{R_{jt}^{demand} - D_{jt}}{D_{jt}}\right)^2 \tag{3.1}$$

In this equation Z_1 Presents the objective function, j represent the reservoirs in the model such as, the Karun IV, Karun III and the Karun I, respectively (Equation (3.1)). R_{jt}^{demand} is the variable of the monthly release from the j^{th} dam and D_{jt} is the downstream requirement from each dam.

The second function presents the hydroelectric energy production from existing power plants on reservoirs (Equation (3.2)). This function can be defined as the difference in the distance between power productions with the goal value which is the capacity of power plants installed according to megawatt or gigawatt hours of energy per month.

$$Minimize\ Z_2 = \sum_{j=1}^{3}\sum_{t=1}^{T}\left(\frac{P_{jt} - Power_{jt}}{Power_{jt}}\right)^2 \tag{3.2}$$

In this equation Z_2 presents the function, P_{jt} as the value of hydroelectric production variable in the j reservoir in each month of the year, $Power_{jt}$ as the value of power plant installation capacity in jth reservoir (Figure 3.11) which is 1000 megawatt for the Karun IV reservoir, 2000 megawatt for the Karun III reservoir and 2000 megawatt for the Karun I reservoir.

To test the performance of the desired developed algorithm to solve nonlinear and non-convex problems in the field of water resources management, utilization optimizing of hydropower energy of Karun dams in southern Iran has been selected.

In this issue, the objective function is defined in the form of minimizing the loss of production comparing to the plant installed capacity.

$$Minimize \quad F = \sum_{t=1}^{T} \left(1 - \frac{P(t)}{PPC}\right) \tag{3.3}$$

Where in the above relationship, P(t) is production in period t and PPC is plant installed capacity.

In order to calculate the production, in addition to the amount of water released from the reservoir, effect of the amount of water on turbines should be defined, too. Therefore, the issue of hydropower optimal operation of reservoir has non-linear constrained and its searching environment is non-convex. In general, the constraints of this issue can be defined as follows:

$$P(t) = \min\left[\left(\frac{g \times \eta \times r(t)}{PF}\right) \times \left(\frac{h(t)}{1000}\right), PPC\right] \tag{3.4}$$

$$h(t) = \left(\frac{H(t) + H(t+1)}{2}\right) - TWL \tag{3.5}$$

$$H(t) = a + b \times S(t) + c \times S(t)^2 + d \times S(t)^3 \tag{3.6}$$

$$S_{min} \leq S(t) \leq S_{max} \tag{3.7}$$

$R_{min} \leq R(t) \leq R_{max}$ (3.8)

$S(t+1) = S(t) + Q(t) + R(t) - loss(t)$ (3.9)

$r(t) = c(t) \times R(t)$ (3.10)

In the above formulas, g is gravitational acceleration (in m/s^2), power-plant output, PF is plant factor, h(t) is effective water load on power-plant is calculated by (using (3.5), H(t) is reservoir balance in the period t (a function of reservoir volume in period t), R(t) is the water flow rate passing through the turbine in period t, S (t) is reservoir storage at the beginning of period t, Q (t) is inflow amount into the reservoir in period t, losst the lost amount in the period t, R_{min} is minimum amount released from the reservoir, R^{max} the highest rate of release of the reservoir, S_{min} is the minimum allowed reservoir storage, S_{max} is the maximum allowed reservoir storage, c (t) is conversion ratio of passing discharge from the turbine (m^3 / s), TWL is Tail Water Level, in order to calculate the effective water load on the turbines, by using the information about reservoir volume- height a third degree polynomial function is fitted by (3.6) which its constant coefficients are listed below.

a= 878.7987956768

b= 0.1941700727

c= - 0.0001147356

d= 0.0000000270

The main factor in determining the optimal operation system of a dam - including single dam and multiple dam - is the nonlinear relationship between hydropower energy production, the amount of water released from turbines under uncertainty conditions of input flows and the amount of demands for electrical energy (C.-T. Cheng et al., 2008; Heydari, Othman, & Qaderi, 2015). The optimization model for planning operating systems of multiple dams should reflect the exchange between the benefits obtained from the storage and saving of the water and the benefits obtained from releasing the water. On the other hand, there is an exchange between the benefits of storing water in high-level and the loss resulting from the overflow of water. This study's aim is to create and develop a general flexible model which includes the structure and main features of the problem as much as possible (Heydari, Othman, & Taghieh, 2016).

The third objective is flood controlling (Equation (3.11)). This function also presented by minimizing the subtraction between the stated goal value; this ideal amount of volume for flood control is considered 212 million cubic meters for the Karun IV reservoir and 2970 million cubic meters for Karun III reservoir and 2993 million cubic meters for the Karun I reservoir.

$$Minimize\ Z_3 = \sum_{j=1}^{3}\sum_{t=1}^{T}\left(\frac{S_{jt} - S^{T}{}_{jt}}{S^{T}{}_{jt}}\right)^2 \tag{3.11}$$

Z_3 shows 3rd objective function, S_{jt} is the volume variable of the j^th^ dam (Equation (3.11)) and $S^{T}{}_{jt}$ is the goal volume in the j^th^ dam for flood control. The constraints of this relationship can also be included within the changing volume of each dam. "It is important to note that for flood controlling model 6 months of a year is considered i.e. November to April."

3.3.2 The constraints of the problem

For optimizing the above-mentioned objective, we should consider different constraints. The constraint related to the first objective function includes the scope of the water release (Equation (3.1)). Besides this constraint, there is also another constraint called overflow, which plays an important role. Overflow in the model is defined when water surplus exceeds the maximum capacity of storage. Explicit lower and upper bounds on storage for recreation, providing flood control space, and assuring minimum levels for dead storage and power plant operation are expressed as follows:

$$H_{j,t} \geq HeadMin_{j,t} \quad , j = 1,2,3; \tag{3.12}$$

$$H_{j,t} \leq HeadMax_{j,t}, \quad j = 1,2,3; \tag{3.13}$$

$R_{min\,j,t} \leq R_{j,t} \leq R_{max\,j,t} \quad , j = 1,2,3;$ (3.14)

$R_{2,t} \geq WReq_t$ (3.15)

$D_{min_{jt}} \leq R_{jt}^{demand} \leq D_{max_{jt}}, j = 1,2,3;$ (3.16)

$Spill \approx 0, j = 1,2,3$ (3.17)

Where, HeadMinj,t is the minimum head allowed for reservoir j at time t, HeadMaxi,t is the maximum head allowed for reservoir j at time t, $R_{minj,t}$ is the minimum discharge allowed for the downstream of reservoir j at time t, $R_{maxj,t}$ is the maximum discharge allowed for the downstream of reservoir j at time t and WReqt is the water discharge required at Karun III to satisfy water demand at time t.

Those limits maintain minimum desired downstream flows for water quality control and fish and wildlife maintenance, as well as protection for downstream flooding.

Equation (3.18) to (3.20) are related to hydroelectric. One important constraint of the relationship is related to the elevation of the reservoir to its volume, which is obtained from and surface-volume-height curve.

$P_{jt} = f\left(\gamma, \mu, R_{jt}^{Power}, H_{jt}\right), j = 1,2,3;$ (3.18)

$\overline{H_{jt}} = f(S_t)$ (3.19)

$0 \leq R_{jt}^{Power} \leq R_{j_{allowable}}^{Power}, j = 1,2,3;$ (3.20)

Each of the three dams that are located in this area has a hydroelectric generating station with 1000, 2000 and 2000-megawatt power, in the Karun IV, Karun III and the Karun I dams, respectively. The variables of energy release from power plants and energy production are considered in the modelling, which is the relationship between hydroelectric release and the elevation of the reservoir. As will be discussed, the elevation is counted in relation to the volume of the reservoir. This relation would be as follows Equation (3.21):

$power\ (GWh) = 0.002725 \times \mu \times R_{jt}^{Power}\ (mcm) \times \overline{H_{jt}}(m)$ (3.21)

The units were set in a way that the achieved solution is in gigawatt-hours per month. In fact the output and elevation variables are in the monthly average. In these equations, $\overline{H_{jt}}$ is the water elevation above the turbine in j^{th} reservoir, γ is specific weight of water, μ is hydroelectric turbine efficiency and R_{jt}^{Power} is water release from hydroelectric turbine. As for the constraint related to elevation, it should be noted that this equation can be calculated by fitting a curve of the relationship which can be written in the form of a third degree curve or in the form of another relationship, such as Power curve, etc. To express the relationship between surface of the reservoir and its volume, the evaporation from the surface of the reservoir should also be calculated. These equations change the model from linear to non-linear.

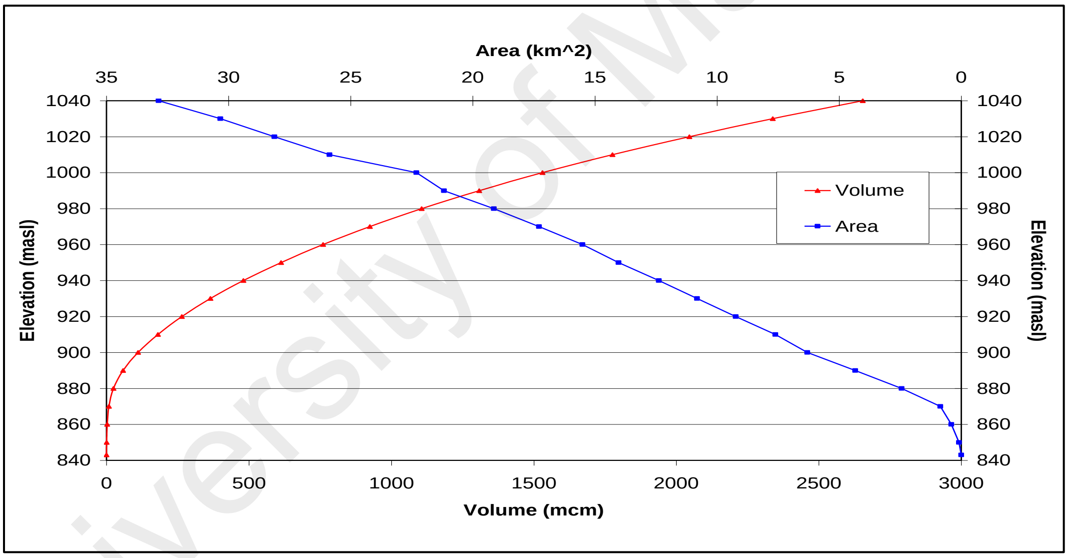


Figure 3.12: Area-Volume-Elevation relationship for Karun IV reservoir

According to the elevation-storage curve of Karun IV reservoir (Figure 3.12), the points are fitted by curve-fitting toolbox and power equation was used to calculate the relationship. This relationship is defined as follows:

Mathematical Relationship Equation for Karun IV

$$V_1 = (-110.5044148 + 0.000149722 \times H_1^{\ 2})^2 \tag{3.22}$$

$$A_1 = 0.129792102 + 0.365874798 \times V_1^{\ 0.56739394} \tag{3.23}$$

$$H_1 = 847.574447407301 + 7.39836791 \times V_1^{0.41234972} \qquad (3.24)$$

The correlation coefficients for fitting those equations to the data, are 0.999945779, 0.997632, and 0.99869621.

Figure 3.13 shows the elevation-storage curve of the Karun III dam and the physical relationship equation were calculated using Equation (3.25) to (3.27):

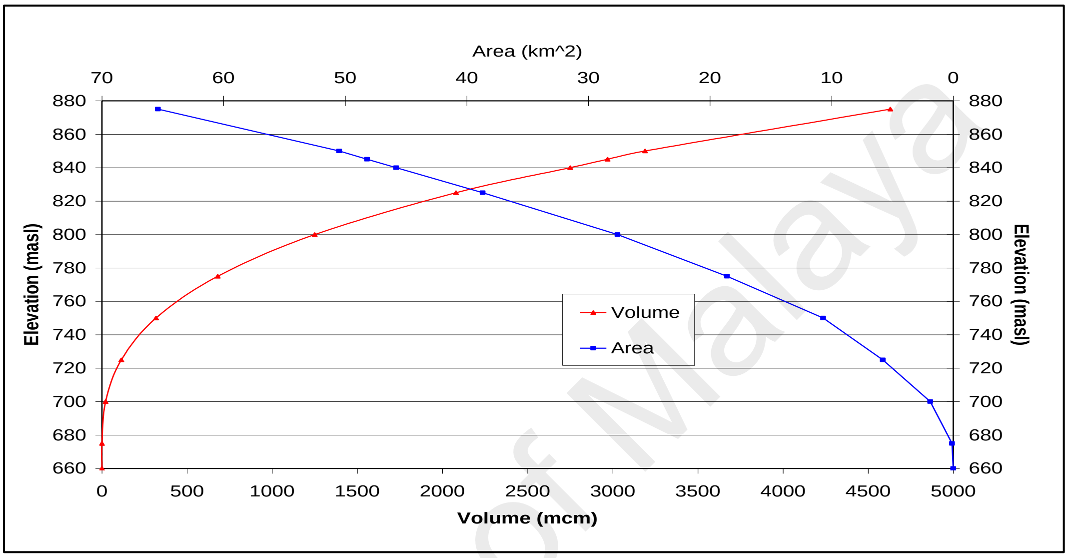


Figure 3.13: Area-Volume-Elevation relationship for Karun III reservoir

Physical Relationship Equation for Karun III

$$V_2 = (-68.78891392 + 0.00000020418 \times H_2^{3})^2 \qquad (3.25)$$

$$H_2 = 663.3719832 + 13.10495829 \times V_2^{0.32896663} \qquad (3.26)$$

$$A_2 = 0.038624415 + 0.2452244 \times V_2^{0.66109414} \qquad (3.27)$$

The correlation coefficients for fitting those equations to the data, are 0.999431047, 0.999489651, and 0.999850022.

Figure 3.14 shows the elevation-storage curve of the Karun I dam and it is calculated by (3.28. to 3.30)

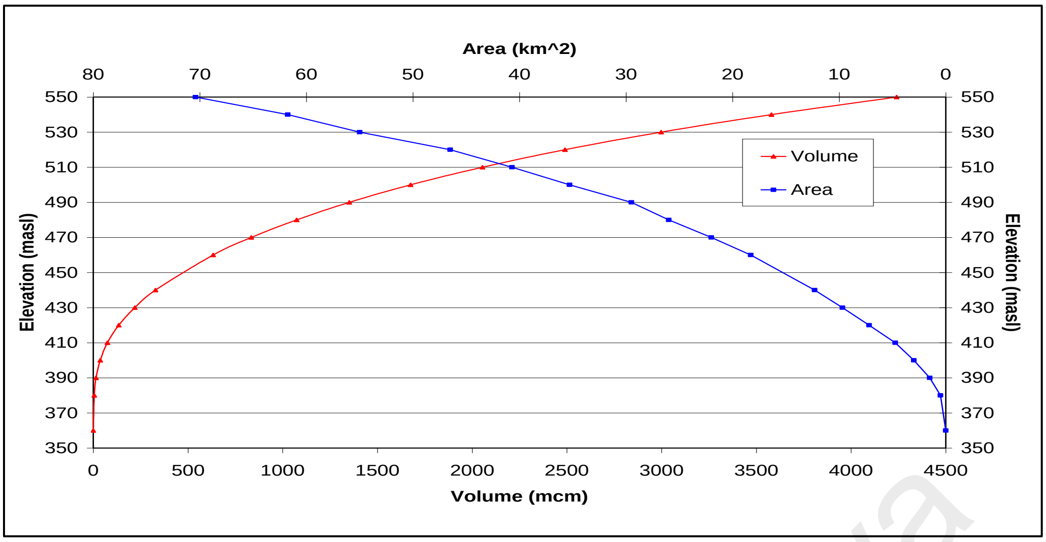


Figure 3.14: Area-Volume-Elevation relationship for Karun I reservoir

Physical Relationship Equation for Karun I

$$V_3 = (-31.35212677 + 0.0000005790 \times H_3^{\ 3})^2 \tag{3.28}$$

$$H_3 = 360.629964 + 11.4338866 \times V_3^{\ 0.33643137} \tag{3.29}$$

$$A_3 = 0.800397138 + 0.153137141 \times V_3^{\ 0.73144711} \tag{3.30}$$

The correlation coefficients for fitting those equations to the data are 0.999951298, 0.999885332, and 0.999034531.

Other provisions of the model which are common among all three objectives contain the equation related to the confines of the reservoir storage, continuity equation considering the waste of water which is the relationship between the surface of the reservoir and evaporation rate.

$$S_{j_{min}} \le S_{j_t} \le S_{j_{max}}, j = 1,2,3; \tag{3.31}$$

$$S_{j_{t+1}} = S_{j_t} + I_{j_t} - R_{j_t}^{demand} - R_{j_t}^{power} - Loss_{j_t} - Spill_{j_t}, j = 1; \tag{3.32}$$

$$S_{j_{t+1}} = S_{j_t} + I_{j_t} - R_{j_t}^{demand} - R_{j_t}^{power} + \left(R_{j-1_t}^{demand} + R_{j-1_t}^{power} - D_{j-1_t}\right) - Loss_{j_t} - Spill_{j_t}, j = 2,3; \tag{3.33}$$

$$Loss_{j_t} = f\left(Ev_{j_t}, A_{j_t}\right), j = 1,2,3; \tag{3.34}$$

$$A_{j_t} = f(S_{j_t}, j) = 1,2,3; \tag{3.35}$$

$$Ev_{j,t} = (A_{j,t} + A_{j,t-1})/2 \times EvRate_{j,t} \tag{3.36}$$

$$R_{j,t} = RD_{j,t} + DemAgr_{j,t} + DemInd_{j,t} + DemQual_{j,t} \tag{3.37}$$

In these equations $Loss_{j_t}$ is the water waste from j^{th} reservoir, which is considered as surface evaporation in this model. I_{j_t} is the discharge of j^{th} reservoir input in a year in terms of million cubic meters. $R_{j_t}^{power}$ is the release to hydroelectric turbine for energy production, as each turbine has an allowable amount of maximum design ($R_{j_{allowable}}^{power}$) which is mentioned in the constraints. $E\upsilon_{j_t}$ is the evaporation rate from the surface of reservoir which is usually measured in millimeters. A_{j_t} is the surface area of the jth reservoir which is in non-linear relation to its storage. EvRate j,t is evaporation rate from reservoir j at time t, RDj,t is the release from reservoir j and inflow to the downstream reservoir at time t , DemAgrj,t is the agriculture water demand from reservoir j at time t, DemIndj,t is the industrial and municipal water demand from reservoir j at time t, DemQualj,t is the water demand from reservoir j at time t to satisfy water quality standards.

Decision and State Variables

Decision variables are courses of action to be taken for each time period. In optimization models which are developed in this study, the discharge of each reservoir j at time t (Rj,t) are chosen as decision variables (control variables). Moreover, the reservoir storage at time t (Stj,t) are considered as state variables.

The state variables are the variables describing the state of the system at any time t. At any time t there are input state variables Stj,t and output state variables Stj,t+1.

The state variables of the system in the optimization model have the function of linkage to the succeeding stage so that, when each stage is optimized separately the resulting decision is automatically usable for the entire problem.

3.3.3 Data required for the models

1. Volume-area-elevation relationship for each reservoir Equation ((3.22) to ((3.30)
2. Hydropower characteristics (Discharge-Level-Hydropower production) (Table 3.2)
3. Water Demand for agriculture in downstream of Karun III at time t)
4. Evaporation rates at each reservoir j at time t (Table 3.3)
5. Inflow rate at j location at time t with its probability
6. Hydropower production required at time t
7. Minimum water requirement at time t for water quality standards.
8. Initial value for volume at time 0 for each reservoir j.

Table 3.2: Hydropower characteristics

	Karun I	Karun III	Karun IV
Reduction factor for dry periods(α)	0.91	0.94	0.92
Plant factor coefficient (PF)	0.17	0.14	0.16
Hours working hours in a power plant	4.1	3.4	3.8
Average inflow to the power plant (Qave)	27.3	123.0	211.3
Installed capacity (MW) (IC)	2000	2000	1000
Efficiency Hydropower Station (ep)	0.85	0.85	0.85
Percentage of Q used in Hydropower	1.0	1.0	1.0
Minimum allowable storage (Smin)	1675	1250	1441
Maximum allowable storage (Smax)	2997	2970	2192
Active storage	1322	1720	751
Minimum head for each reservoir (masl)	363	400	800.
Tail Water level (masl)	366	660	842
End Head at the end of planning period (masl)	400	800	985
Minimum operation level (WLmin)	500	800	996
Normal water level (NWL)	530	845	1025
Crest level (masl)	542	850	1032

Table 3.3: Evaporation Rate from Open Water surface in (mm per day) at time t

Month	Karun IV	Karun III	Karun I
Jan	0	0	0
Feb	0	0	0
Mar	0	0	0
Apr	1.7	1.1	2
May	4.9	4.8	4.9
Jun	9.4	10	9.5
Jul	11.6	13	12.3
Aug	11.8	13.5	11.9
Sep	9.9	11.6	9.6
Oct	6.6	7.5	6.1
Nov	2	2.4	1.7
Dec	0	0	0

Table 3.4: Demand Irrigation (MCM) existing irrigation (partial)

Month	Karun IV	Karun III	Karun I
Jan	0.00	0.83	0.00
Feb	0.00	7.00	0.00
Mar	0.00	15.58	0.00
Apr	0.00	38.60	0.00
May	0.00	87.04	0.00
Jun	0.00	179.76	0.00
Jul	0.00	196.95	0.00
Aug	0.00	140.60	0.00
Sep	0.00	94.25	0.00
Oct	0.00	52.25	0.00
Nov	0.00	23.11	0.00
Dec	0.00	5.12	0.00

For an average year reservoir inflows, the monthly optimization program is used with existing partial irrigation, water supply, industry demands for all three reservoirs case. **Figure 3.15** represents the monthly reservoir inflows.

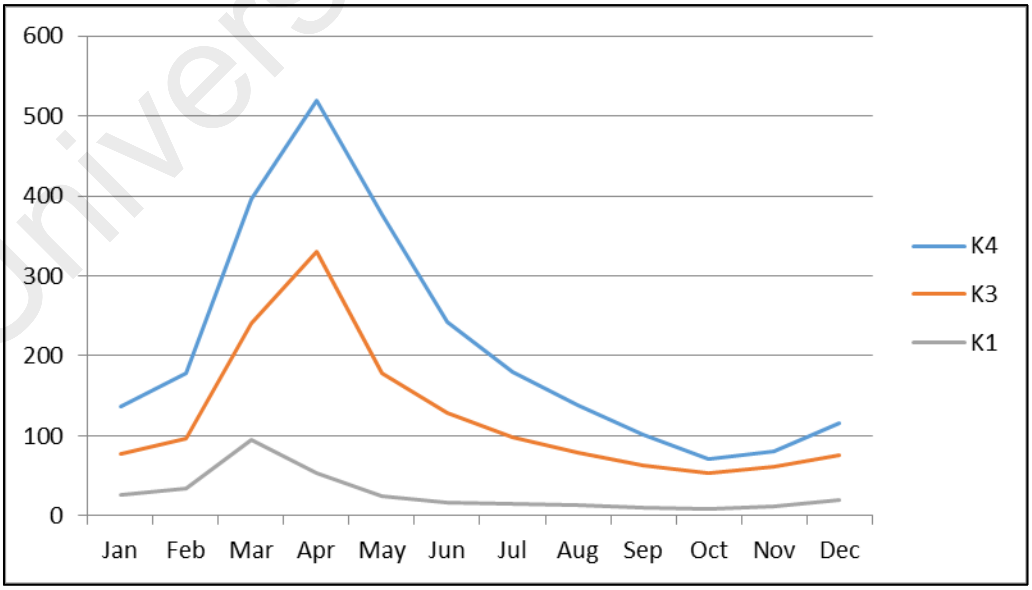


Figure 3.15: Reservoir Inflows

Output

- A policy for release water from each reservoir j at time t for the certain objective function.

Assumptions

- Inflow is the only stochastic parameter
- The water downstream reservoirs are almost near the channel level.
- There is no time lag between each reservoir.

Optimization Engine Inputs

- Inflows: There are the inflows into each reservoir at time t
- Basic:
    - The maximum head allowed at each reservoir at time t.
    - The minimum head allowed at each reservoir at time t.
    - The maximum Volume allowed at each reservoir at time t.
    - The Minimum Volume allowed at each reservoir at time t.
    - The maximum Area allowed at each reservoir at time t.
    - The minimum Area allowed at each reservoir at time t.
    - The maximum Discharge allowed from each reservoir at time t.
    - The Minimum Discharge allowed from each reservoir at time t.
    - It has the information for Initial water level for each reservoir,
    - Final water level for each reservoir,
    - Tail water level in each reservoir,
    - the minimum water required for water quality standards,
    - Efficiency Hydropower Stations,
    - Percentage of Q used in Hydropower.
- Losses-other:
    - All losses except the evaporation rates (Seepage, bank storage, etc).

- o The evaporation rates
- Demand
  - o Agricultural demand at the downstream of each reservoir at time t.
  - o Industrial and municipal demand at the downstream of each reservoir at time t.
  - o Other demands at the downstream of each reservoir at time t.

The users can examine the following scenarios:

- Different inflows values and pattern for each reservoir.
- Different hydropower efficiency.
- Different water loses scenarios include different evaporation rates.
- Different scenarios for Agriculture demand, Industrial and municipals demand, and Power demand.
- Different constraints regarding Maximum, Minimum Head and Volume allowed for each reservoir for flood protection.
- Different constraints regarding maximum and minimum area from reservoir and discharge from each reservoir for environmental factors (fishes, soil degradation, channel maintenance).
- Different operation of selected set of reservoirs.

Several different scenarios had been tested successfully.

3.3.4 Description of the flood control

The Dams Operation Office has provided some classic flood control rules based on peak discharge and flood volume. In order to work out the rules, instantaneous peak discharges into the dam have been derived for different return periods. Then the inflow flood volume has been assessed for different durations. A specific duration has been determined for each dam by analyzing historical flood data. Return periods and flood volumes are determined based on real time inflow peak discharges. Reservoir release is subsequently determined from the known flood volume and the downstream catchment flood and river safety capacity.

Operating Rules for flood control

Different rules can be defined for reservoir flood control depending on the simulation objectives. Bearing in mind that the main object of the study is the downstream flood mitigation plans, assumption which is compatible with planning of flood mitigation projects has been considered. Downstream flood mitigation plans will be under safety by considering critical operation rules at upstream reservoirs under any condition. In this case the flood peak discharge magnitude is the maximum which the river system can deliver. The following assumptions have been made for each element:

1. The reservoir is full and the initial level is the normal level when the flood occurs;
2. The control point defines downstream of each dam to determine releases;
3. Reservoir flood routing is accomplished by storage method;
4. The flood release is equal to the inflow discharge while the release peak discharge does not exceed downstream safe capacity and the spillway capacity is sufficient to release;
5. The release is limited to the downstream safety, capacity, and the reservoir water level exceeds the normal water level (NWL) if the release from downstream capacity is exceeded;
6. If the reservoir level exceeds the flood control level, the reservoir level must be adjusted to flood control level. In this case, the reservoir release would be equal to the inflow discharge if the spillway had no limitation in the capacity;
7. For the previous rule, if the release is greater than the spillway capacity, the reservoir release is limited to spillway capacity and the reservoir water level exceeds flood control level;
8. The reservoir discharges (up to the limit of downstream capacity) after recession of flood until the reservoir level reaches NWL. After this moment, release is equal to the inflow discharge and reservoir level is maintained at NWL.

Downstream safe capacity

In this study, the control point was immediately defined downstream of each dam for the determination of downstream safe capacity. This factor is one of the most important parameters involved in reservoirs flood control. Since the reservoir flood control volume is defined based on the downstream capacity (or the most critical flood damage areas of the river system), the downstream capacity was determined by designed flood control volume, considering 100-year flood as the operational flood. The capacity was calculated such that the reservoir flood control volume is filled based on the 100-year flood without breach of the downstream capacity during flood release. Table 3.5 shows the results of downstream capacity of the dams in existing situation including Karun IV, Karun III and Karun I reservoirs as parallel dams.

Table 3.5: Downstream capacity of dams based on 100 year return period flood and designed flood control volume (cms)

	Karun IV	**Karun III**	**Karun I**
Existing situation	2650	3750	4320

Reservoir Flood Attenuation

Figure 3.16 shows a schematic of the Dez and Karun river simulation model in current condition. In the Karun river system, control points include Karun IV, Karun III, Karun I, Upper Gotvand, Gotvand regulation dam and the confluence point of the Shoor and Karun rivers.

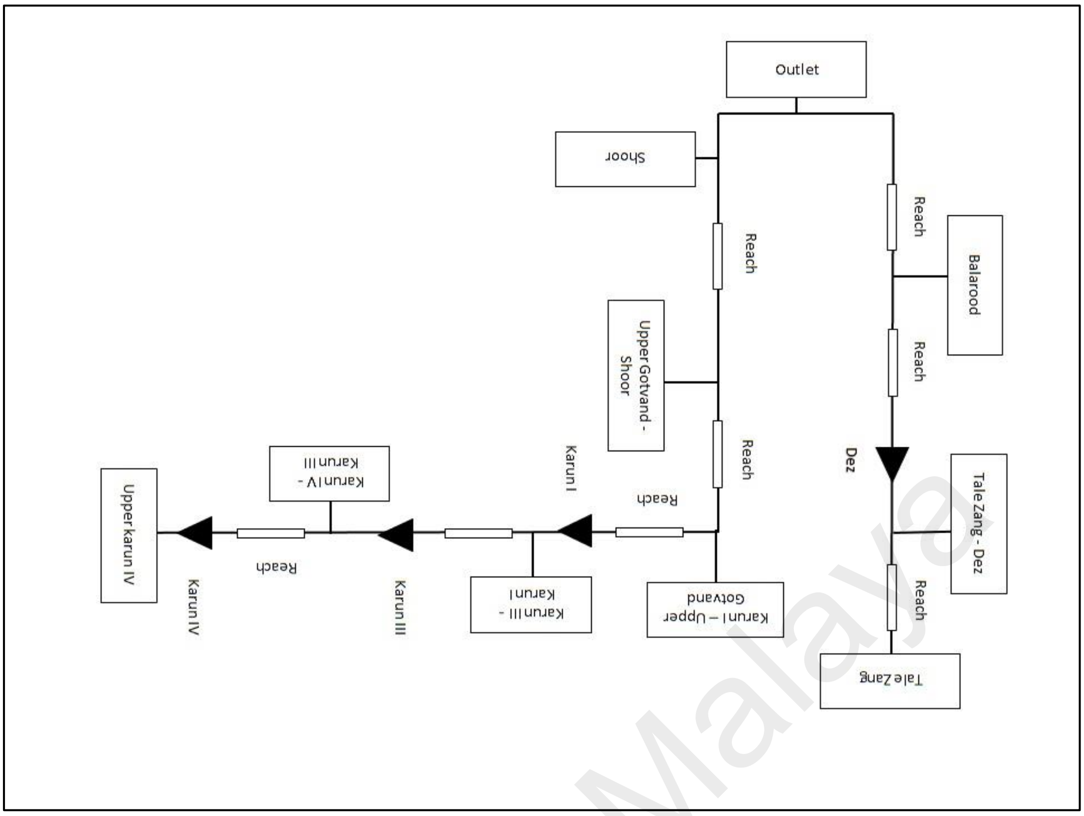


Figure 3.16: Layout of flood control simulation

The delay time between the routed release flood hydrograph from the dams and the intermediate flood hydrograph was determined so that the peak discharge of the superposed hydrograph had a maximum peak discharge.

The downstream capacity was considered constant for another return period after determining the downstream capacities, based on the 100-year flood. Reservoir flood control simulation results are summarized in Table 3.6 to Table 3.8 for flood return periods from five to 1000 years. Figure 3.17 to Figure 3.22 show the respective results of the 100 and 200-year flood control simulation of different dams.

The reservoir flood control volume is not completely filled during floods with return period less than 100 years because the inflow peak discharge is similar to the outflow peak discharge and less than the downstream capacity. In contrast, with return periods more than 100 years, the outflow peak discharge exceeds the downstream capacity; hence, the reservoir flood control volume is filled by floods. During these flood events, reservoirs retard the release peak discharge for floods below 100-year return period.

Table 3.6: Flood peak discharge of Karun IV River

Flood return period (year)	K4 Inflow (m^3/s)	K4 outflow (m^3/s)	K4 MOL (masl)	K4-K3 intermediate flow (m^3/s)
5	1999.0	1999.0	1025.0	1669.0
10	2516.0	2516.0	1025.0	2100.0
20	3012.0	2650.0	1025.3	2514.0
25	3171.0	2650.0	1025.5	2646.0
50	3630.0	2650.0	1026.2	3029.0
100	4032.0	2650.0	1027.0	3365.0
200	4411.0	4054.0	1027.0	3680.0
500	4977.0	4903.0	1027.0	4153.0
1000	5500.0	5189.8	1027.1	4590.0

Table 3.7: Flood peak discharge of Karun III River

Flood return period (year)	K3 Inflow (m^3/s)	K3 outflow (m^3/s)	K3 MOL (masl)	K3-K1 intermediate flow (m^3/s)
5	2995.2	2995.2	845.0	997.0
10	3625.8	3625.8	845.0	1255.0
20	4419.0	3750.0	845.7	1502.0
25	4423.9	3750.0	845.7	1580.0
50	5050.2	3750.0	846.8	1809.0
100	5598.7	3750.0	848.0	2010.0
200	5804.5	5284.1	848.0	2199.0
500	6247.0	6247.0	848.0	2482.0
1000	6916.2	6916.2	848.0	2742.0

Table 3.8: Flood peak discharge of Karun I River

Flood return period (year)	K1 inflow (m^3/s)	K1 outflow (m^3/s)	K1 MOL (masl)	K1-UG intermediate flow (m^3/s)
5	3969.7	3969.7	530.0	1382.0
10	4849.1	4320.0	530.4	1739.0
20	5251.6	4320.0	531.1	2082.0
25	5329.9	4320.0	531.3	2191.0
50	5559.0	4320.0	531.8	2508.0
100	5758.5	4320.0	532.0	2787.0
200	7370.9	6889.1	532.0	3048.0
500	8637.0	8637.0	532.0	3440.0
1000	9576.3	9576.3	532.0	3801.0

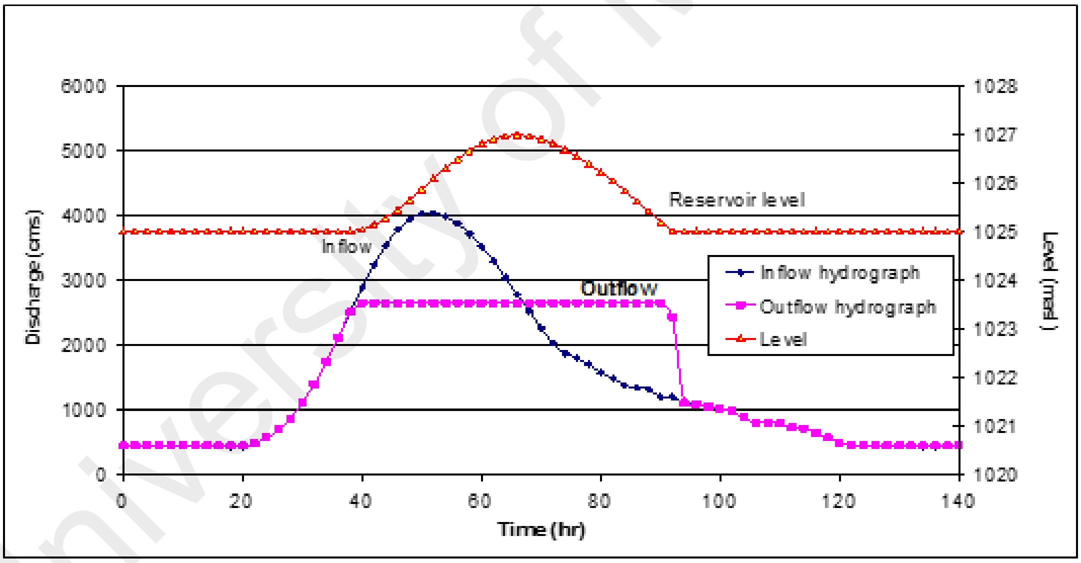


Figure 3.17: 100 year flood control of Karun IV dam

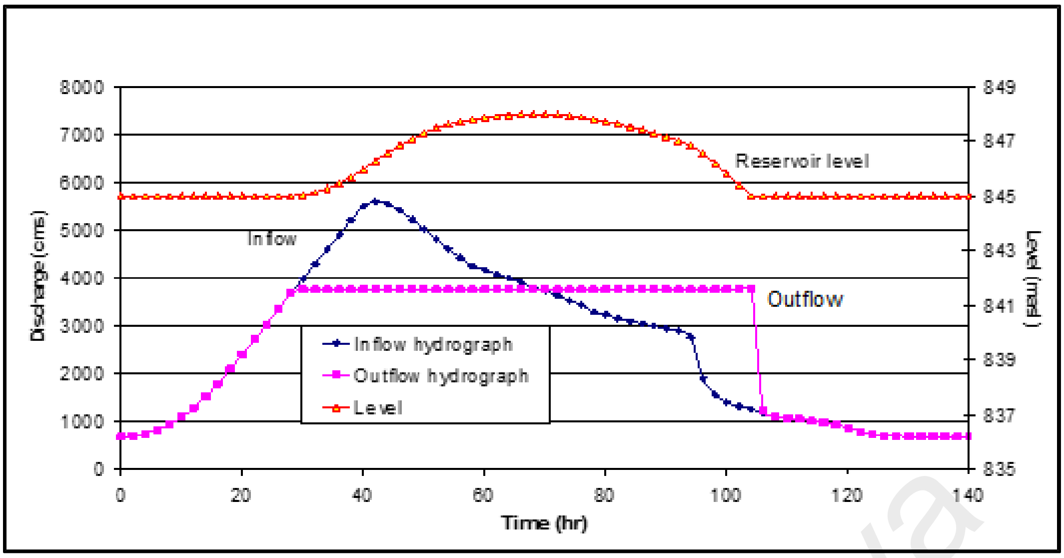


Figure 3.18: 100 year flood control of Karun III dam

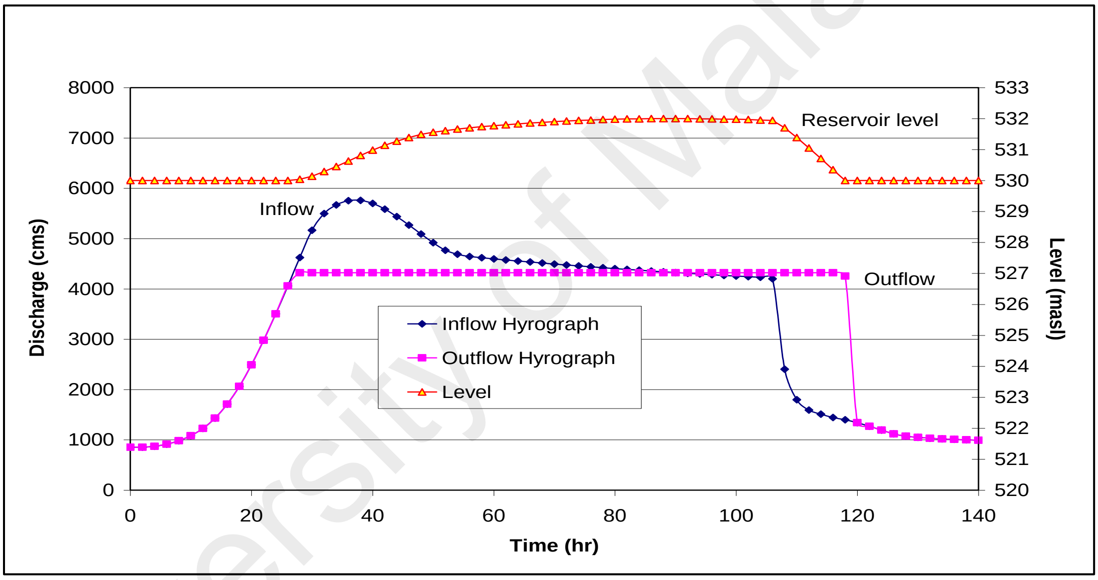


Figure 3.19: 100 year flood control of Karun I dam

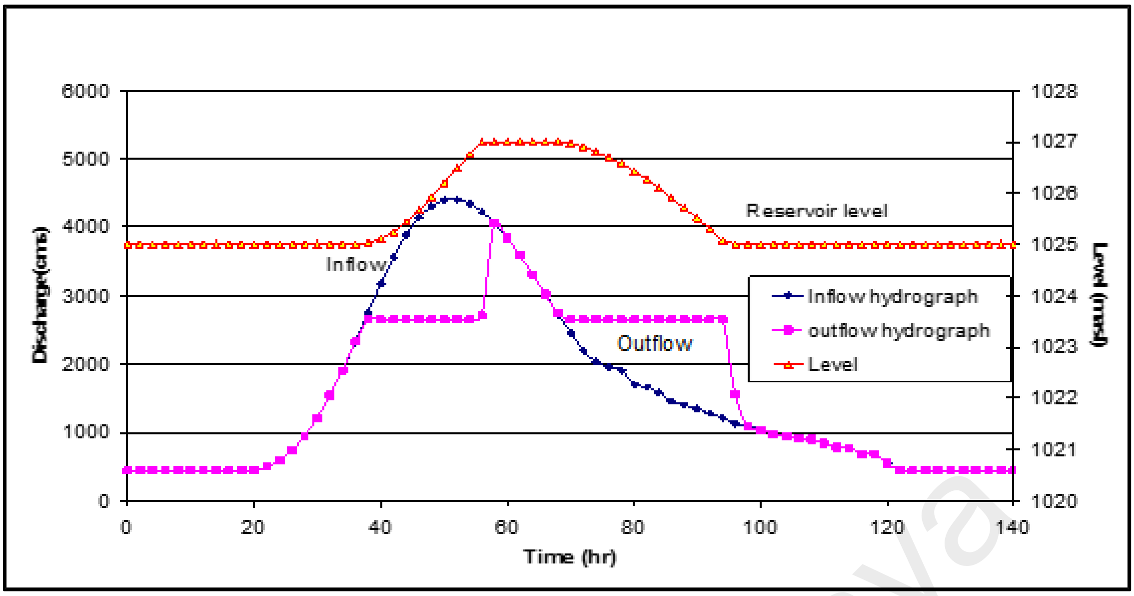


Figure 3.20: 200 year flood control of Karun IV dam

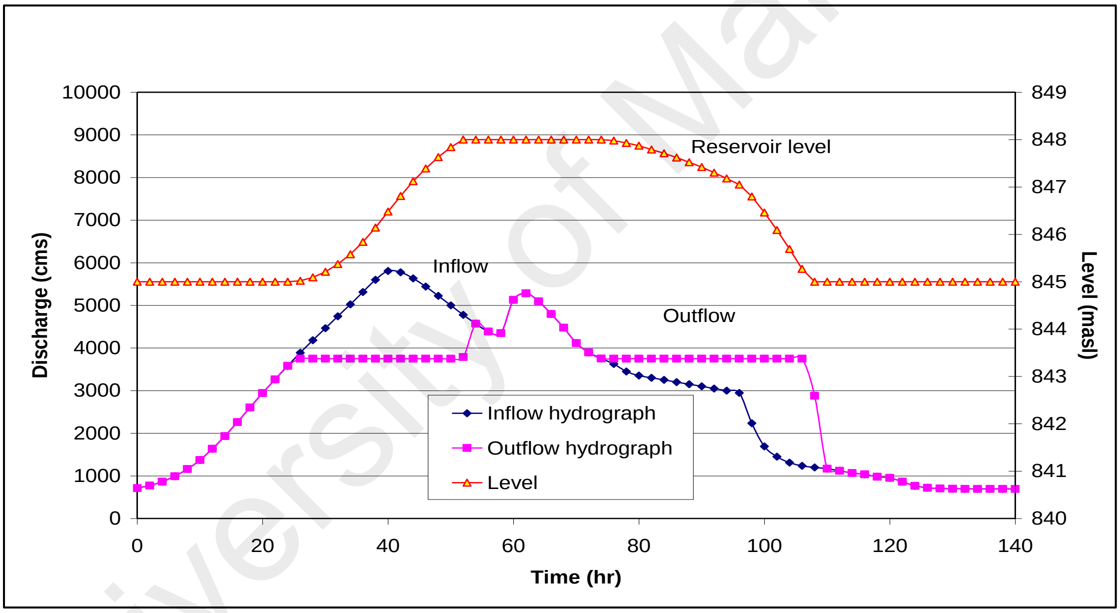


Figure 3.21: 200 year flood control of Karun III dam

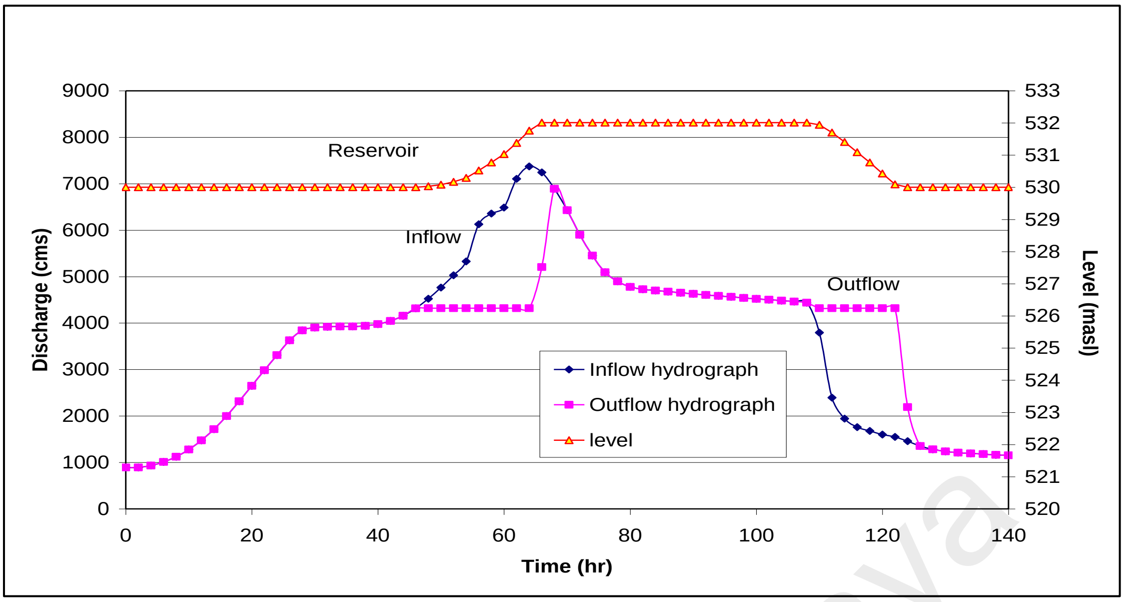


Figure 3.22: 200 year flood control of Karun I dam

In the Karun River, the peak discharge at the outlet of Karun catchment after superposition of Shoor river hydrograph is 3,495 and 10,010 m^3/s for the 5 and 1000-year return periods, respectively. Determination of the flood peak discharge in the flood plain area involves hydraulic modelling because of the effect of flood routing in these areas.

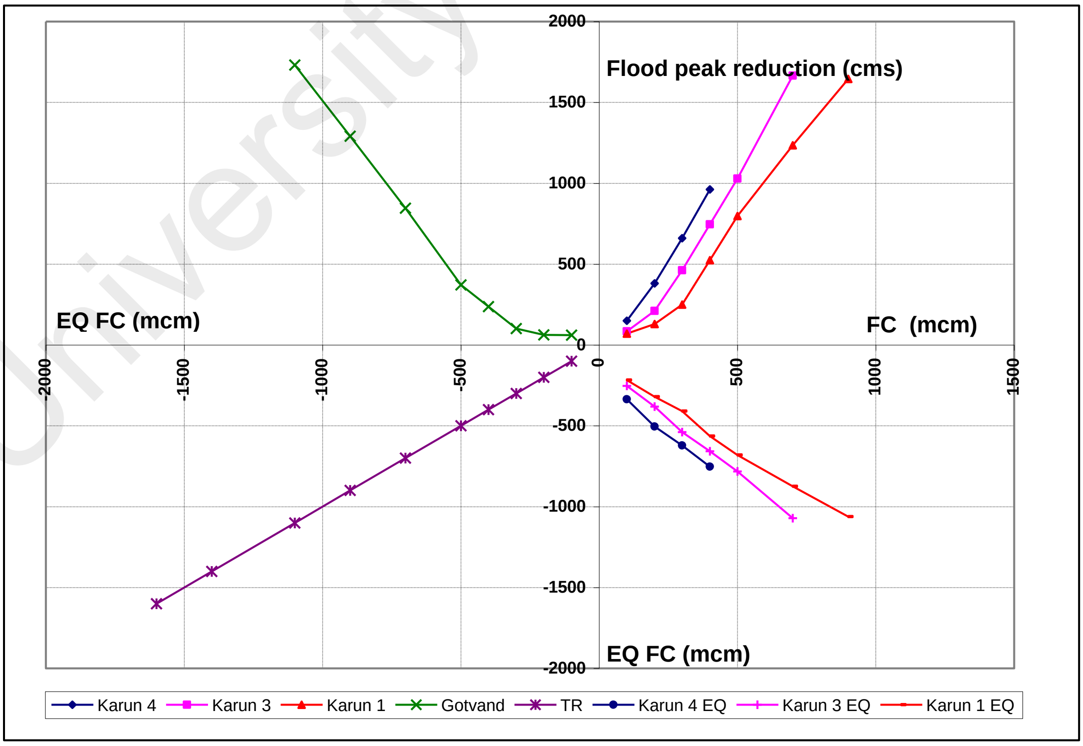


Figure 3.23: Relations of flood control storage equivalent for a 100-year flood, the interval Upper Karun

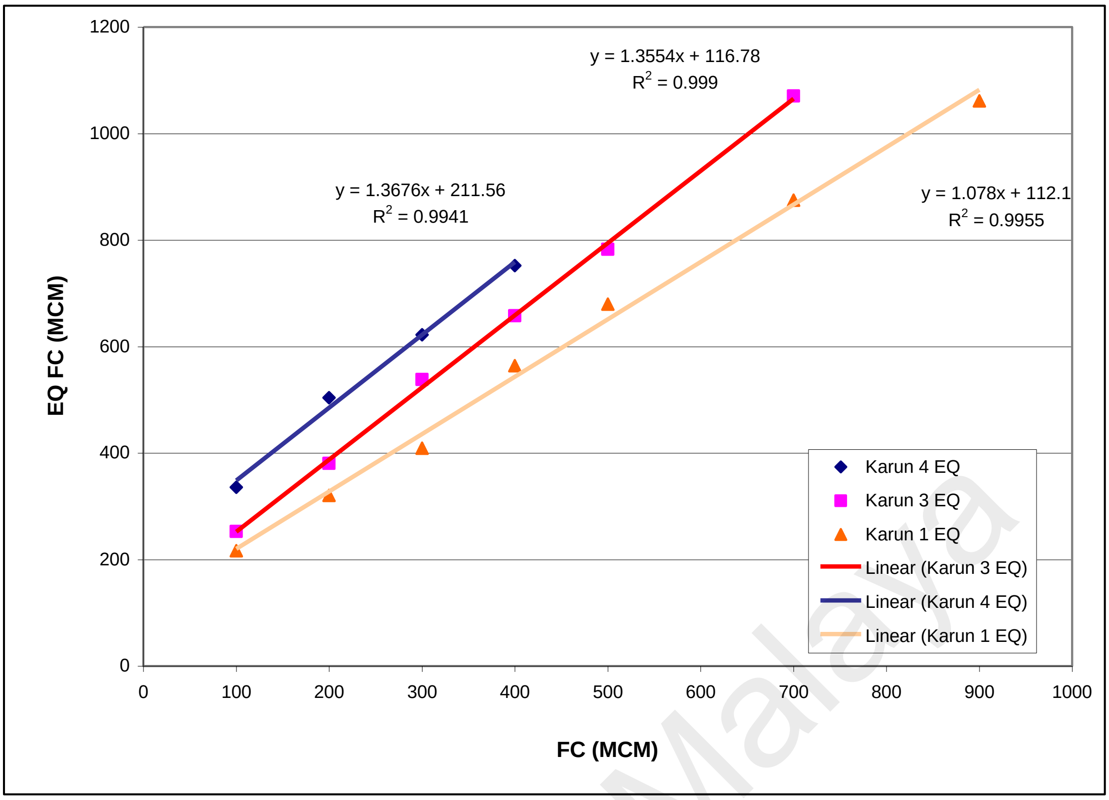


Figure 3.24: The relation between flood control reservoir storage in upstream and 100-year flood in the upper Karun range

3.3.5 Description of the optimal cropping pattern

Water resources development projects with the aim of increasing area of water for irrigation are of infrastructural plans that are considered in countries with arid and semi-arid climate such as Iran. For designing an optimal cropping pattern in an irrigation and drainage network, that has defined resources and restrictions, different methods are available for managers and researchers.

One of the methods that is frequently used in the optimal allocation of scarce resources is the use of mathematical programming models. Due to the special features of the model parameters and variables such as crops, crop rotation, crop operations calendar, calendar of common irrigation consequent, Wide range of agricultural crops cultivated ingredients, limited arable land and product serious competition for water, the best way that encompasses information to guide in regulating water to their fields by the farmers and also provides the optimization of these activities, is mathematical programming models.

Linear programming patterns of the past decade and especially in the current era were used to achieve the objectives of policy in some sectors such as agricultural sector, determining the optimal combination cultivated and agricultural inputs, different patterns cultivated and different ways to deal with water pollution that has been widely used to estimate the demand for irrigation water.

Regarding the nature of the matter, applying linear programming is one of the efficient and common methods. Therefore, most of the resources, restrictions, aims and sensitivities of these kinds of matter that can be compiled with developing models based on linear programming are considered for determination of an optimal cropping pattern.

Based on this, applying a program by using linear programming that includes all of the above items requires designing a model that first includes three principles: aims, variables, constraints and the relation between these principles should be defined in a matrix called programming matrix. The designer can follow side goals in the framework of variables and constraints by using linear programming in addition to final goals. The conditional point in using this method at first is understanding the available relations among aims, change resources, constraints and then domination on software and program.

After determining the optimum outflow value of the reservoirs, we must determine the best cropping pattern in accordance to current conditions like water and land situation, especially in the Karun III reservoir (because in downstream of the Karun III, the water needs of agriculture are already defined.). Therefore, the first step should be specifying area of fertile soil, then the conditions for proper drainage, cultivation and other terms are being considered. Below is an overview of soil classification. In short, the methodology is demonstrated in the following flowchart (**Figure 3.25**).

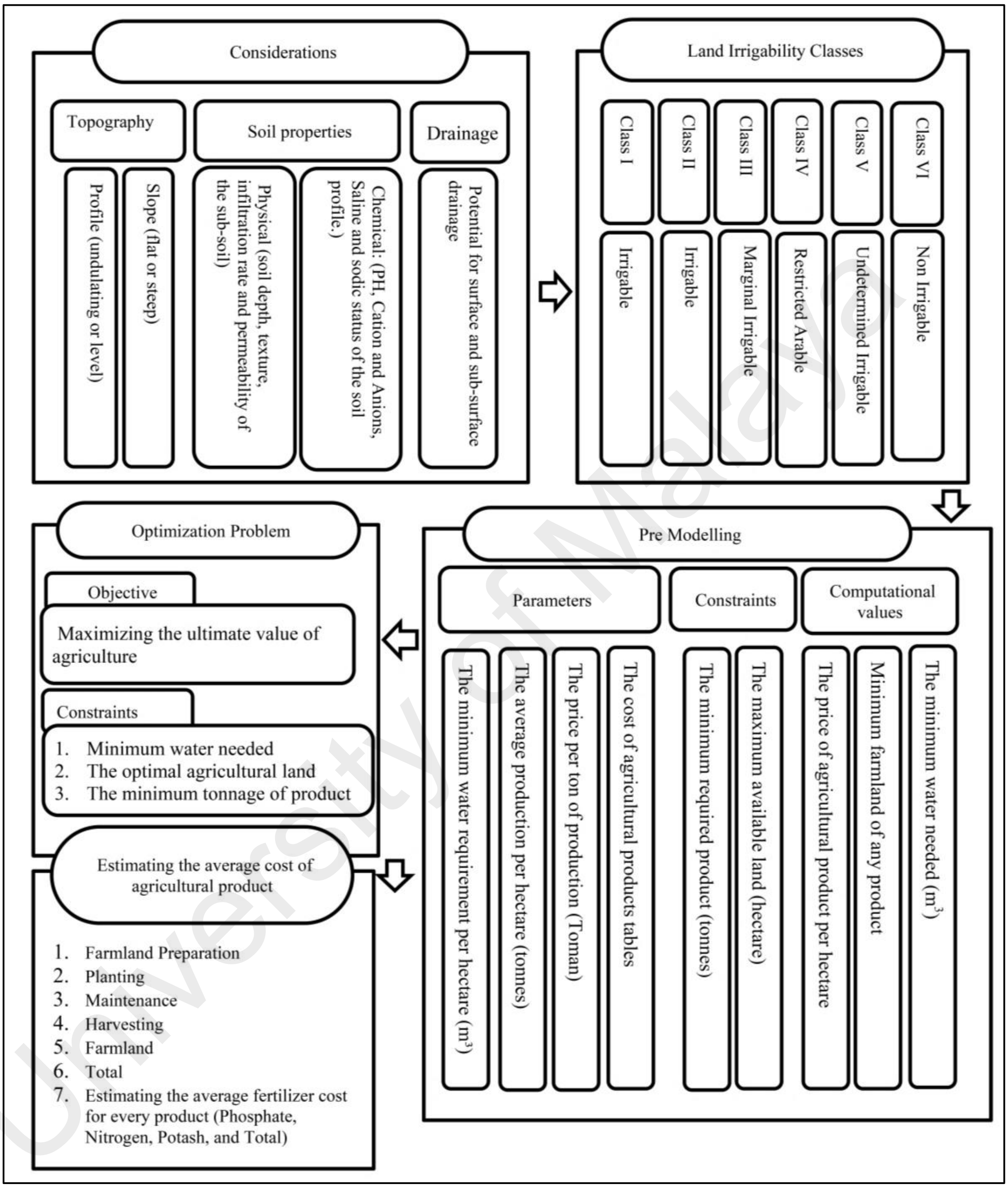


Figure 3.25: The flowchart of the cropping pattern and estimating the average cost of agricultural products methodology

General Overview:

Brief descriptive notes on the land suitability classifications were provided by the KWPA. These classifications appear to have been developed for use with the production of annual crops, cereals and plantation of crops under gravity system of irrigation.

In determining the classification of lands for their suitability for irrigated crop production consideration has been given to the following factors:

a) Topography: Slope (flat or steep) and Profile (undulating or level)

b) Soil properties: Physical (soil depth, texture, infiltration rate and permeability of the sub-soil) and Chemical (pH, cation exchange capacity, proportion of cations and anions and the saline and sodic status of the soil profile.)

c) Drainage: Potential for surface and sub-surface drainage

The analysis of the suitability of land for use in irrigated agriculture appears to have been evaluated as a two-step process. The primary step has been the determination of land classification classes, here in referred to as Land Suitability Classes, in which soils are evaluated for use in irrigated agriculture. The second step appears to be the preparation of Land irrigability Classes where more definitive definition of the suitability of the land for irrigation is stated. A survey of the Salinity Classes has also been undertaken but no tabulated data of the areas has been made available.

Determination of agricultural land suitable for irrigation

The standards for the classification of soils and land suitability have been developed by a number of international and national agencies. The United States Department of Agriculture established the initial set of criteria that has subsequently been expanded by the FAO and other international agencies, thereby enabling the application of a consistent set of standards for the classification of land. The maps and briefing notes provided confirming that these standards have been applied to the surveys undertaken in the Dez and Karun river basins.

Land Irrigability Classes: This classification system has been used to define the level of management, resources and infrastructure required to enable sustainable irrigated agriculture. The limitations made are based on the current standards of irrigation applied in the Dez and Karun river basins and do not take into account the advances made internationally in irrigation methods and management (Figure 3.26).

Class I – Irrigable: These are land areas without apparent limitations of soil, topography or drainage or have limitations that can be fully corrected by land improvements.

Class II – Irrigable: These areas are suitable for irrigated agriculture provided the required land improvements are made.

Class III – Marginal Irrigable: These areas are expected to have marginal suitability for irrigation even after the required improvements have been made.

Class IV – Restricted Irrigable: These lands are not suitable for irrigated agriculture except under special conditions of land development, management and possibly only for specific crops.

Class V – Undetermined Irrigable: These lands have severe limitations of soil, salinity and/or drainage that will require considerable investment in soil improvement works and evaluation of suitable crops.

Class VI – Non-Irrigable: These lands are not suitable for irrigation and have severe limitations that require land improvements works that are not economically feasible.

After taking into consideration topography, soil properties and drainage, agricultural land was categorized into six classes. In this study, only 2100 hectares of agricultural land in the first class (Class I) that had the best agricultural conditions (Table 3.9) was studied. The amount of water allocated to the mentioned land was about six million cubic meters (MCM). Seventeen important agricultural products of the region, namely Wheat, Barley, Husks, Corn, Pea, Lentil, Cotton, Sugar beet, Watermelon, Cucumber, Potato, Onions, Tomatoes, Canola, Beans, Soya bean and rice were used for the modelling.

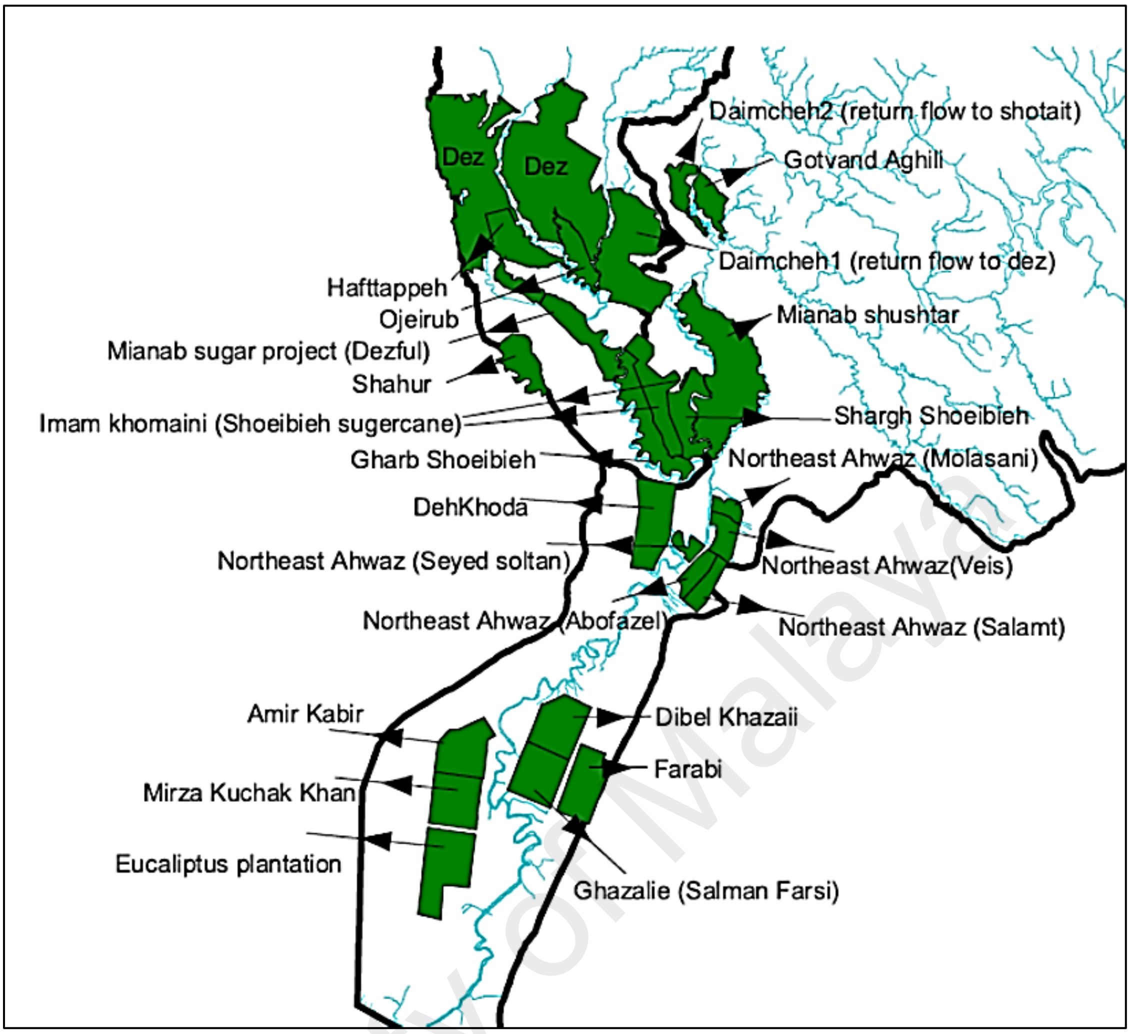


Figure 3.26: The agricultural network

Table 3.9: The soil classification in downstream of Karun III (area in hectares)

Description	Class I	Class II	Class III	Class IV	Class V	Class VI	Total Reported
Karun III downstream	2100	10600	13400	440	21300	20960	68800
Total (Khuzestan)							931256
% of Total Area	0.23	1.14	1.44	0.05	2.29	2.25	7.40

Pre Modelling: Data needed for modelling were prepared in the form of constants, values of the upper and lower limits and computational values in the pre modelling phase. Table 3.10 shows the constants and constraints of the problem.

Table 3.10: Input amount of the problem (The data in this table is assumed only for the case study and annual time distribution is considered)

	Constants			Constraints	
Agricultural Products	**MWN**	**APH**	**PVT**	**MAL**	**MLN**
	(m^3)	(ton/ha)	(1k Toman)	(ha)	(ha)
Wheat	4340	2.68	1050	400	374
Barley	3730	2.71	780	300	185
Husks	4180	4.25	850	40	24
Corn	5060	6.39	870	20	8
Pea	3940	1.05	1900	200	57
Lentil	4630	1.2	2000	200	59
Cotton	9160	2.37	2200	200	8
Sugar beet	4710	42.02	210	30	2
Watermelon	11850	27.69	374	40	3
Cucumber	3800	19.48	300	40	2
Potato	2970	29.03	300	40	3
Onions	4530	37.18	200	40	3
Tomatoes	1650	37.69	200	40	5
Canola	6590	2.08	1900	140	72
Beans	4930	1.67	1800	200	60
Soy spring	3220	2.34	1700	60	56
Rice	8890	4.23	2700	110	95

By using relations 3.41 to 3.43 computational values were obtained.

Computed values:

(Min water required to provide the desired capacity) i = (Min land required)$_i$ * (Min. required water per hectare) $(\forall i = 1,2,3,\dots,17)$. (3.38)

Min land required for production = (Min tonnage i) /(Average production per hectare $_i$) $(\forall i = 1,2,3,\dots,17)$. (3.39)

Value per hectare i = (The product value per tonne) i*(Average production per hectare) i $(\forall i=1, 2,3,\dots,17)$. (3.40)

Therefore, the above relations can be written in the form of following mathematical equations.

$$MWND_i\,(m^3) = \frac{\prod_1^{17}(\mathrm{MWN\ (m3)} * \mathrm{MT(ton)})_i}{\mathrm{APH\ i\ (ton)}} \quad (3.41)$$

$$MLN_i\,(ha) = \frac{\mathrm{MT\ i\ (ton)}}{\mathrm{APH\ i\ }(\frac{\mathrm{ton}}{\mathrm{ha}})} \quad (3.42)$$

$$VPH_i\,(\mathrm{Toman}) = \prod_1^{17}(APH * PVT)_i \quad (3.43)$$

Table 3.11: Computed value of problem (The data in this table is assumed only for the case study and annual time distribution is considered)

	VPH	MLN	MWND
	(1000 Toman)	(ha)	(m^3)
Wheat	2.81	374	1622430
Barley	2.11	185	688192
Husks	3.62	24	98260
Corn	5.56	8	39618
Pea	2	57	225143
Lentil	2.39	59	271213
Cotton	5.21	8	77332
Sugar beet	8.82	2	8967
Watermelon	10.35	3	19018
Cucumber	5.84	2	7803
Potato	8.71	3	10229
Onions	7.44	3	14623
Tomatoes	7.54	5	8757
Canola	3.95	72	475469
Beans	3.01	60	295210
Soy spring	3.97	56	179272
Rice	11.42	95	840861

Optimization Modelling and Implementation

The optimization problem was modelled with the aim of maximizing the ultimate value of agriculture and subject to minimum water needed, the optimal agricultural land and the minimum demand of the product (Equation 3.44 to Equation 3.45).

Objective Function:

Max Z = Σ(The optimal area of agricultural land for production*Value per hectare) i $(\forall i = 1,2,3, \ldots ,17)$. (3.46)

Constraints:

Minimum water required to provide the desired capacity ≤the total allocated water (3.47)

The optimal area of agricultural land $_i$ ≤ max available agricultural land $_i$ (3.48)

The optimal area of agricultural land $_i$ ≥ min land required for production $_i$ (3.49)

The min tonnage $_i$ ≥ average production per hectare i (3.50)

Also, the above relations can be written in the form of following mathematical equations.

Objective Function:

$$\text{Max } Z = \sum_{i=1}^{i=17} (OPTarea * VPH)_i \quad \forall\, i = 1,2,3, \dots, 17 \tag{3.51}$$

Constraints:

$$MWND_i \leq TAW \quad \forall\, i = 1,2,3, \dots, 17 \tag{3.52}$$

$$OPTarea_i \leq MAL_i \quad \forall\, i = 1,2,3, \dots, 17 \tag{3.53}$$

$$OPTarea_i \geq MLN_i \quad \forall\, i = 1,2,3, \dots, 17 \tag{3.54}$$

$$MT_i \geq APH\ i \quad \forall\, i = 1,2,3, \dots, 17 \tag{3.55}$$

The Cost Forecasting

The estimated costs of the different stages of farming (including planting, maintenance and harvesting) and the predicted expenses of the fertilizer of farming (including phosphate fertilizer, nitrogenous fertilizer, and potash fertilizer) were the final stage. Considering the objective function determined the optimum cropping pattern in terms of the number of acres of each crop, we can estimate and predict the cost of the different stages of agricultural process. For this purpose, we must multiply the obtained results of cultivation pattern in acre to cost breakdown values in tables taken from ministry of agriculture (Table 3.12 and Table 3.13).

Table 3.12: The average consumed quantity and cost of fertilizer per acre (Currency unit: TOMAN, Weight: Kg)

	Fertilizer									
	Phosphate		Nitrogen		Potash		Other		Total	
	cost per kg	weight	cost per kg	Weight	cost per kg	weight	cost per kg	weight	cost per kg	Weight
Wheat	78	152	66	232	61	18	126	8	72	410
Barley	75	152	60	180	64	9	120	9	68	350
Husks	109	249	43	398	92	22	349	11	65	680
Corn	83	144	73	331	77	19	286	7	81	502
Pea	79	48	62	50	54	6	179	0	69	104
Lentil	80	89	74	98	54	6	1500	0	77	188
Sunflower	81	162	73	215	60	26	133	5	76	408
Cotton	80	191	65	244	63	14	612	2	74	452
Sugar beet	94	246	73	275	66	45	128	23	83	589
Watermelon	91	187	75	194	81	16	184	46	90	443
Cucumber	92	254	79	411	82	56	205	70	90	791
Potato	89	269	81	361	69	70	316	12	90	713
Onions	99	233	94	333	67	28	185	29	98	623
Tomatoes	102	238	94	379	81	16	232	33	102	687
Canola	83	183	66	225	67	19	341	5	78	433
Beans	93	148	78	162	79	10	157	5	86	325
Soya bean	62	107	46	157	67	45	1582	3	67	311
Rice	136	162	102	219	71	27	189	3	114	412

Table 3.13: The average cost of producing one hectare of agricultural products according to the different stages of farming (Currency unit: Toman)

0	The average cost of producing one hectare of agricultural products according to the different stages of farming (Unit: Toman)											
	Total		Farmland		Harvesting		Maintenance		Planting		Farmland Preperation	
	Percent	Cost	Percent	Cost	Percent	Cost	Percent	Cost	Percent	Cost	Percent	Cost
Wheat	100	638649	30.36	193888	11.32	72293	28.17	179934	19.17	122399	10.98	70135
Barley	100	556660	25.73	143203	12.46	69340	30.41	169267	18.59	103487	12.82	71363
Husks	100	2492794	26.96	672075	12.43	309817	28.78	717548	21.2	528399	10.63	264955
Corn	100	875784	32.5	284626	9.92	86917	35.63	312030	13.14	115041	8.81	77170
Pea	100	361688	22.78	82378	22.17	80204	27.9	100908	15.91	57556	11.24	40642
Lentil	100	627963	21.78	136774	26.8	168299	26.58	166899	15.35	96394	9.49	59597
Sunflower	100	1039942	21.27	221172	20.1	209002	35.6	370252	14.06	146246	8.97	93270
Cotton	100	1156955	15.1	174699	21.55	249301	45.95	531586	10.69	123656	6.72	77713
Sugar beet	100	1418594	14.18	201101	24.34	345266	42.01	595928	14.06	199455	5.42	76844
Watermelon	100	1190808	16.76	199613	26.13	311186	27.93	332545	19.45	231559	9.73	115905
Cucumber	100	2588252	12.84	332278	31.92	826160	28.86	746842	20.15	521644	6.23	161328
Potato	100	2782335	12.77	355286	17.19	478416	22.91	637528	43.63	1214020	3.49	97085
Onions	100	2634561	13.7	360982	32.18	847830	32.01	843384	16.04	422665	6.06	159700
Tomatoes	100	2964669	13.08	387807	40.04	1187023	28.15	834572	14.51	430180	4.22	125087
Canola	100	755590	33.66	254338	9.84	74379	34.95	264063	11.24	84911	10.31	77899
Beans	100	1190464	23.05	274446	19.29	229585	34.14	406442	16.68	198524	6.84	81467
Soya bean	100	725466	39.45	286180	11.67	84670	27.18	197208	9.75	70760	11.94	86648
High quality medium grain rice	100	2512094	29.34	736960	14.49	364078	23.96	601820	21.73	545799	10.49	263437

Assumptions of the problem:

Important indices required for designing cropping patterns

- Economic indices in cropping pattern should be determined in a way that with selection of type of product along with increasing operation of available resources (water, soil, etc.) we can achieve maximum revenue for farmers and producers; and farmer can invest and develop their activities with increasing revenue and interest of selling products and therefore we can observe economic flourish in agriculture section.
- Place of essential products in cropping pattern in designing the cropping pattern should pay special attention to essential and strategic products such as wheat, corn and oilseeds to supply food security of the state desirably and obtain self-sufficiency for required products of the state.
- Relative advantage of that group of agricultural products, which have more advantages and higher economic desirability that they should be placed in cropping pattern after essential products with priority.
- Protecting basic resources and environment with the aim of stability in producing agricultural crops, preserving basic resources (water, soil etc.) and environment should be specially considered in designing cropping pattern.
- Optimal consumption of water regarding this matter that the county is placed in arid and semi-arid belt, cropping pattern should be designed by considering the optimal operation of water resource.
- Different parameters are involved in designing cropping pattern and selecting plants for an irrigation and drainage system. Some of them are:

- Government explained policies based on priorities of development and increasing production of strategic products for meeting nutritional requirements of the state's population
- Considering climate and soil of the region and its relation with compatibility of agricultural plants
- Creating variety in agricultural crops for controlling pests, diseases and weeds
- Increasing soil fertility
- Creating jobs in different seasons of the year
- Operation of lands is possible
- The quantity of irrigation water
- Crop rotation
- Crop water requirement
- Economy of agricultural productions

3.4 A description of optimization methods

3.4.1 Genetic Algorithm

The genetic algorithm is an inquiry method and optimization based on principles of natural evolution. This method is among the optimal optimization algorithms, which are able to find the optimal solutions or the solutions close to them.

As the generation is done by a set of chromosomes and therefore Human traits are inherited through the generations, GA mimics this natural behaviour and chooses the best solution to be the parents of the next generation. This method produces several generations of feasible solutions, which try to move toward the optimum.

In the GA initial population of solutions (chromosomes) is selected randomly to be evaluated through objective functions and the constraints. A set of chromosomes is chosen from the initial random population, whose objective function value is better than the others. This set is assigned to be the parents for the next generation of chromosomes. The new offspring of new parents replaces inferior chromosomes from previous generations and therefore the next generation is formed. This is done until the last generation reaches the optimum solution.

Process:

1. A random population of n chromosomes is generated.
2. Each chromosome in the population is evaluated in the fitness function
3. A new population is created by repeating the following steps
   - Two parent chromosomes are selected from a population according to their superiority.
   - With certain probability function, the two parents are mated and new offspring is produced with the aid of crossover function.
   - Mutation is applied and the offspring may change.
   - New offspring in the new population replaces inferior ones.

4. New population acts as the next generation in the next step of the algorithm.

5. The algorithm stops if the termination conditions are met. Therefore, the algorithm returns the best solution.

6. Step 2 is repeated.

Genetic algorithm allows a population composed of many individuals who have been made during a special selection rule; fitness function would be optimized during the process of evolution. This method was developed by John Holland in 1975. Then, his findings were generalized in order to solve some problems such as operation of the gas pipeline by one of his students, David Goldberg in 1989. In the book published by him which has been one of the most comprehensive sources in the genetic algorithm field, the merits of this algorithm is comparison with the other methods are stated as follows:

- Capability of optimization in continuous and discrete spaces
- It does not require any information about derivate function
- It is able to work with a large number of decision variables
- It is possible to optimize very complex objective functions by using this algorithm
- To begin, instead of using a single value, it uses a population with potential solutions
- It provides a possibility to use coded values of variables instead of using them
- It uses probable rules than certain rules to guide the searching process

This algorithm is able to find the optimal solutions in many cases that traditional optimal methods are unable to do. However, it should not be thought that genetic algorithm is a good way to solve all the optimization problems. For instance, to find the optimum point of a curve, which has just a point of absolute minimum or maximum, classic methods which work based on derived, can find this point very easily and very fast. Nevertheless, genetic algorithm may need double time compared to the classical methods to find the answer. However, for functions that have many local extremum points, definitely a classic method will have a problem, while, genetic algorithm will comprehensively search the answer space, therefore, and the probability of convergence in local optimum is very low.

Limitations of Genetic Algorithms:

1. If wrong evaluation function is selected, are may not get the correct answer.

2. Population size, mutation and crossover rate may directly affect the performance of the algorithm. Therefore, setting the right values of these parameters is vital.

3. Another problem that is often seen in small populations, i.e. if one chromosome is significantly away from most of its generation or is much better than others, it may result in early convergence and lead to a local optimum solution.

Mechanisms of Genetic Algorithm

Genetic Algorithm begins with creation of an initial population of chromosomes. In other words, chromosomes are series of suggested values for the problem decision variables and each of them represents one probable solution for the problem. In the next part, these chromosomes will be evaluated due to the objective of optimization and the chromosomes will be considered the better solution for the mentioned problem, and have more chance to reproduction for problem solution. Formulation of a fitness function of chromosomes, accelerating the computing of convergence speed toward the global optimum solution is very important, because the amount of fitness function must be calculated for each chromosome in genetic algorithm and since we encounter many chromosomes in many problems, calculation of the evaluation function is time consuming. For some problems, application of genetic algorithm is practically impossible. The genetic algorithm process is an iterative process, as the number of chromosomes in the initial population is divided into two groups in any iteration; selected and dropped which the next generation will be created of selected chromosomes. During the process of generation iteration, different operators of the algorithm are playing to reach the stopping criterion.

Genetic Algorithm Operator

After selecting the initial population of the algorithm, which is debated a lot, the following operators are applied to the algorithm in order.

Evaluation:

As it was mentioned, each chromosome is representative of a series of solutions for the optimization problem. After selecting the initial population, every chromosome must be evaluated in the fitness function which is the objective function of the model and its output amount from the fitness function must be compared with the amount of other individuals of the population (chromosomes) and the best will be selected among these amounts due to an objective model (maximum or minimum).

Crossover

Crossover is the most important operator in genetic algorithm. While operating this operator, population of old generation have combined with each other and created new generation. This function gradually diminishes population distribution during iteration of generations, because the superior individuals combine to each other in any iteration and since the criterion for superior individuals is to move to the optimal solution, the distribution will be as low as possible.

Mutation

This operator plays an important role to search all the parts in the possible space, because changing of the amount of some genes in each individual of population, makes it also possible to search blind spots of possible space and it may cause the individuals who have been changed their genes, find the possible solution faster. This operator performs much effectively and is helpful in the large-scale problems (**Figure 3.27**).

Genetic algorithm

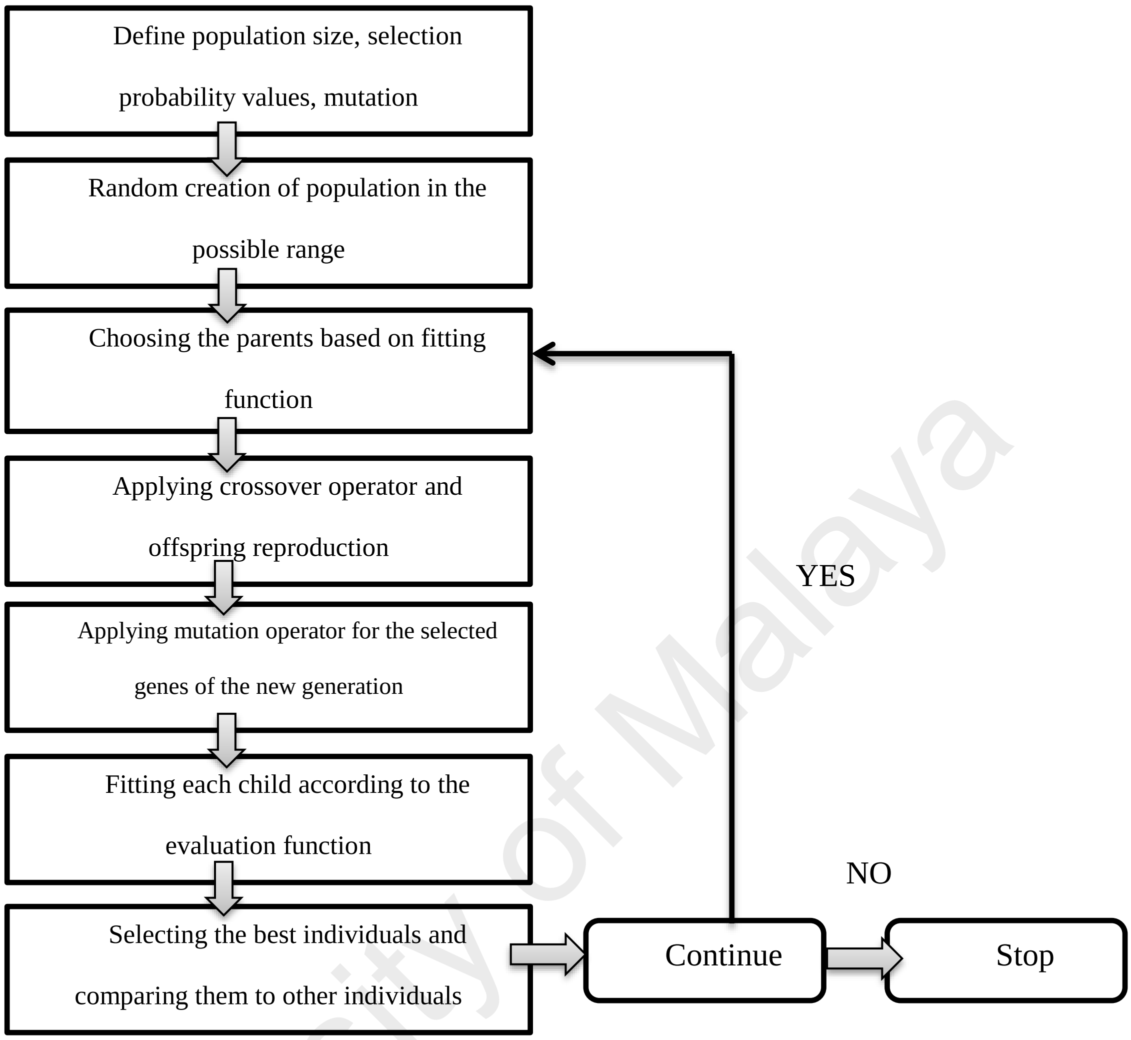


Figure 3.27: Genetic algorithm flowchart

NSGA II:

If there is more than one objective function then the problem will be complicated. For example if one wants to build a structure that is both light and stiff, since these two features are in contrast, we can look for alternative designs and relationships. Thus, there would be the lightest and the most difficult design as well as an infinite number of plans that are in compromise between stiffness and lightness. These sets of so-called alternative designs are known as Pareto-Sets. Also with the help of the best chosen designs, we can draw the trade-off curves that are obtained by plotting the weight against stiffness.

Figure 3.28 presents the answers to a double-objective problem of minimizing. Pareto is described as a point that each of its corresponding objective values shouldn't be worse than the rest of the points or at least one corresponding objective of this point should be better than the other answers. This point is referred to as Pareto or non-dominated, and a set of answers related to these are called a set of Pareto (In Figure 3.28 the blue point are Pareto and the white points are dominated answers of the problem). In this relationship, same as the single-objective optimization, there are two approaches: classical methods and evolutionary algorithms. However, there is a great difference between the two approaches.

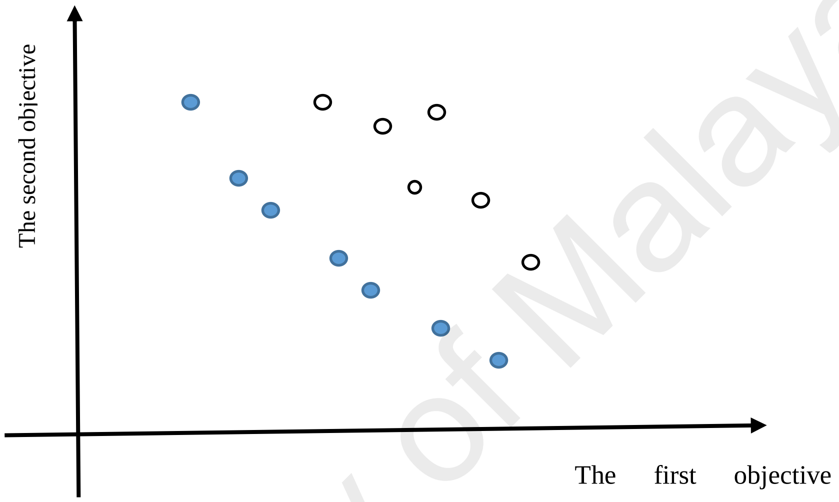


Figure 3.28: Non-dominated answers in Pareto range

Different classical methods which are based on mathematics and mathematical derivations are described below. The mathematical equation of a multi-objective problem can be defined as follow:

$$Minimize\ \ [F_i(x), F_i(x), F_i(x)]^T \tag{3.56}$$

Subject to (3.57)

$$g(x) \leq 0, \tag{3.58}$$

$$h(x) = 0, \tag{3.59}$$

$$x_1 \leq x \leq x_u \tag{3.60}$$

F_i shows i^{th} objective function, g(x) and h(x) are equal and unequal constraint functions, respectively. [x] is the vector of problem's decision variables.

3-4-2 Evolutionary approach based on sorting

In the past two decades, a number of multi-objective evolutionary methods have been proposed. Among these methods the genetic algorithm with non-recessive sorting of the solutions, has been one of the successful and promising approach. The first non-recessive sorting of genetic algorithm (NSGA) was introduced by Srinivasa and Deb in 1994. The algorithm was capable of obtaining any number of Pareto optimal solutions in each implementation. NSGA-II is the developed version of the first method and it was introduced to deal with the complexity of computation and diversity of the problems. The algorithm consists of five major stages: forming the initial population, sorting non-recessive solutions, crossover, mutation and eugenics.

This algorithm consists of following steps:

1. Random creation of the initial population so that the population lies in the possible range. Then there is the evaluation of the population in the objective function and the sorting of the non-recessive solutions, so that the population is changed into several subsets, each with different ratings (For example, number 1 is assigned to the first set of the non-recessive solutions, number 2 to the next set and etc.).
2. Crossover implementation for the selected population and the race selection operators (which is normally half of the initial population, value of the ratio is defined at beginning of the algorithm). To produce the next generation so that the total population is the same as the initial population.
3. Evaluating the offspring's cost function and repeating the sorting of the non-recessive solutions and classifying the population based on the present ratings.
4. Selecting the new parents and producing offspring, implementing the mutation and crossover operators and then evaluating the cost function again.
5. Repeat step 3 and 4 until the stopping criterion for the algorithm is met.

6. Since this algorithm is introduced for non-constraint optimization models, the penalty function is used for writing and including the problem constraints. Continuity constraints of the reservoir are the most important constraints dominating the problem. In other words the procedure of this algorithm is shown in the flowchart below (Figure 3.29):

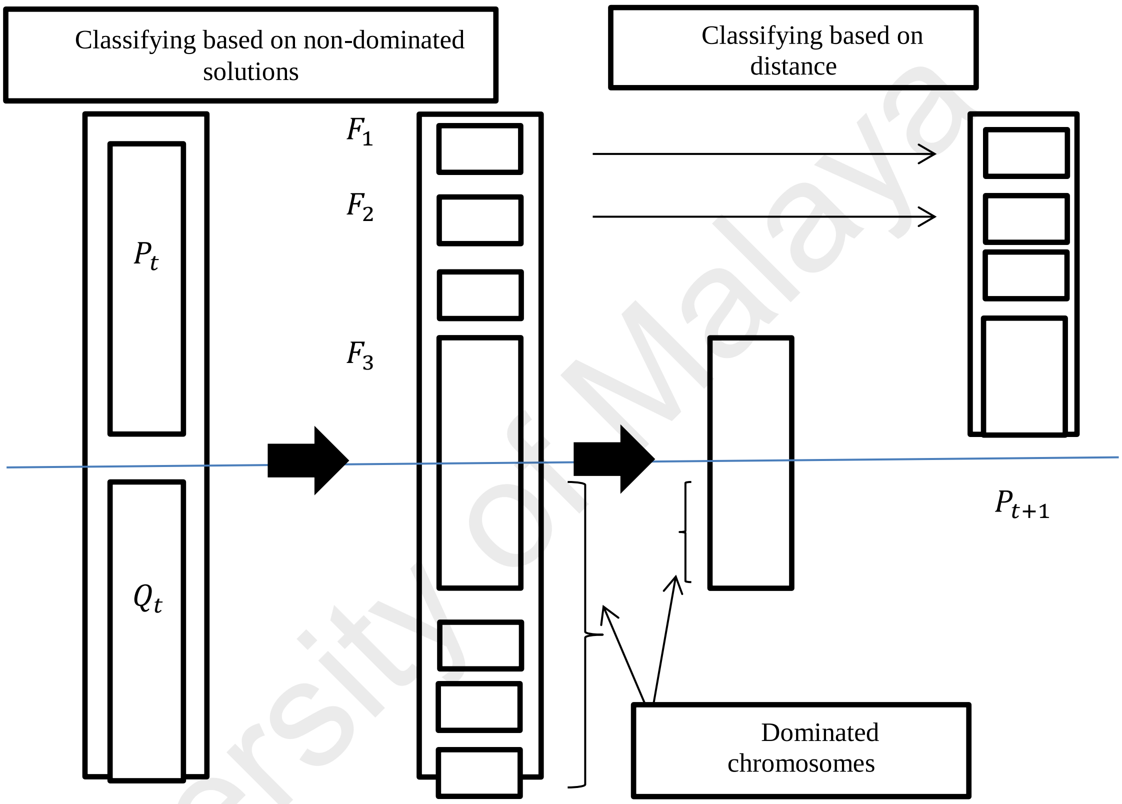


Figure 3.29: Genetic algorithm with non-recessive sorting of solutions

1. Randomly produced parent generation P_0 in N numbers.
2. Classifying the first generation of the parents based on non-dominated solutions.
3. Considering an appropriate order with non-dominated level for each non-dominated solution (1for the best level, 2 for the next best level after 1and etc).
4. Offspring reproduction Q_0 in Nnumbers by using the selection, crossover and mutation operators.
5. Considering the first reproduction, which is consisted of parent and offspring chromosomes, the next reproduction is as follow:

a. Composition of parent P_t and offspring Q_t chromosomes, and reproduction R_t in 2N numbers.

b. Classifying R_t generation based on non-dominated method of sorting and identification of non-dominated mantles ($F_1, F_{2,\ldots,} F_t$).

c. Parent reproduction for the next iteration P_{t+1}, using produced non-dominated fronts in N numbers. In this stage, due to the number of required chromosomes for the parent generation N. At the beginning the first front chromosomes for the parent generation is chosen, and if this number of chromosomes are not enough for the total number of required chromosomes for the parent generation, then they are harvested step by step from 2,3 and… fronts until it reaches the total number of N.

d. Applying crossover operators, mutation on the regenerated parent generation P_{t+1} and regenerating the offspring generation in N numbers.

6. Repeating step 5 to achieve the total number of iterations.

3.4.2 Particle swarm optimization algorithm

The particle swarm optimization algorithm was first introduced by Kennedy and Eberhart in 1997 (Kennedy & Eberhart, 1997). PSO algorithm is an evolutionary computation that is inspired by nature and is based on iteration. The algorithm is inspired by animals' social behaviour, mass movement of birds and fish. Hence, PSO begins with initial random population matrix like other evolutionary algorithms and imperative competitive algorithm. Unlike genetic algorithm, PSO does not have any evolutionary operators like mutation and crossover, therefore imperative competitive algorithm is more similar to PSO than GA. Each element in the population is called a particle (same as chromosome in GA, or a country in an imperialist competitive algorithm). In fact, PSO algorithm is consisted of a certain number of particles, which randomly have initial values. Two values of position and velocity are defined for each particle, which are modelled with position and velocity vectors, respectively. These particles iteratively move in $-$N dimensional space in order to calculate the optimal value as a criterion for measuring to find possible new options. The dimensional space of the problem is equal to the number of existing parameters for optimization in a function. A memory is allocated to storing the previous best position of the particle and one memory is allocated to storing the best-known position of best particle among all the particles. The experience from these memories determines the movement of the particles in the next turn. In any iteration, all particles move in the $-$N dimensional space of the problem to finally find the common optimal point. The velocity and position of the particles are updated based on the best local and absolute solutions. In PSO algorithm, the $\overrightarrow{x_i}$ particle is updated as follow:

$$\overrightarrow{x_i}\ (t) = \overrightarrow{x_i}\ (t-1) + \overrightarrow{v_i}(t) \tag{3.61}$$

$\overrightarrow{v_i}(t)$ represents the velocity vector, and is calculated by the following equation:

$$\overrightarrow{v_i}(t) = \omega.\overrightarrow{v_i}(t-1) + C_1.r_1 - \left(\overrightarrow{x_{pi}} - \overrightarrow{x_i}\right) + C_2.r_2.\left(\overrightarrow{x_{gi}} - \overrightarrow{x_i}\right) \tag{3.62}$$

In this formula $\overrightarrow{x_{pi}}$ is the best solution that $\overrightarrow{x_i}$ had in any iteration and $\overrightarrow{x_{gi}}$ as the best particle among all particles in any iteration. This particle is referred to as the leader. ω is the inertia weight for particles that keeps the balance between local and global experience. r_1 and r_2 are uniformly distributed random numbers in $[0 \text{ and } 1]$ interval. $C_1$and C_2as specific parameters, control the best local and absolute particle. Particles move in the search-space near the best absolute solution (leader) and do not explore the rest of the space; this is called convergence. If a small velocity inertia coefficient is chosen, then all the particles can reduce their speed until their speed is near zero in the 'best local'.

The PSO algorithm (Figure 3.30), updates the velocity vector of each particle and adds the new speed to the position and the value of the particle. Updating the velocity is influenced by both best local and absolute solutions. The best local and absolute solutions are obtained by one particle and the whole population until the algorithm is running. $C_1$and C_2 invariants are perceptual and social parameters, respectively. The main advantage of the PSO is that, it is easy to implement and it needs to provide only few parameters. Moreover, PSO is able to optimize complex cost functions with many of local minimum.

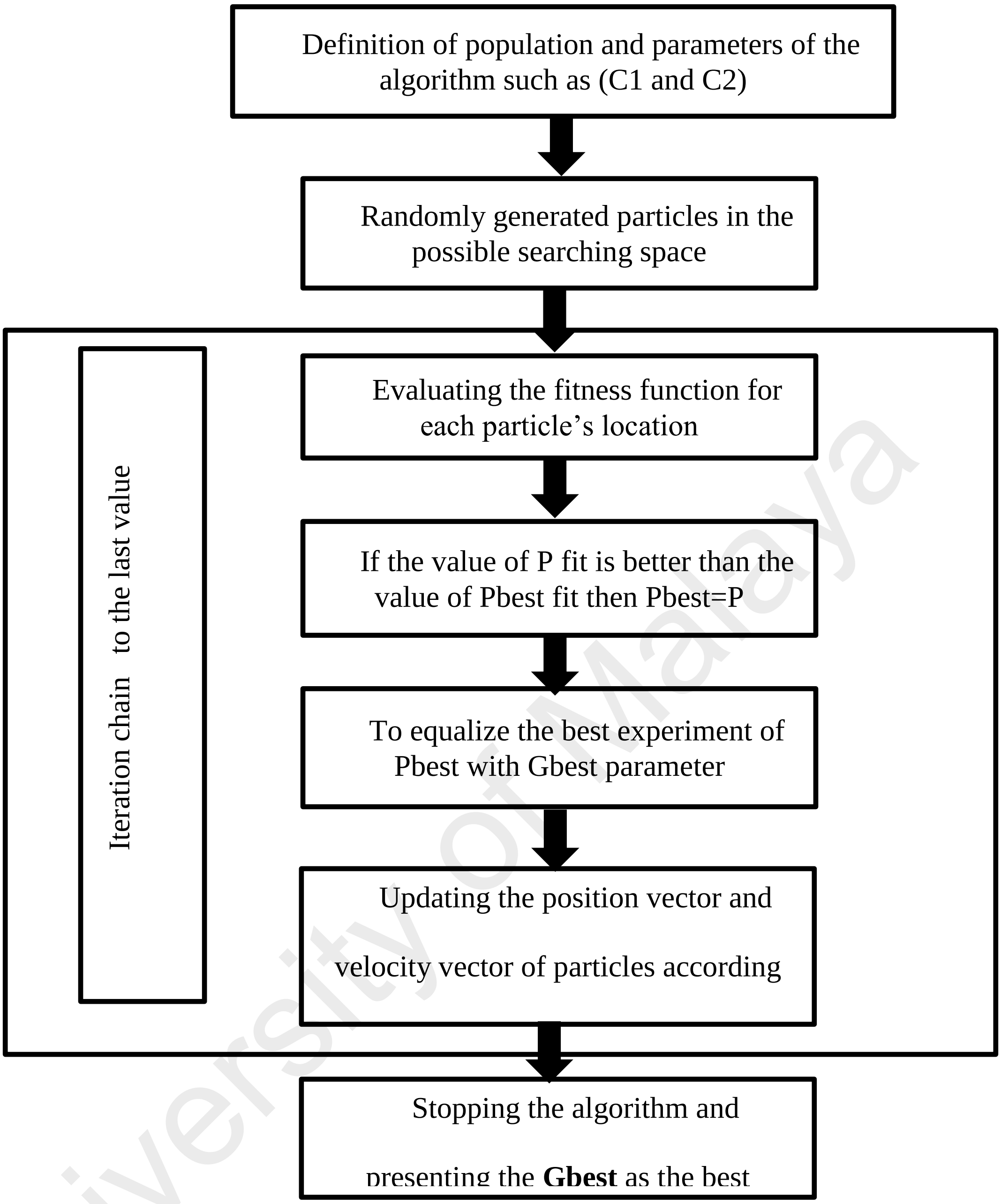


Figure 3.30: Particle swarm optimization algorithm flowchart

3.4.3 HPSOGA

The particle swarm algorithm was inspired by the collective movement of organisms such as birds and fish. A population of particles is used in the algorithm that explore the possible space to find the optimal answers. Each particle has a position and initial speed in the population. In addition, each particle recalls the best position that it has previously attained. Genetic Algorithm and Particle Swarm Algorithm ability to solve complex problems has been proven several times. However, each of these two methods has weak and strong points, the comparison between the genetic algorithm and particle swarm algorithm was done by Eberhart and Anjlayn and according to studies conducted by them, it is suggested that by the combination of these two algorithms, the obtained model converted into a model with strong performance in solving problems and creating a good searching environment. The main objective of this paper is combining Genetic Algorithm and Particle Swarm algorithms and general principle of this method is that the benefits of particle swarm algorithm with very useful operators of genetic algorithm (mutation and crossover) are combined and create hybrid algorithm (Angeline, 1998). One of the advantages of the particle swarm algorithm compared to the genetic algorithm is simplicity and having less parameters, another obvious difference is in the ability to control the convergence to the optimal answer, the operation rate of mutation and crossover can help in a good way to the convergence of genetic algorithm. However, these operators are different from speed, weight-damping operator in the particle swarm algorithm, and in fact, the convergence of the algorithm will be increased by decreasing the effect of the weight over successive iterations. One of the major problems of particle swarm algorithm is premature convergence and this convergence is not necessarily the way to achieve the optimal solution, to prevent this happening, the position of the particles and global best must be changed, and changing the situation is done by the combination of genetic algorithm. Very efficient operators of genetic algorithm are mutation and crossover operators that information is exchanged between two particles of the population by applying the crossover operator. In this way, the desired particle can be transferred to a new point in the context of the decision. The purpose of applying the second operator (mutation) is to increase diversity and creating diversity in population and ultimately preventing to achieve local optimal answer.

If the searching environment is D-dimensional, in this case, the initial positions of each particle will be shown by the D-dimensional vector Xi = (xi1, xi2, ... xiD) and its initial velocity by Vi = (vi1, vi2, ..., viD). Also, the best position of the particle and the best position that the group have experienced, have been shown, respectively, by Pi = (pi1, pi2, ..., piD) and Pg. In this case, the position and velocity of the particle can be expressed by two following equations:

$$\mathrm{V}^{n+1} = \mathrm{V}^{n} + C_1 r_1 (P_i^{\,n} - X_i^{\,n}) + C_2 r_2 (P_g^{\,n} - X_i^{\,n}) \tag{3.63}$$

$$\mathrm{X}_i^{n+1} = \mathrm{X}_i^{n} + \mathrm{V}_i^{n+1} \tag{3.64}$$

Where n is the number of repeats, c1 and c2 are constant coefficients that are called cognitive and social parameters, respectively, and r1 and r2 are random numbers in the range of 0 and 1. In fact, these two relationships represent an early version of particle swarm algorithm. In this algorithm, there is no mechanism for controlling the speed of the particles. Therefore, the velocity of the particles increases in an uncontrollable way. This causes that particles pass beyond the appropriate answers. For this reason, different methods are used to control the particle velocity. One of these methods is to apply the maximum value for the speed. In this way, if the velocity of the particles were higher than this amount, the maximum speed would be considered. Another method, which is more common, is the use of factor "w" as weight inertia. If this parameter is used, the Equation 3.65 will be as follows:

$$\mathrm{V}^{n+1} = \lambda (w\mathrm{V}^{n} + C_1 r_1 (P_i^{n} - X_i^{\,n}) + C_2 r_2 (P_g^{\,n} - X_i^{\,n})) \tag{3.66}$$

c1, c2 and w are obtained through the following relationships. In the above equation, λ is the contraction coefficient (Clerc, 1999) and the purpose of using it to ensure the convergence of the algorithm. How to get this coefficient is below.

$$W^{(n)} = w_{max} - (n / iter_{max}) (w_{max} - w_{min}) \tag{3.67}$$

Where w_{max} and w_{min} are the inertia in the beginning and end of the process, respectively. n is the number of iteration times of the algorithm so far, and $iter_{max}$ is the total number of iterations in the algorithm.

Chromosome are randomly modified to increase their appropriateness in the genetic algorithm. There are two basic solutions to this. The first solution is to use a crossover operator which the process is simulated based on the combination of chromosomes during reproduction in the living organisms. And the second solution is the use of mutation operator.

Gene diversity and variety will be effectively improved by the two operators and these two operators can be used in the particle swarm algorithm to improve the efficiency of it. The flowchart of the combination of these two algorithms is presented in Figure 3.31.

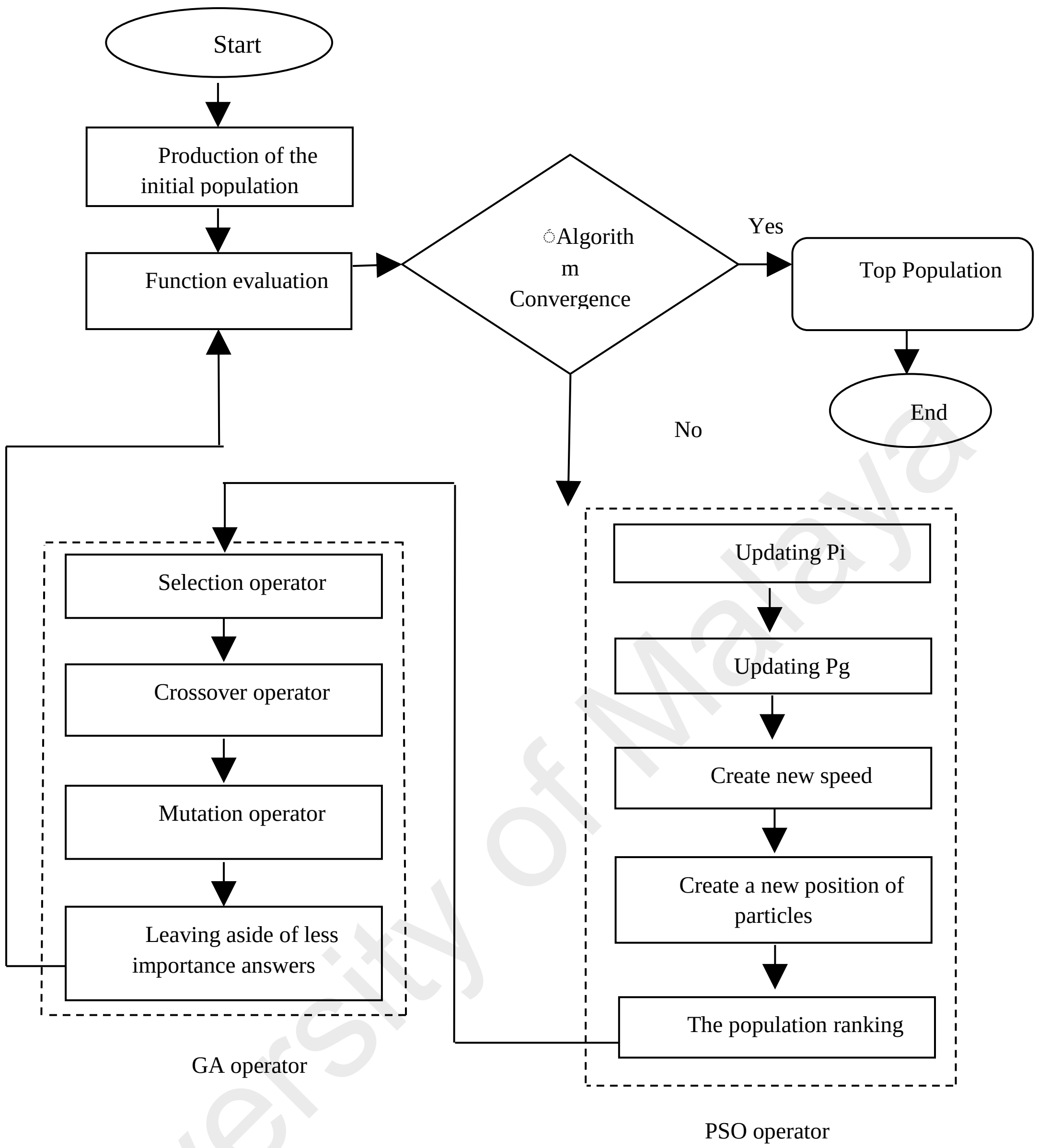


Figure 3.31: The combination of Particle Swarm Optimization Algorithm and Genetic Algorithm (Production HPSOGA hybrid model)

3.5 A description of computational tools

3.5.1 LINGO

Lingo is a powerful tool for linear and nonlinear optimization to solve and analyse formulated models of major and minor issues. Optimization helps to achieve the best result, and highest profit, outcome or satisfaction or attain the least cost, losses or dissatisfaction. These issues often include efficient use of the resources (the best way possible) which consists of money, time, machinery, staff, stock, etc. optimization issues are divided into two categories: linear and nonlinear, depending on whether the relations between the variables are linear or not.

Generally, each optimization model includes the following three items:

Objective function: It is a formula expressing what exactly should be optimized.

Variables: They are quantities, under control and their best values are to be decided.

Constraints: Almost without exception, some limits can be considered on the amounts of variables in a model (At least one resource is limited, such as time, raw materials, budget, and etc.) these limits that are expressed as formulas which are a function of model variables, are known as constraints.

Objective function 1:

The purpose of performing the optimization model in the cropping pattern is to maximize the income, therefore; the objective function is defined as follows:

$$\text{MAX:}\ \ Z=\sum_{j=1}^{n}\left(C_j . X_j\right) \tag{3.68}$$

Subject to

$$\sum_{i=1}^{n}\left(a_{ij} . X_j\right) \leq b_i \qquad i=1, 2\ldots m \tag{3.69}$$

$$Xj \geq 0 \tag{3.70}$$

Where:

Z: Objective function

Xj: Activities related to the production of various agricultural products

Cj: The coefficient matrix of the objective function

aij: Matrix of technical coefficients of production factors

bi: constraints' values

Xj≥0: indicating the positivity of variable values

3.5.2 Solver in Excel

The described model was resolved by Linear Programming (LP) in Microsoft Excel (Solver).

Excel solver is a powerful tool for optimization problems. This solver can solve most of optimization problems like linear, nonlinear and integer programming. This tool was first created by Frontline Systems, Inc (Fylstra et al., 1998). Excel solver uses Generalized Reduced Gradient (GRG2) algorithm in order to optimizie nonlinear problems and also uses the simplex algorithm for solving linear programming (Del Castillo, Montgomery, & McCarville, 1996; Kemmer & Keller, 2010). The aim of linear programming is to maximize or minimize the objective function of the farm's manager regarding some of the constraints (available resources) and decision variables (activities) simultaneously.

3.6 A description of performance measures

3.6.1 RMSE

RMSE is often applied for measuring the difference between observed and calculated values. One advantage of normalizing the RMSE is that it facilitates the comparison between the datasets or models with various scales. The term coefficient of variation of the N, CV (RMSE) might be used to prevent vagueness, during the normalizing by the mean value of the measurements.

$$RMSE = \sqrt{\frac{\sum_{J=0}^{P}\sum_{i=0}^{N}(y_0 - y_c)^2}{NP}} \quad (3.71)$$

$$NRMSD = \frac{RMSE}{Xmax - Xmin} \quad (3.72)$$

$$CV(RMSE) = \frac{RMSE}{\bar{x}} \quad (3.73)$$

Where Yo is the i[th] observation data (Lingo results) and $\widehat{Yc}$ is i[th] computed data (The optimal solution obtained by evolutionary algorithm) .$\bar{x}$ is a mean of the data.

3.6.2 Regression

Regression Method

One of the most widely used statistical methods in different science fields is implementation of regression techniques to determine the relationship between a dependent variable with one or more independent variables. The dependent variable, response and independent variables are also called explanatory variables. A linear regression model assumes there is a linear relationship (direct line) between the dependent variable and the predictor. Running a regression model is possible by defining the regression model. The linear regression model with the dependent variable Y and independent variable p $x_1, x_2, ..., x_p$ is defined as follows (Tunçal, 2010):

$$y_i = b_0 + b_1x_{i1} + \ldots + b_px_{ip} + e_i \quad (3.74)$$

Where

yi: is the amount of i^{th} dependent variable

p: is the number of predictors

bj: is the amount of i^{th} coefficient, j = 0,..., p

Xij: is the value of i^{th} of j^{th} predictor

ei: is the observed error of the value for ith

The model is linear because the value of dependence of b_i is increased by increasing predictive value -i^{th}. b_0 is the intercept, that when any predictive value is zero, the value of predictor model b_0 is the dependent variable. In order to test hypotheses about the values of model parameters, linear regression model also takes into consideration the following assumptions:

• The error term has a normal distribution with a mean of zero

• The variance of the error term is constant in all cases and it is independent of the variables in the model. (An error term with inconstant variance is called heteroscedastic).

• The amount of the error term for a given amount is independent of the variable value's in the model and is independent of the amount of error term or the other cases.

In the present problem, amount of inflow to dam (I) and Karun dam storage capacity (S) are independent variables and the release from dam (R) value is a dependent variable.

3.6.3 Artificial Neural Network

Although regression models are still used to water resources problems such as exploring the internal relations, prediction of weather and climate elements (Christensen, Jian, Ziegler, & Demonstration, 2000; Piao et al., 2010), today, with the progress of science and innovating some intelligent methods in different sciences, predictions of various parameters is done using more intelligent methods such as artificial neural networks. These networks have a great ability in modelling and prediction of weather and climate elements. Creating an Artificial Intelligence system that can learn and have the flexibility of human being is the main purpose of research in artificial intelligence. Trying to imitate the human process has faced intensive activities in the past, which is followed by world research centres through in-depth and purposeful studies nowadays. Many models of intelligent biological systems are evolved during this period, which the goal of each of these models has been to act as the brain and nerve system of humans. Particularly research has been done from purely theoretical research into applied research, in information processing which is no solution or in hard problems. Due to this issue, the growing interest has been created in the development of intelligent, dynamic systems of unlimited model based on experimental data. Artificial Neural Network which is called Simulated Neural Network and or typically called neural networks too, are among these dynamic systems that transfer knowledge or the underlying rule in data to network structure through processing empirical data. That is why these systems are called intelligent, because they learn general rules based on calculations of numerical data.

These networks are trained to overcome the limitations of conventional methods to solve complex problems. These networks have shown very high performance regarding Estimation and Approximation. In fact, wherever estimation, prediction, classification and control are necessary, neural networks have been proposed there in different forms. Intelligent neural networks have been successfully and widely developed to solve a very wide range of issues. The scope of application of mathematical models based on the performance of the human brain is very broad which can be mentioned as a small sample of using the mathematical tool to predict the weather (Faridah Othman, Sadeghian, Heydari, & Sohrabi, 2013).

The major component of a neural network is called a cell. Essentially biological cells are combined with each other in different ways through receiving input from some sources and then they offer the final output by doing non-linear operations on the inputs. Neural networks often include one input and one or more intermediate layer (hidden layer), and an output layer. Each entry is multiplied by the weight of its own. In the simplest case, bias and outputs are added together and then pass through activation function to produce outputs. These systems are trying to model the brain structure of the Nero-synaptic based on computational intelligence. Figure 3.32 shows processing information in a real and artificial cell of neural networks simultaneously.

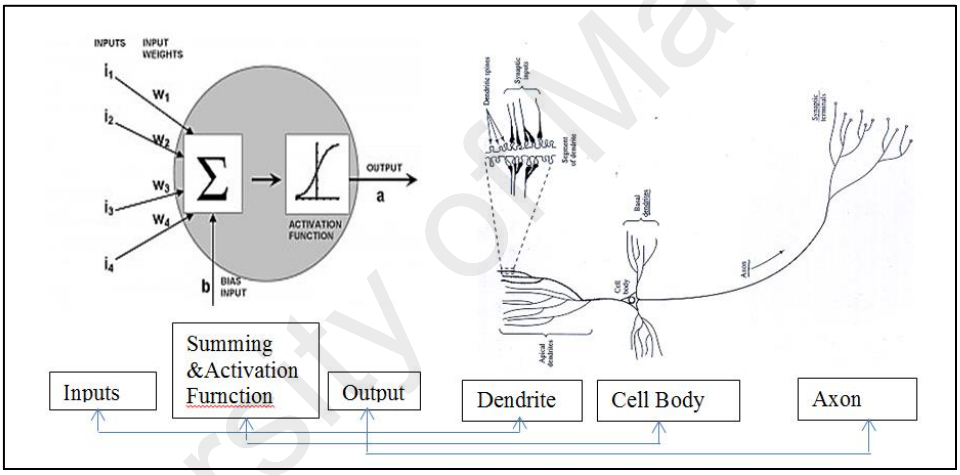


Figure 3.32: The real neural schematic cell and artificial neural network

Activation functions are generally made of linear or nonlinear algebraic equations. The most important step in the neural network is the training part of the network. In general, there are two ways for Network training, which include controllable and uncontrollable training. The most common training algorithm is training algorithm after propagation. The neural network is trained through the algorithm after propagation by changing the weight of the intermediate layer and these changes are stored as data network.

Multilayer Perceptron (MLP): Multilayer Perceptron networks are a type of of feed forward neural networks, which are one of the most used of models of artificial neural network in modelling and prediction of climate elements. Several layers of neuron in each layer are connected to all neurons of the previous layer in the Multilayer Perceptron network. Such networks are called fully connected network. Regarding the issue of estimation of atmospheric elements, Multilayer Perceptron networks have been repeatedly used in different studies by the researchers because of train-ability and high learning ability.

Implementation method:

The overall structure of the neural network model consists of three layers:

1. Input Layer: in this layer, the input data is introduced to the model.

2. The Hidden Layer: in this layer the information is being processed.

3. Output Layer: The results of the model are produced.

The structure of a neural network is determined with the number of layers, number of neurons in each layer, the stimulus (control the output of each neuron) teaching method, correction algorithm weights and types of model.

Schematic of an artificial neural network model is shown in the following Figure 3.33:

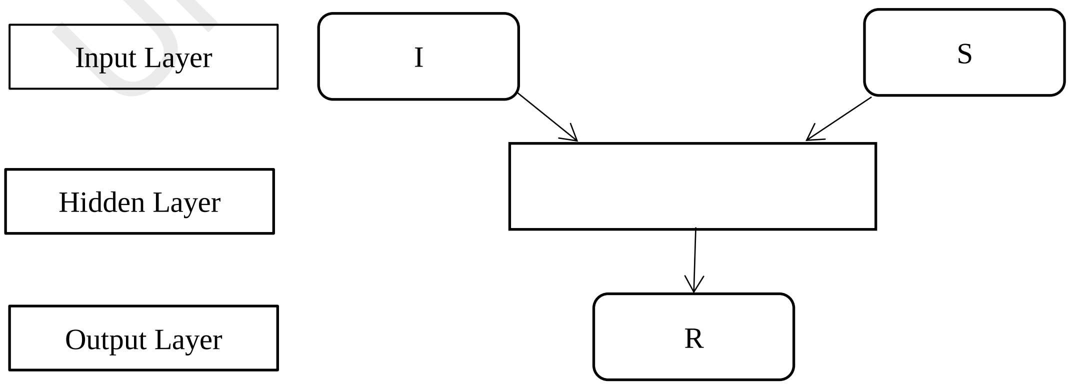


Figure 3.33: The schematic of ANN model (input and output of our model)

In which:

R: is the release from the dam, which consists of outflow for downstream need and spillway from the dam.

I: is inflow to the dam, which consists of upstream basin dam spill and environmental needs.

S: is Karun dam's storage capacity.

Validation of the rule curve:

In order to calibrate the Karun's dam rule curve, by using artificial neural network method, the MATLAB software version 2013a was used.

Pre-processing: The pre-processing is a broad concept, this action includes a selection of influential variables, selection of ten training models and testing, classification of models and normalization patterns (standardizing) of models.

Normalize Data: The purpose of normalization is to make all elements in a model to be equivalent. Suppose that artificial neural has two general types of the input neurons. The data of the first neuron or neurons have been scattered among a large range, but the data of the second neuron has been built in a small range. If the data has been supplied to the network as raw form, the network considers the changes of second neuron a small amount comparing to the first neuron and it can be said that it does not recognize the existence of the second neuron while the information about the second neuron can be very valuable information. For this purpose, it is necessary for the input of all neurons to be normalized. To create balance, first all the data will be normalized to lie between +1 and -1 according to the following equation.

```
function xN = Normalize_Fcn(x,MinX,MaxX)
xN = (x - MinX) / (MaxX - MinX) * 2 - 1;
end
```

Network Architecture: In this study, the Levenberg-Marquardt algorithm was used for Training Network in MATLAB software. The Mean Squared Error (MSE) was also used for the performance evaluation. About 80% of the data for training and 20% complete data were selected for the test. Stopping criterion of 1000 duplicated Epoch was used for network. Statistical methods such as Root Mean Square Error RMSE,andMean Square Error MSE are mostly used to verify results. In this study, we used the mean square error to estimate the accuracy of the results for training and testing data. The formula for its calculating is given in the below relationship ((3.75).

$$\mathrm{MSE}=\frac{\sum_{i=1}^{n}(\widehat{Yi}-Yi)^2}{n} \tag{3.75}$$

As mentioned, the decision to choose the best network in each program was the coefficient of determination R^2, and the lowest error of RMSE and MSE and that their relationship is presented below.

$$R^2 = 1- \frac{\sum(y_0-y_c)}{\sum y_0{}^2-\frac{\sum yc^2}{n}} \tag{3.76}$$

$$\mathrm{MSE} = \frac{\sum(y_0-y_c)^2}{n} \tag{3.77}$$

In the above equations, we have:

y_0 is observed values, Yc is predicted values, n is number of data, P is number of output variables and N is number of samples in output layer.

3.6.4 Compared to the wet situation

The first step to validate the reservoir's volume, is to find the years that the reservoir has its maximum and minimum volume. Normally, in drought years, the reservoir has the minimum inflow and during the wet years, the reservoir has the maximum inflow. The compatibility of range of changes with the gained results in the optimization model is indicative of the validity of the model especially in terms of flood control. Therefore, the time series of inflows have to be prepared and then the monthly outflow has to be subtracted from the averages inflow. The next step is to find the driest and wettest years, then a linear model, which is modeled in LINGO, is used to calculate the maximum volume of the reservoir. The gained values can validate the obtained results.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

A possible approach to operate reservoir systems is through the use of pre-defined operating rules that provide guidelines to the system operator as a function of a small group of variables.

The simplest example of such guidelines is a rule curve. For a single reservoir, this curve indicates the ideal storage level as a function of the time of the year. The system operator attempts to maintain these ideal conditions by releasing water if the storage level is above the target, or by reducing discharges if the storage level is below the target.

More complete operating rules indicate not only the target conditions but also what actions should be taken if these ideal conditions are not achievable. For a single reservoir, a release rule is one example of such operating rules. This rule indicates the release from the system as a function of the time of the year and the storage level in the system. The storage level in the system is represented by the equivalent percent of basin storage used, defined as the total upstream reservoir storage level plus the predicted inflow in excess of the predicted releases for the next 5-day period divided by the total upstream reservoir storage capacity.

For multi-reservoir systems, the operating policy needs to specify not only the total release from the system, but also which reservoirs should be used to satisfy that release. For deciding from which reservoirs to release, the operating rules should take into account concerns like the probability of spillage, the energy factor or head and evaporation rates of each reservoir.

For multi-reservoir systems, the set of operating rules may include individual reservoir storage balancing functions to define which reservoirs should be used to meet the system release. These reservoir balancing functions indicate the ideal storage level in each reservoir given the system storage and the time of the year. A set of release rules and balancing functions clearly defines the actions to be taken and allow some coordinated operation of all system structures. For example, if the water available in the system is scarce, these rules will probably suggest reduced releases from all reservoirs to save water for high priority demands, even from the reservoirs with high storage levels. An independent release policy at each reservoir would probably suggest large releases from reservoirs with high storage levels.

For systems with more than one demand site per reservoir, allocation functions can be defined to establish a relationship between the amount of water released from the reservoir and the amount of water allocated to a specific use. If a system relies on aquifers to supply water demands, pumpage rules that specify the aquifer yield as a function of waterbed levels can also be defined.

The relationship between outflow from reservoir with its inflow and storage volume of Karun reservoirs are shown in Figure 4.1 to Figure 4.3.

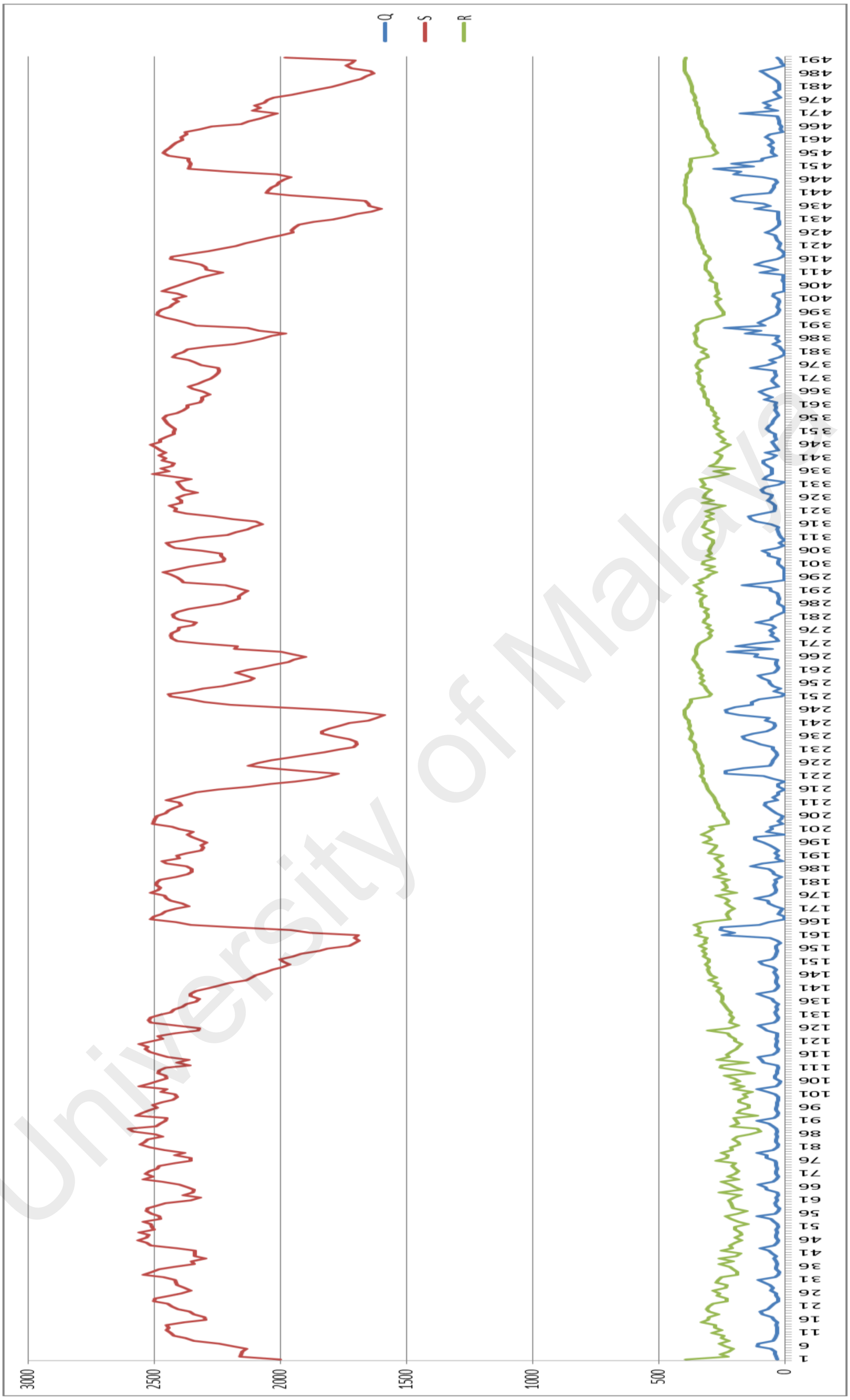


Figure 4.1: The obtained results for input, output and storage volume in the Karun I reservoir (m^3)

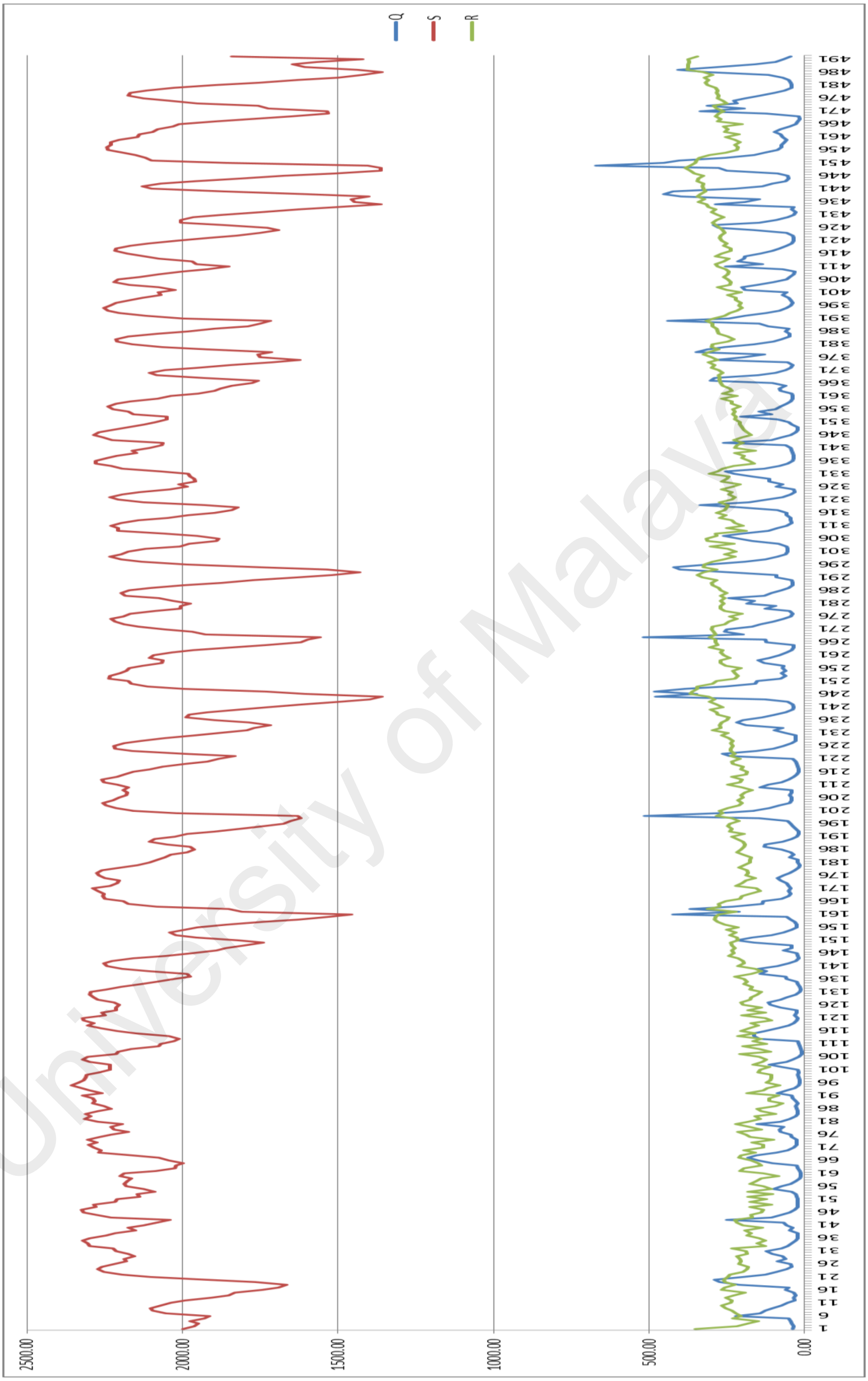


Figure 4.2: The obtained results for input, output and storage volume in the Karun III reservoir (m^3)

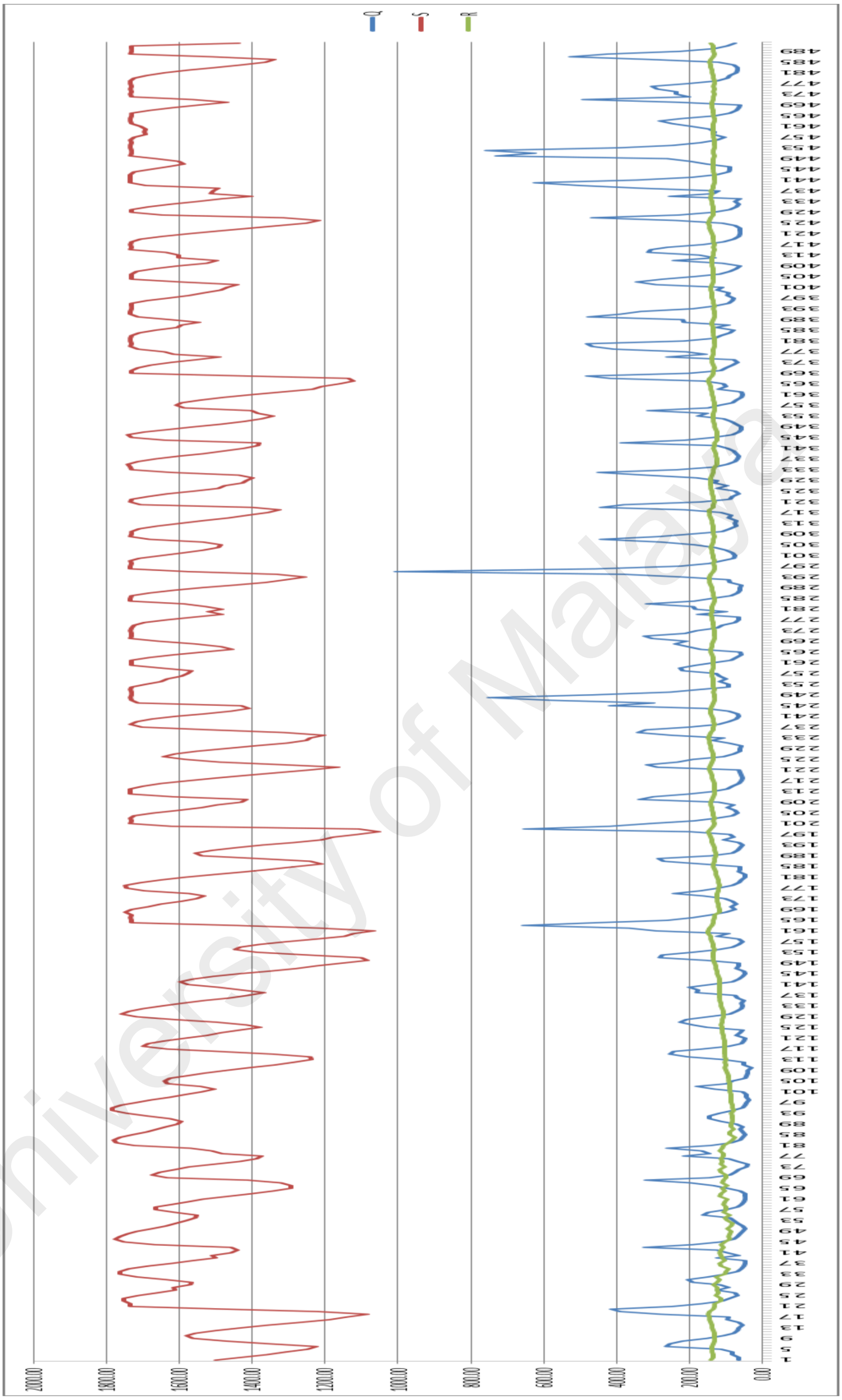


Figure 4.3: The obtained results for input, output and storage volume in the Karun IV reservoir (m^3)

4.2 Hydro power generation

Table 4.1 to Table 4.12 show the obtained results of the optimization model. These monthly average results are presented in different tables. To calculate them, the results of the optimization model in the MATLAB environment were transferred to Excel environment and the calculations were summarized and presented in accordance with governing relations in Excel environment.

Table 4.1: The optimal solution of the objective function by HPSOGA algorithm and calibration method (LINGO)

	The optimal solution of the objective function	
	LINGO	**HPSOGA**
Karun I	40.8	41.4
Karun III	68.0677	68.85
Karun IV	9.9776	10.5

Table 4.2: Percent of the average monthly energy deficit in various reservoirs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	5.2	4.7	0.8	0	0	0	1	0.8	1.4	2.8	4.6	3.1
Karun 3	4.3	2.9	1	0.6	0.3	0.2	0.7	0.6	0.7	1.4	3.4	3.4
Karun 1	3.5	1.5	0.4	0.6	0.1	0.6	1.9	2.4	1.9	1.9	4.8	5.4

Table 4.3: Maximum monthly energy shortage in different reservoirs **(**GWh**)**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	37.9	40	15.6	0	0	0	18.9	21.1	55.6	54.9	55.7	45.2
Karun 3	43.4	39.1	15	8.6	5.6	6.6	11	11.2	14	43.4	42.8	43.4
Karun 1	55.6	43.1	15.8	15.5	4.7	14.2	16.9	20.7	20.6	16.5	29.5	55.6

Table 4.4: Monthly average values of primary energy production (GWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	98	99	101	109	109	109	107	108	107	101	99	101
Karun 3	194	199	198	214	215	215	213	213	213	204	197	197
Karun 1	249	256	251	268	270	268	263	261	263	254	244	242

Table 4.5: Monthly average values of secondary energy production (GWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	17	26	100	139	193	129	62	11	4	6	2	14
Karun 3	43	61	174	232	287	231	142	44	14	23	9	15
Karun 1	36	93	177	245	308	246	157	69	18	26	13	20

Table 4.6: Monthly average values of total energy production (GWh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	115	125	200	248	302	237	169	119	111	107	100	115
Karun 3	237	260	372	446	501	446	356	257	228	227	206	213
Karun 1	285	348	428	513	578	513	420	330	281	281	257	262

Table 4.7: Average primary plant factor coefficient for study area reservoirs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	0.136	0.137	0.145	0.146	0.146	0.146	0.144	0.144	0.143	0.141	0.137	0.14
Karun 3	0.135	0.138	0.143	0.144	0.144	0.145	0.143	0.143	0.143	0.142	0.137	0.137
Karun 1	0.173	0.178	0.18	0.18	0.181	0.18	0.177	0.175	0.177	0.177	0.169	0.168

Table 4.8: Average secondary plant factor coefficient for study area reservoirs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	0.023	0.036	0.143	0.187	0.259	0.173	0.083	0.015	0.006	0.008	0.002	0.02
Karun 3	0.03	0.043	0.125	0.156	0.193	0.155	0.096	0.029	0.01	0.016	0.006	0.011
Karun 1	0.025	0.064	0.127	0.165	0.207	0.165	0.106	0.046	0.012	0.018	0.009	0.014

Table 4.9: Average total plant factor coefficient for study area reservoirs

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	0.16	0.173	0.288	0.333	0.405	0.319	0.227	0.16	0.149	0.149	0.139	0.16
Karun 3	0.164	0.181	0.268	0.3	0.337	0.299	0.239	0.173	0.153	0.158	0.143	0.148
Karun 1	0.198	0.242	0.308	0.345	0.388	0.345	0.282	0.222	0.189	0.195	0.178	0.182

Table 4.10: Monthly average spillage in study area reservoirs (MCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	0	0	0	0	0	0	0	0	0	0	0	0
Karun 3	0	0	0	0	0	0	0	0	0	0	0	0
Karun 1	0	0	0	0	0	0	0	0	0	0	0	0

Table 4.11: Monthly average of storage in Karun reservoirs (MCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	1569	1543	1590	1697	2180	2108	2079	1986	1915	1794	1672	1601
Karun 3	2075	2068	2149	2400	2961	2838	2752	2610	2462	2331	2180	2086
Karun 1	2540	2542	2594	2726	2980	2962	2933	2880	2792	2703	2582	2524

Table 4.12: Monthly average of release from turbine in Karun reservoirs (MCM)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun 4	310	310	492	614	721	527	392	275	275	265	255	310
Karun 3	625	627	816	1063	1148	995	793	614	545	553	517	586
Karun 1	840	919	1056	1341	1503	1312	1039	842	743	762	676	722

Variability of the Demand

The peak power demand forecast tends to be based on percentage increases of historic peak demand, taking into account economic growth, affordability, additional consumers and other social factors. The forecast does not take account of exceptional events, which might unexpectedly influence the demand, such as exceptional weather. It may not be possible to fully cover the potential impact on peak demand of exceptional weather, but a margin of 15% combined with demand-side management measures are considered appropriate.

Exceptional Demand Growth

The base case demand growth forecast is based on 5% to 6% growth per annum. It is not uncommon in countries experiencing rapid economic growth for electricity demand to exceed 10% per annum for several successive years.

If it is assumed that it would take three years to mobilise additional generation capacity in the event of such a growth spurt, peak demand might have increased by 15% above its forecast level before the additional capacity would be operational. Hence, a margin of around 15% would provide adequate capacity to ensure that demand can be met in the event of a surge in demand growth while plans for development of additional capacity are accelerated.

Definition of Firm Capacity

For the hydroelectric plant, the “firm” capacity is based on the 1 in 10 year reliable hydrology of the river, and the head available for generation, in such conditions, with deductions for units out for planned maintenance and for typical forced outage rates. In theory, the derived firm capacity should have a probability of 90% of being available. However, because the low flows in such years will affect all of the hydroelectric schemes, and the conditions apply for extended periods, the reliability of this “firm hydro capacity” is considered comparable to the firm capacity adopted for the thermal plant.

Table 4.13 shows the monthly peak power demand on the KWPA system as a percentage of the peak annual power demand.

Table 4.13: Monthly Peak Demand as Percentage of Annual Peak Demand

Month	Percentage of Annual Peak Demand
Jan	60%
Feb	62%
Mar	59%
Apr	60%
May	84%
Jun	95%
Jul	98%
Aug	100%
Sep	98%
Oct	78%
Nov	57%
Dec	57%

Import-Export Loads

Historically energy has been exchanged between the KWPA system and the national grid. At times of energy deficit on the KWPA system (typically during the late Spring and Summer months when demand is high and hydro energy is limited) energy is imported from the National Grid. When there is a surplus of energy available from the hydroelectric schemes and demand is low, energy is exported to the National Grid.

4.2.1 Calibration test by Linear Programming (LINGO)

As explained earlier, the Lingo environment was used to calibrate the model. The applied code can be found in Appendix B for Karun 4 dam. The objective function amount is almost same as the calibration model result. It shows a good accuracy of the obtained solution especially for Karun I and Karun III.

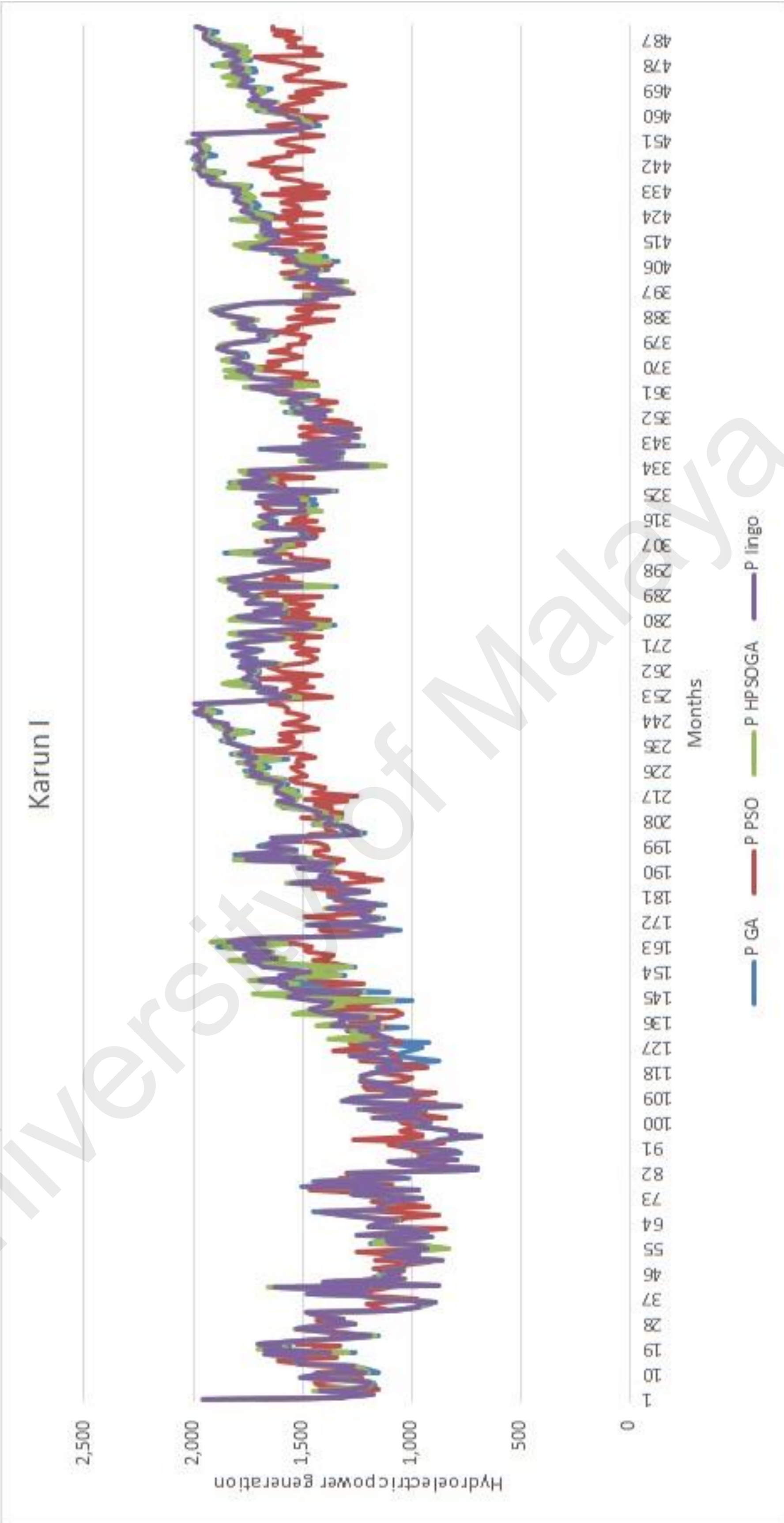


Figure 4.4: Comparison of 4 optimization method's results for the optimal monthly amount of hydroelectric generation (MW) for Karun I dam

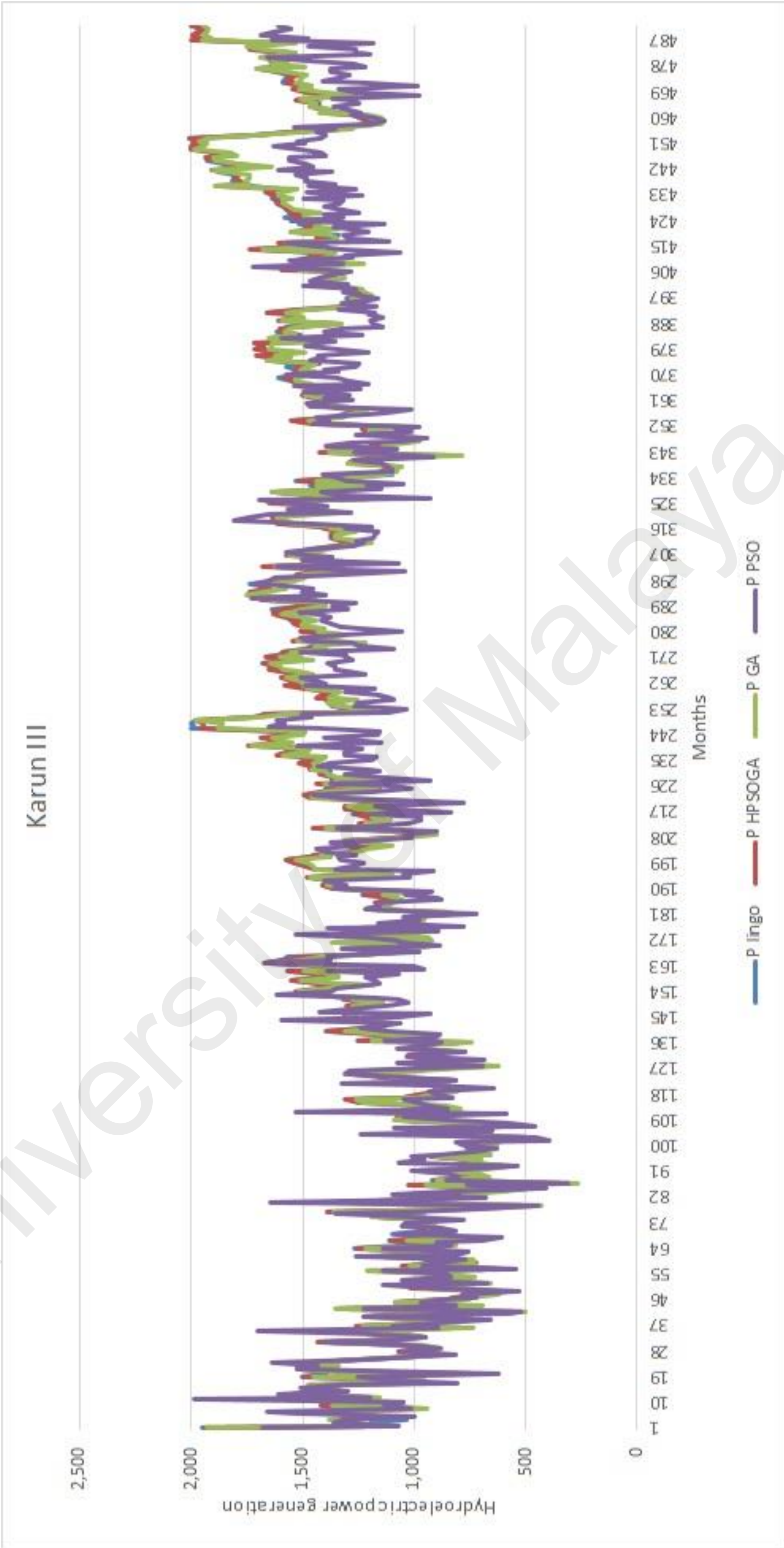


Figure 4.5: Comparison of 4 optimization method's results for the optimal monthly amount of hydroelectric generation (MW) for Karun III dam

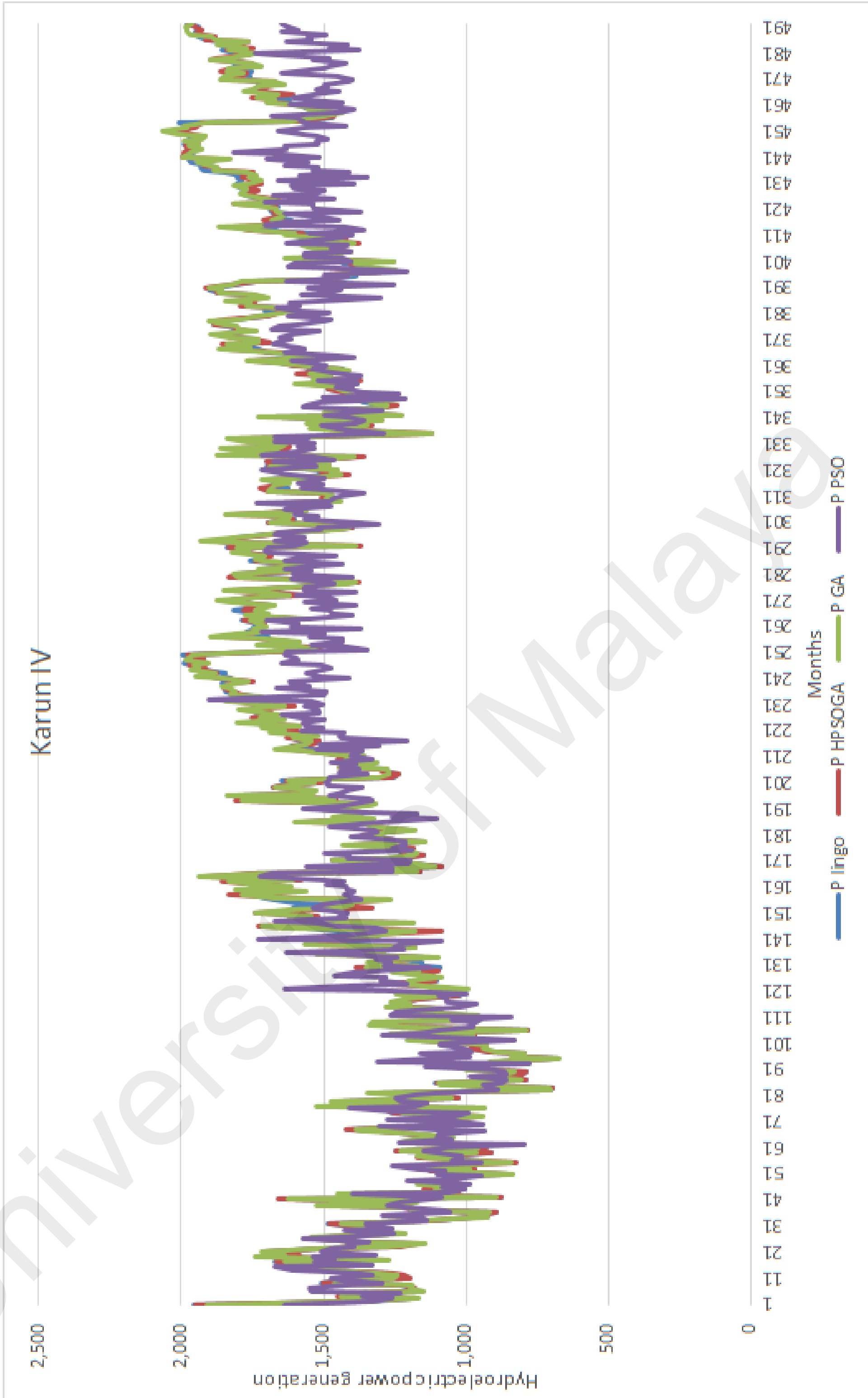


Figure 4.6: Comparison of 4 optimization method's results for the optimal monthly amount of hydroelectric generation (MW) for Karun IV dam

Table 4.14: Validation results for hydroelectric power generation

	Karun I	Karun III	Karun IV
RMSE	50.194	55.236	28.505
NRMSE	0.038	0.034	0.063
CV(RMSE)	0.033	0.042	0.031

4.2.2 Validation test by ANN and Regression

Artificial Neural Network (ANN):

The neural network details are shown in Figure 4.7 to Figure 4.9.

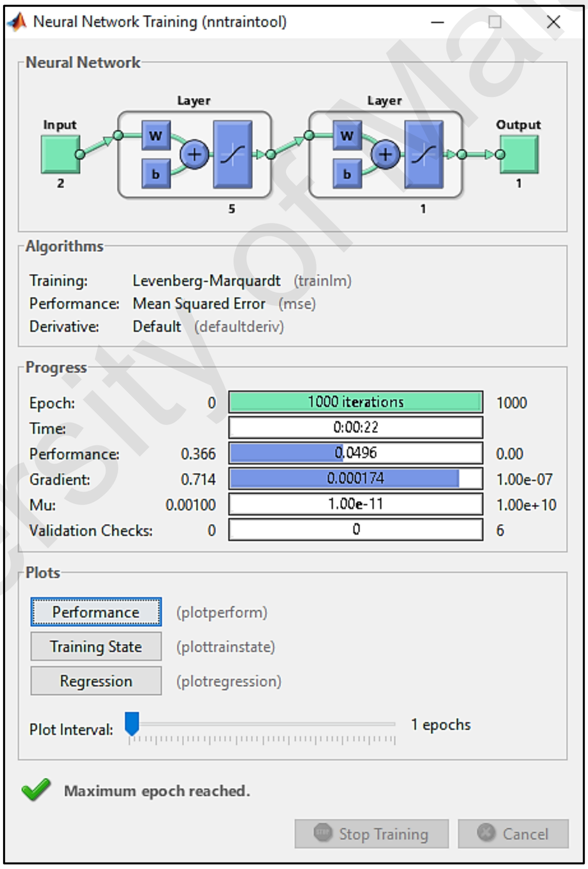


Figure 4.7: Karun 1 neural network training details

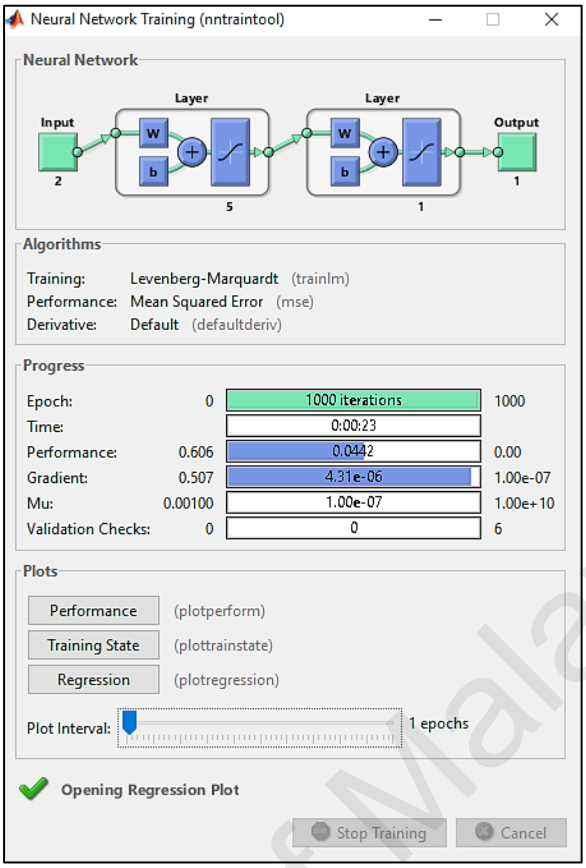


Figure 4.8: Karun 3 neural network training details

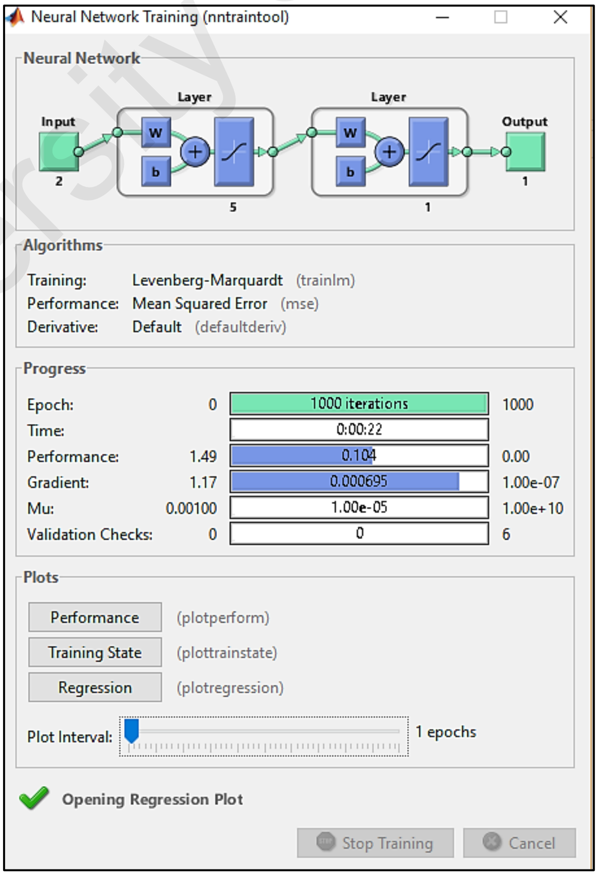
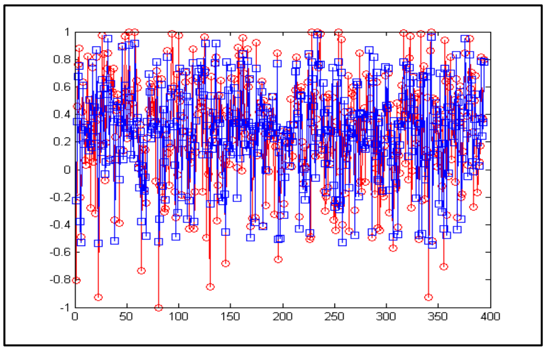
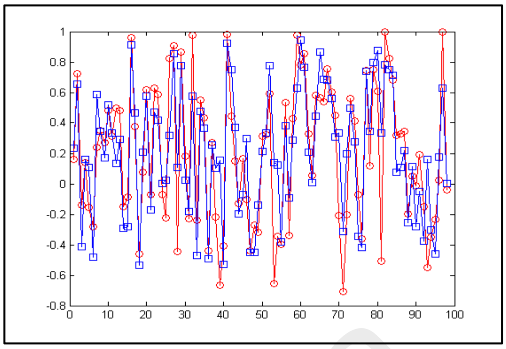


Figure 4.9: Karun 4 neural network training details

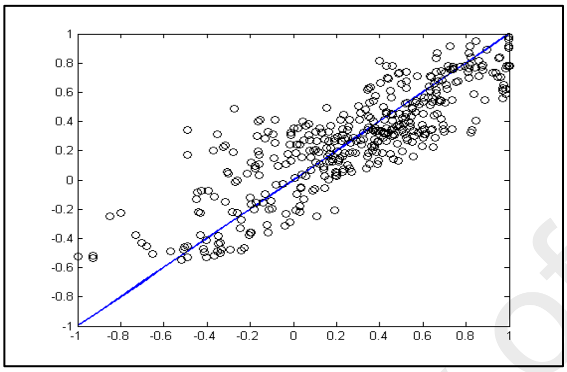
The results of the Mean Squared Error on the training data have been demonstrated in the Figure 4.10 to Figure 4.12.



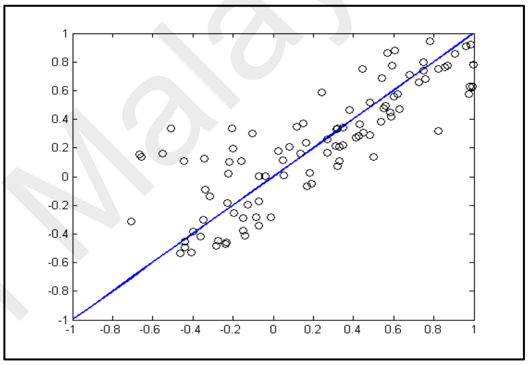
MSE for train data in Karun 1



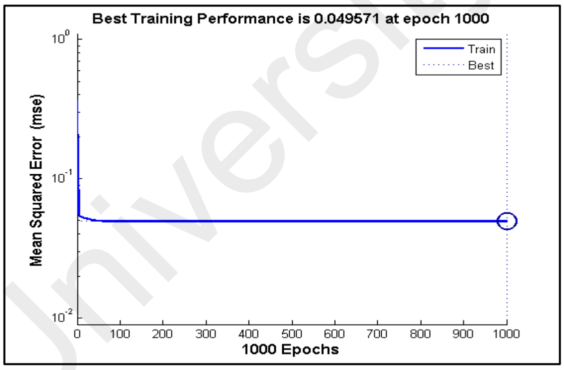
MSE for test data in Karun 1



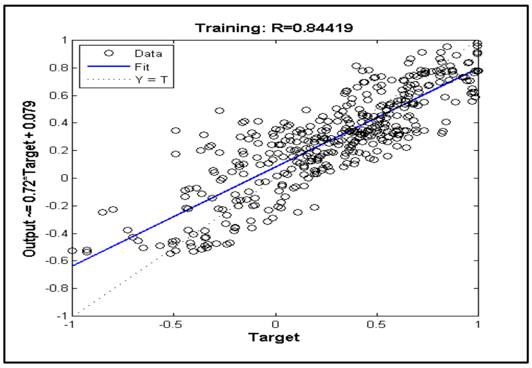
Comparison of predicted and actual data in train data for Karun I



Comparison of predicted and actual data in test data for Karun I

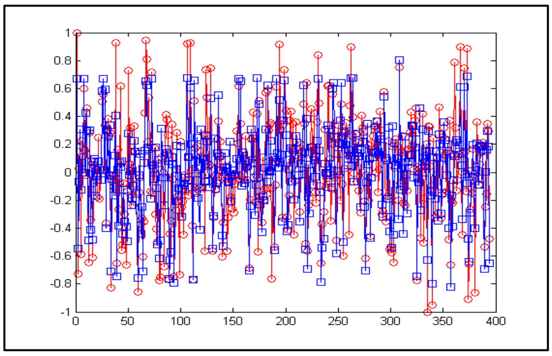


Best training performance at 1000 epoch in Karun I

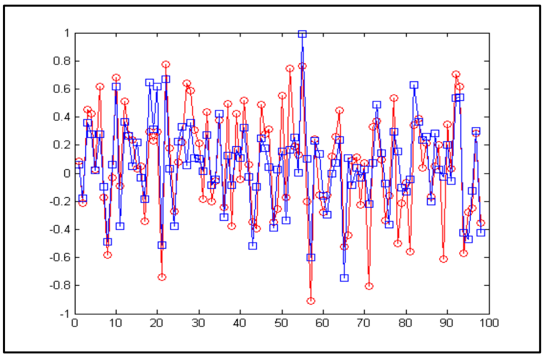


Output-Target diagram for Karun I result

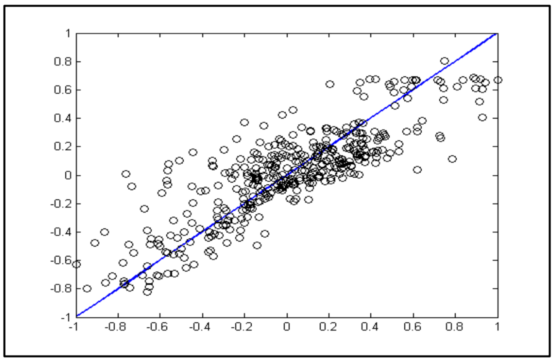
Figure 4.10: MSE train and test for Karun I



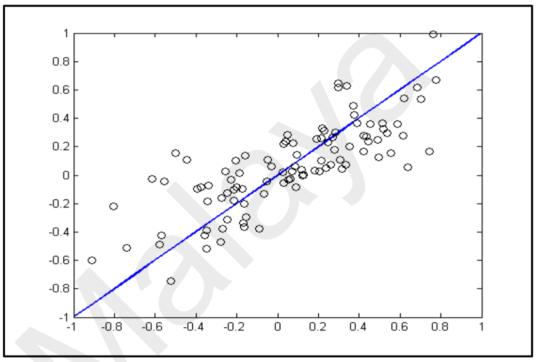
MSE for train data in Karun III



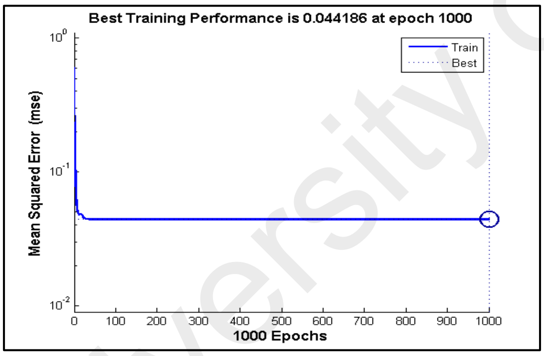
MSE for test data in Karun III



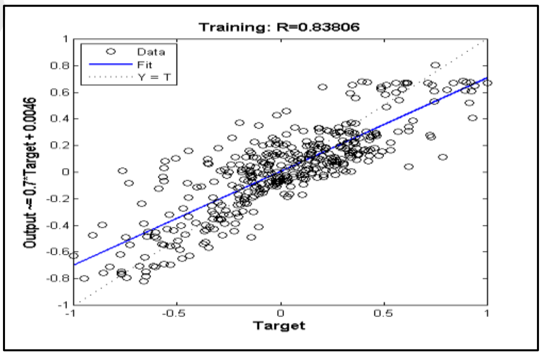
Comparison of predicted and actual data in train data for Karun III



Comparison of predicted and actual data in test data for Karun III

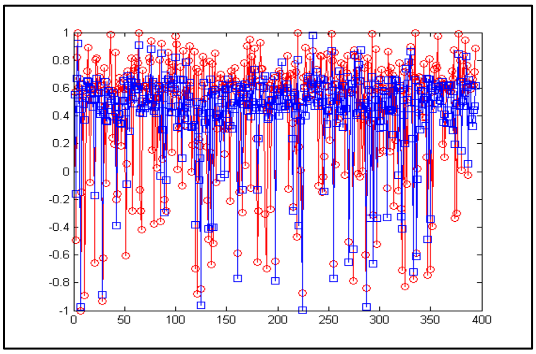


Best training performance at 1000 epoch in Karun III

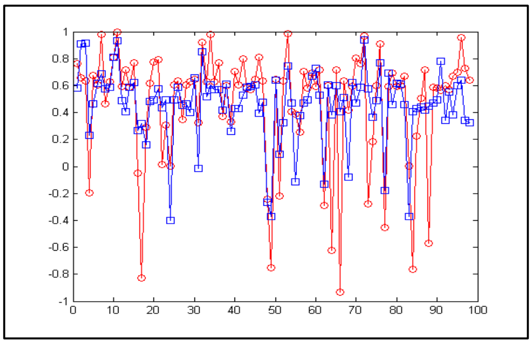


Output-Target diagram for Karun III results

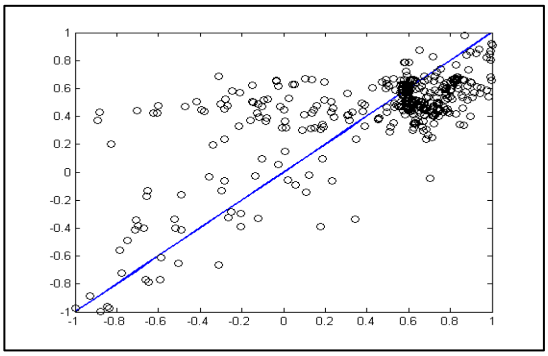
Figure 4.11: MSE train and test for Karun III



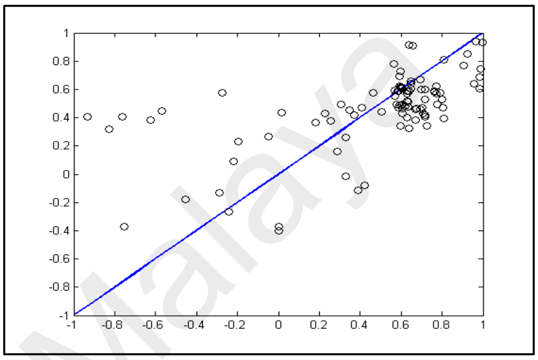
MSE for train data in Karun IV



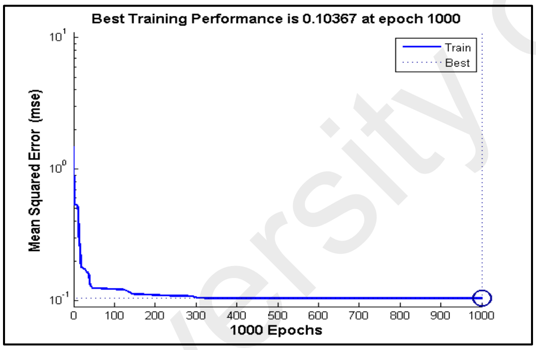
MSE for test data in Karun IV



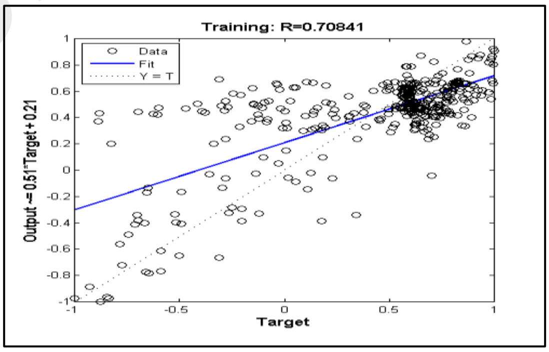
Comparison of predicted and actual data in train data for Karun IV



Comparison of predicted and actual data in test data for Karun IV



Best training performance at 1000 epoch in Karun IV



Output-Target diagram for Karun IV result

Figure 4.12: MSE train and test for Karun IV

Table 4.15: Summary of MSE results

	K1	K3	K4
MSE train	0.0496	0.0442	0.1037
MSE test	0.0688	0.0551	0.119

Regression Analysis Results

The t-test is one of the simplest and most common tests that are used for main comparison. The full name of this test is Student's t-test.

The P value indicates the probable level that the hypothesis under testing (the null hypothesis) is true. Therefore, if the p-value is 0.05, the probability of being true null hypothesis is 0.05. Since in most cases the null hypothesis is tested, we want a lower level of P to reject the null hypothesis. In the form of short, small amounts of p (p less than 0.05 indicates difference and the equal to or greater amount than 0.05 indicates that there is no difference. Obviously, the smaller to be obtained p, one can conclude with more confidence.

Confidence Limits: confidence limits show the accuracy of the computed average. Confidence limits indicate that if the re- sampling of the population is done, the possibility that samples are put in calculated average rang are 95%.

R-value or correlation coefficient is another statistical tool to determine the type and degree of relationship of a quantitative variable. Correlation coefficient shows the intensity of the relationship and the type of relationship (direct or inverse). This coefficient is between 1 to -1 and if there is no relationship between two variables, it will equal to zero, a large amount of it also shows a strong correlation between the amounts.

Underneath relation shows the calculation of R^2. As the amount of R^2 closes to one, it shows that estimated equation has more accuracy.

$$R^2 = \frac{S_{xy}^2}{S_x^2 S_y^2} = 1 - \frac{SSE}{\sum(yi-\bar{y})^2} \quad (4.1)$$

The value of R^2 is in fact a measure of how well the fitted regression line of the sample is measured. Small amounts show that the model does not comply with the data. The value of R^2 is calculated as follows:

$$R^2 = (1- \frac{\text{Residual SS}}{\text{Total SS}}) = \frac{\text{Regress SS}}{\text{Totall SS}} \quad (4.2)$$

Adjusted R Squared has attempted to correct R square to reflect the highest rate of adaption of in the population. The coefficient of determination was used to determine which model is better:

$$AdjR^2=1-(\frac{\text{Total df}}{\text{Residual df}})(\frac{\text{Residual SS}}{\text{Totall SS}}) \quad (4.3)$$

Standard Error is a measure that shows how much the estimated average obtained is accurate. So, if the SE is smaller, better estimation of population has been taking place and vice versa. SE also is known as the standard deviation of the mean.

$$SE = \frac{SD}{\sqrt{n}} \quad (4.4)$$

Table 4.16: Summary of regression statistics output

	Karun I	Karun III	Karun IV
Multiple R	0.961904297	0.964227	0.984011
R Square	0.925259877	0.929733	0.968277
Adjusted R Square	0.92306653	0.927549	0.966171
Standard Error	80.29878012	63.96084	23.01699
Observations	492	492	492

The analysis of variance or ANOVA table checks the acceptance of the statistic. The regression line shows information about a change in the model. Residual line also shows the information about the change that is not intended for the model. In other words, the residual of a product is equal to the observed the error term for the product. Total output also shows the total data related to regression and residual.

(a) The number of independent observations minus the number of estimated parameters is called the degree of freedom -regression. In other words, the degree of freedom -regression- is a dimensional unknown volume (complete model) minus the given volume (bound model).

(b) The Sum of square (SS) is composed of two sources of variance. In particular, it is obtained from the sum of the SSregression and the SSresidual. It shows total variability in the scores of the predicted variable Y.

$$\sum(Y - \overline{Y})^2 = \sum(Y' - \overline{Y})^2 + \sum(Y - Y')^2 \quad (4.5)$$

(a) RegressionMS=(RegressionSS)/(Regressiondf) (4.6)

(b) F ratio is a number, which is obtained from dividing the average of Timar squares by Residuals mean.

(c) Based on the F probability distribution, If the Significance F is not less than 0.1 (10%) one does not have a meaningful correlation (Wilcox, 2010).

Table 4.17: ANOVA results for Karun I

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	39113249.36	19556624.68	3033.02511	2.4165E-276
Residual	490	3159468.104	6447.89409		
Total	492	42272717.46			

Table 4.18: ANOVA results for Karun III

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	26523584.09	13261792.04	3241.708444	6.742E-283
Residual	490	2004584.377	4090.988524		
Total	492	28528168.46			

Table 4.19: ANOVA results for Karun IV

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	7923455.161	3961727.58	7478.032886	0
Residual	490	259593.2037	529.7820484		
Total	492	8183048.364			

Results of inputs specifications and coefficients of the regression equation for Karun reservoirs are presented in the following tables (Table 4.20 to Table 4.22):

Table 4.20: Inputs specifications and coefficients of the regression equation for Karun I

Karun I	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Q	0.74	0.08	9.87	0.00	0.59	0.89	0.59	0.89
S	0.11	0.00	45.17	0.00	0.10	0.11	0.10	0.11

Table 4.21: Inputs specifications and coefficients of the regression equation for Karun III

Karun III	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Q	0.46	0.03	16.71	0.00	0.41	0.52	0.41	0.52
S	0.09	0.00	45.89	0.00	0.08	0.09	0.08	0.09

Table 4.22: Inputs specifications and coefficients of the regression equation for Karun IV

Karun IV	*Coefficients*	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.00	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Q	0.05	0.01	5.79	0.00	0.03	0.06	0.03	0.06
S	0.08	0.00	73.55	0.00	0.07	0.08	0.07	0.08

The results from Table 4.16 to Table 4.22 and Figure 4.13 to Figure 4.27 show that even if data access is not possible, regression can be used to generate that data. (Future or missing data).

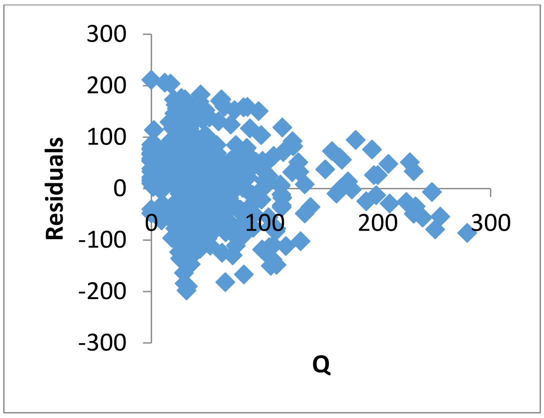


Figure 4.13: Q Residual Plot Karun I

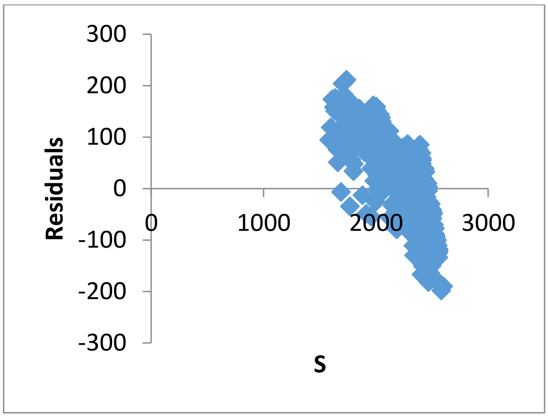


Figure 4.14: S Residual Plot Karun I

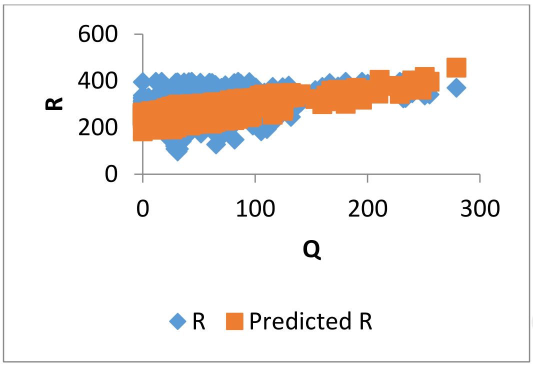


Figure 4.15: Q Line Fit Plot Karun I

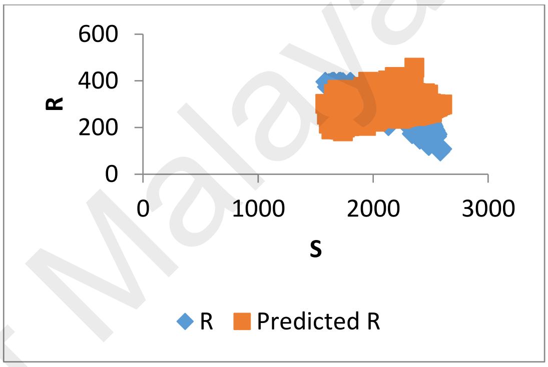


Figure 4.16: S Line Fite Plot Karun I

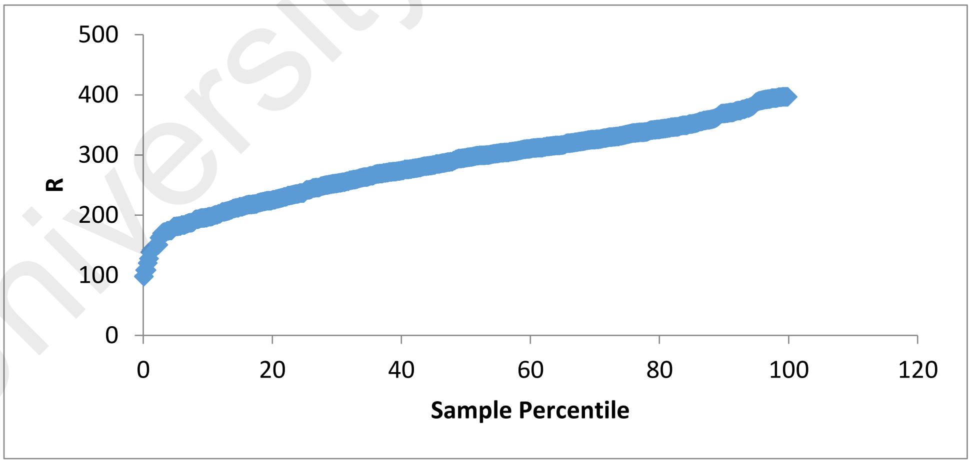


Figure 4.17: Normal Probability Plot Karun I

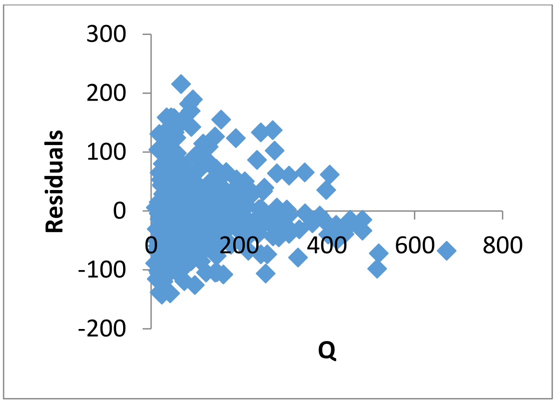


Figure 4.18: Q Residual Plot Karun III

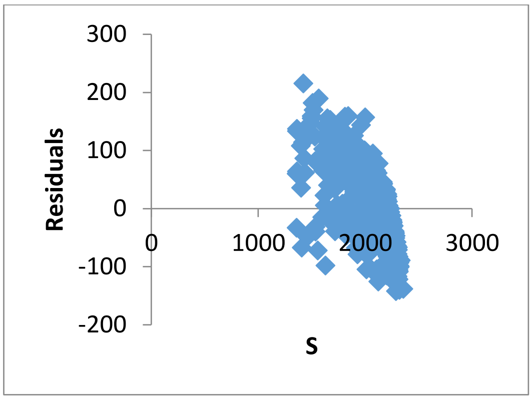


Figure 4.19: S Residual Plot Karun III

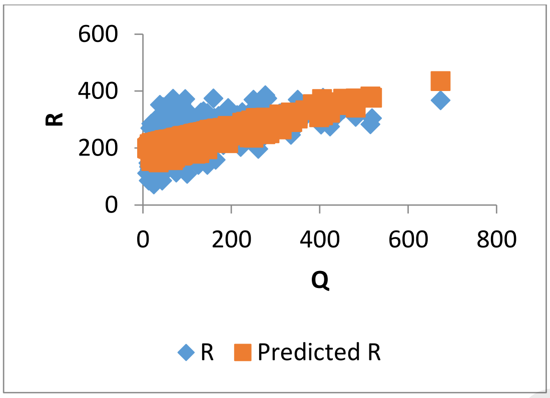


Figure 4.20: Q Line Fit Plot Karun III

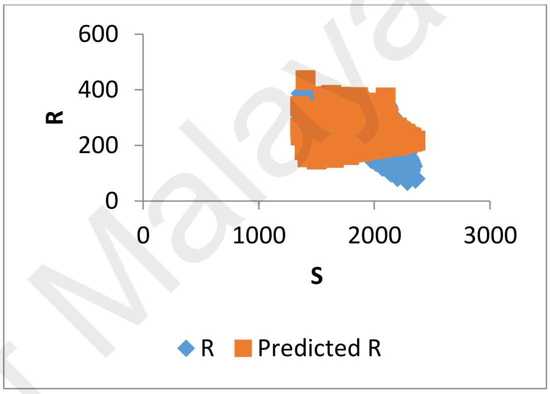


Figure 4.21: S Line Fite Plot Karun III

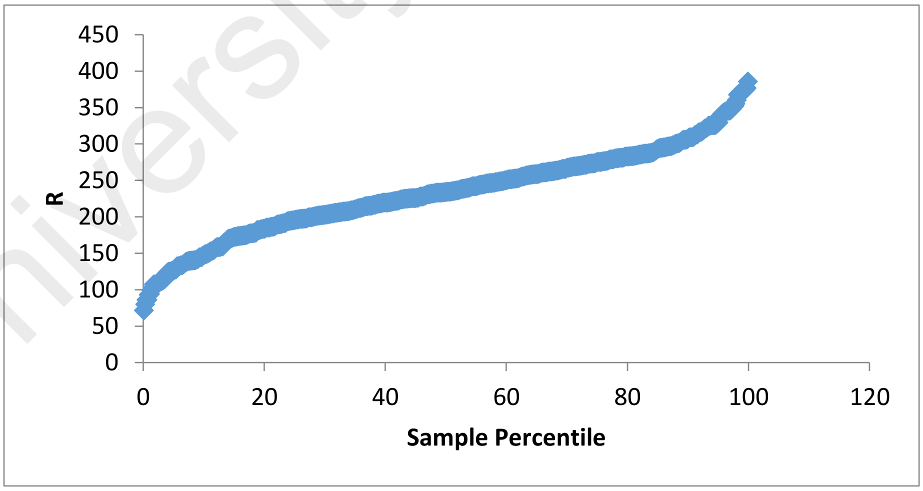


Figure 4.22: Normal Probability Plot Karun III

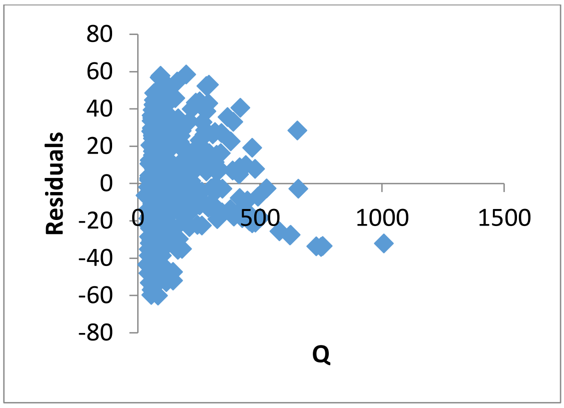


Figure 4.23: Q Residual Plot Karun IV

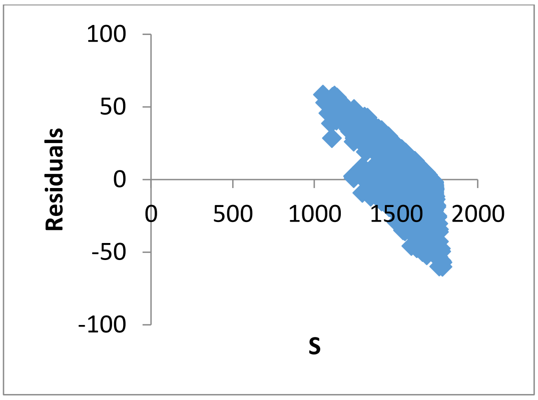


Figure 4.24: S Residual Plot Karun IV

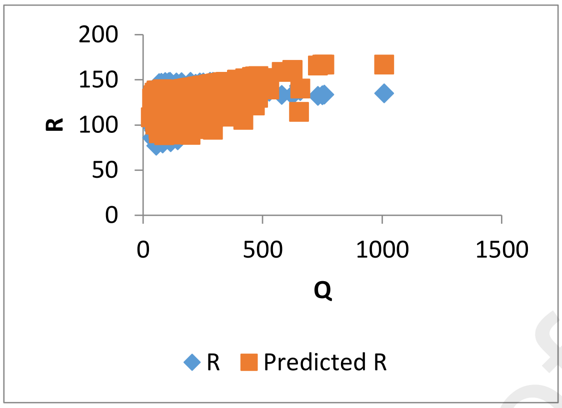


Figure 4.25: Q Line Fit Plot Karun IV

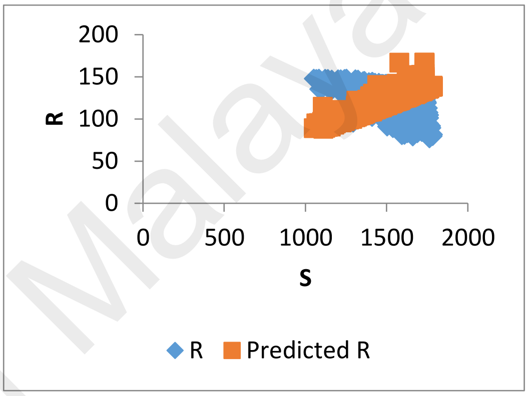


Figure 4.26: S Fite Plot Karun IV

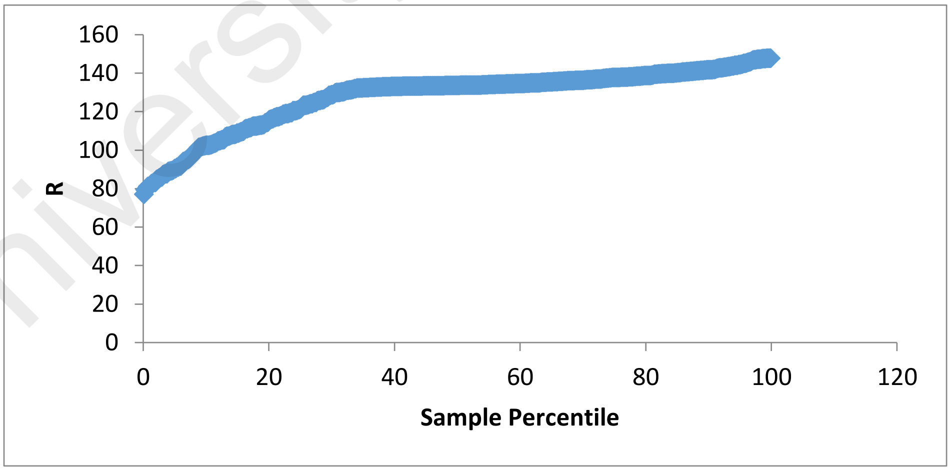


Figure 4.27: Normal Probability Plot Karun IV

4.3 Reservoir Storage

4.3.1 Calibration test by Linear Programming (LINGO)

Figure 4.28: Results of optimal storage for Karun I reservoir

Figure 4.29: Results of optimal storage for Karun III reservoir

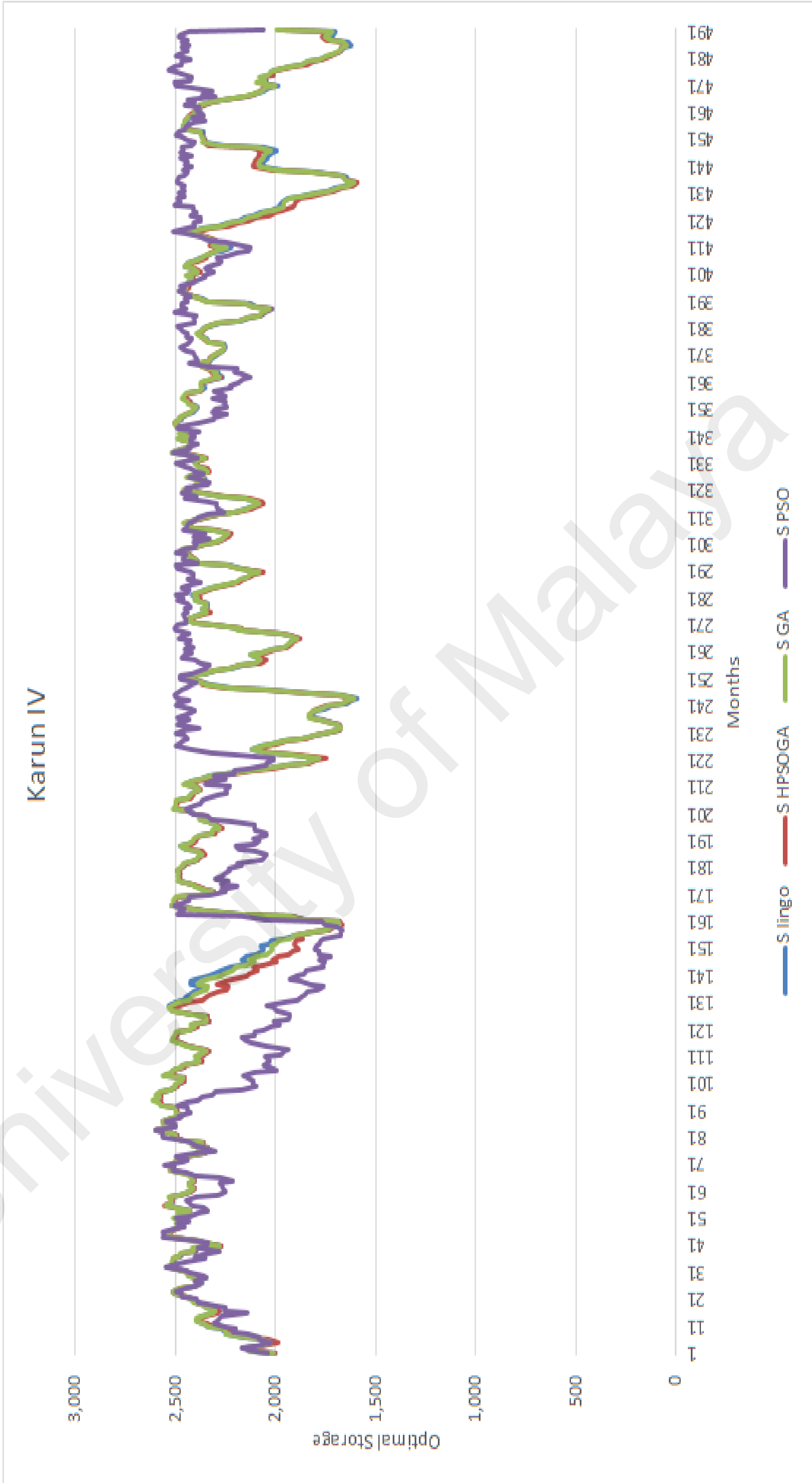


Figure 4.30: Results of optimal storage for Karun IV reservoir

Table 4.23: Validation results for optimal reservoir storage

	Karun I	Karun III	Karun IV
RMSE (MCM)	37.231	24.222	11.850
NRMSE	0.037	0.024	0.022
CV(RMSE)	0.017	0.012	0.007

4.3.2 Validation test by compared to the wet situation

Following the mentioned description in the introduction of model validation method for reservoirs storage (compared to the wet situation section), we perform the following steps. For this purpose, at first, we should provide time series inflow for reservoirs to find out wet and dry years. A part of the inflow of the Karun reservoirs is shown in Table 4.24 to Table 4.26 respectively in MCM. Also a histogram of Karun I, III and IV reservoirs inflow for 41 years is shown in the Figure 4.31.

Table 4.24: Time series of Karun I reservoir inflow

Karun I	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1970	31.54	33.28	36.00	38.88	53.36	110.43	103.50	46.34	36.15	32.44	28.61	30.92
1971	30.75	32.85	30.06	40.97	48.70	87.30	97.45	65.29	52.61	42.57	23.92	24.83
1972	32.17	35.20	54.44	48.34	57.76	78.74	105.82	36.51	24.69	22.71	33.71	34.96
	...											
2008	51.80	46.40	63.90	46.20	56.50	73.40	58.20	10.10	18.60	11.10	21.10	21.40
2009	26.10	29.10	177.30	28.00	77.30	57.30	84.00	47.80	16.10	30.10	44.20	22.60
2010	21.50	19.90	29.60	42.50	64.60	81.40	94.90	43.60	0.00	11.70	17.00	29.50

Table 4.25: Time series of Karun III reservoir inflow

Karun III	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1970	38.37	34.59	43.23	45.28	50.68	221.11	141.90	127.76	103.32	74.56	55.19	33.80
1971	37.26	30.58	36.19	62.22	51.29	211.98	273.74	290.78	198.30	126.82	89.61	59.31
1972	43.29	45.57	88.99	62.74	70.42	104.56	124.34	75.87	56.45	41.37	28.89	22.73
	...											
2008	75.38	73.97	64.12	59.96	70.11	79.49	98.83	78.32	49.15	29.76	21.83	16.71
2009	18.55	125.45	337.29	194.94	313.94	218.82	228.23	192.14	142.70	97.36	64.48	43.45
2010	40.86	45.26	50.69	71.99	118.44	313.96	406.86	280.93	158.96	95.45	68.26	45.80

Table 4.26: Time series of Karun IV reservoir inflow

Karun IV	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1970	64.80	65.30	83.50	82.30	113.20	264.70	252.70	219.30	151.20	106.50	80.90	67.80
1971	64.30	56.50	63.90	96.80	92.80	280.20	391.00	414.30	245.70	166.50	111.50	90.20
1972	69.80	75.10	125.70	92.50	118.60	189.60	205.10	150.40	102.60	68.10	58.20	52.30
	...											
2009	62.60	229.90	492.30	200.80	236.50	236.00	287.80	305.00	206.30	125.30	98.20	91.20
2010	72.30	69.10	70.20	78.40	119.60	306.70	527.50	427.50	226.50	131.70	97.60	77.30

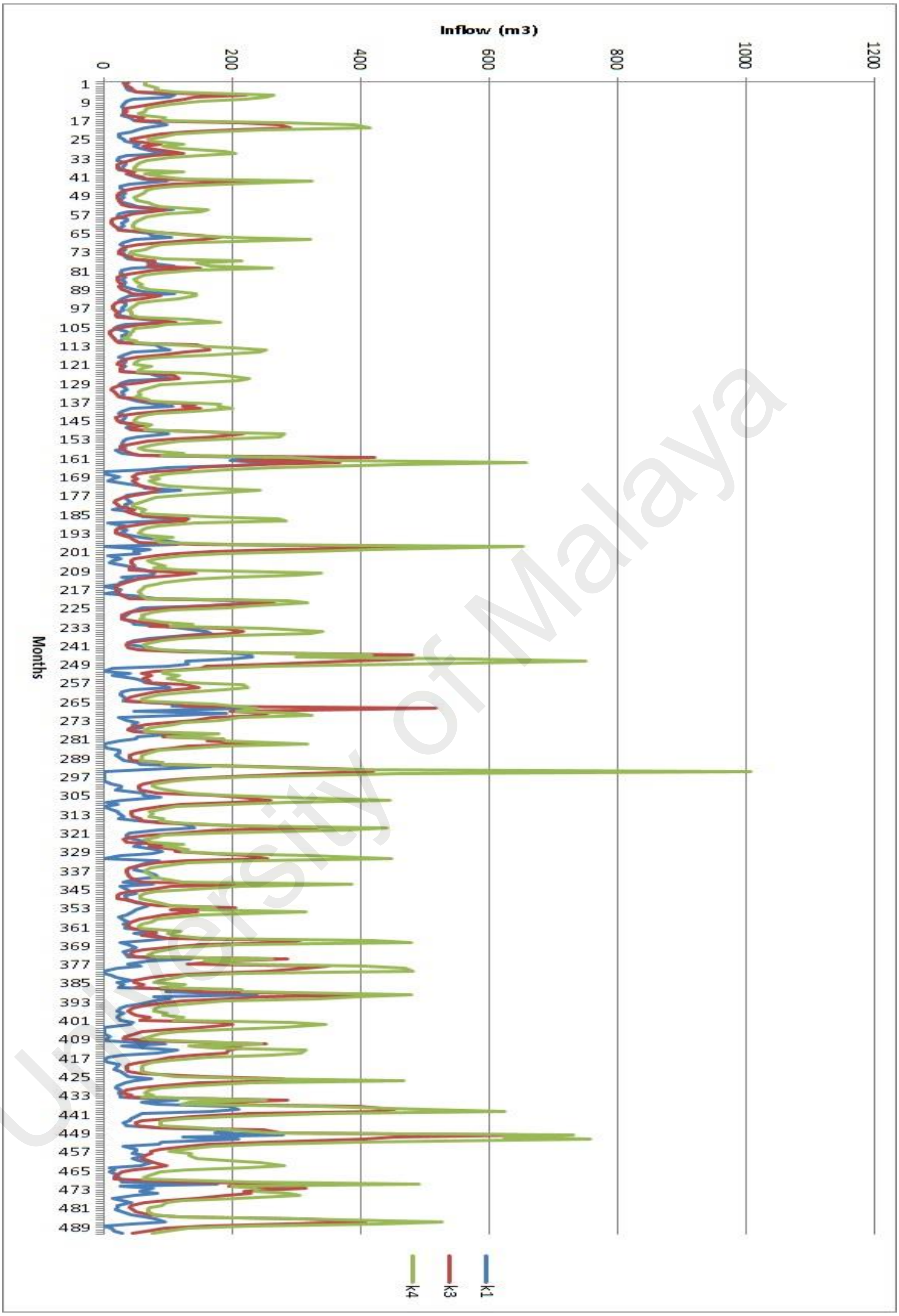


Figure 4.31: The inflow time series for Karun I, III and IV reservoirs

In order to obtain drought series, the average input for each month should be calculated using Table 4.24, then the historical data should be subtracted from the calculated averages (Figure 4.32 to Figure 4.34). The difference between the drought and wet situation in Karun river dams are shown in Figure 4.35 to Figure 4.37.

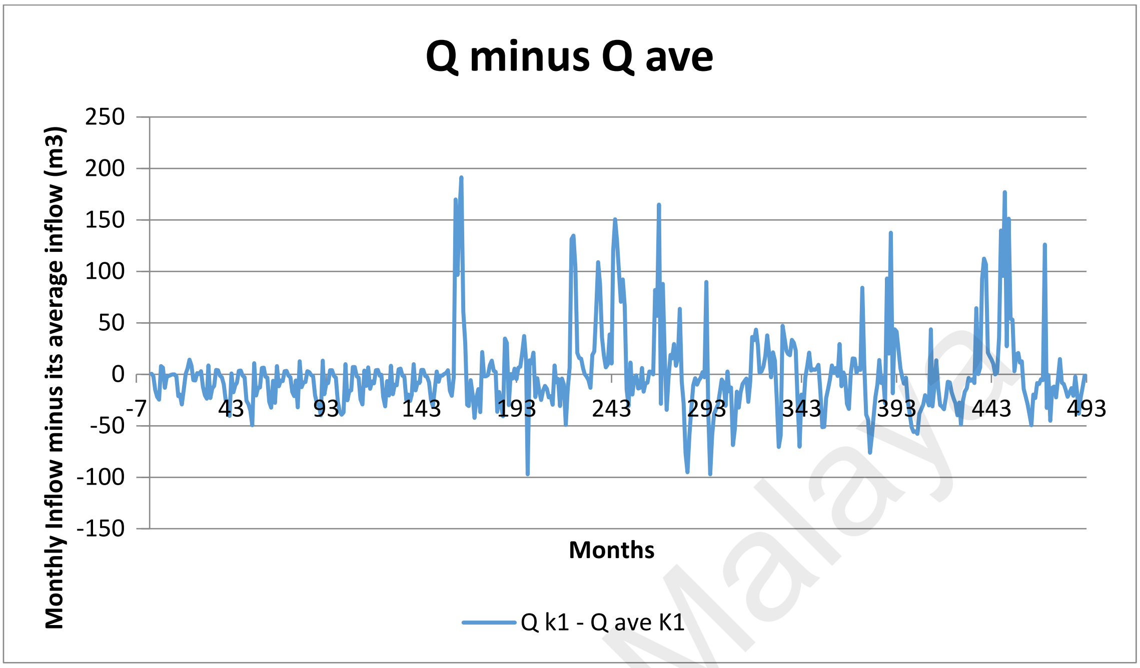


Figure 4.32: The difference between the inflow and average inflow in Karun I

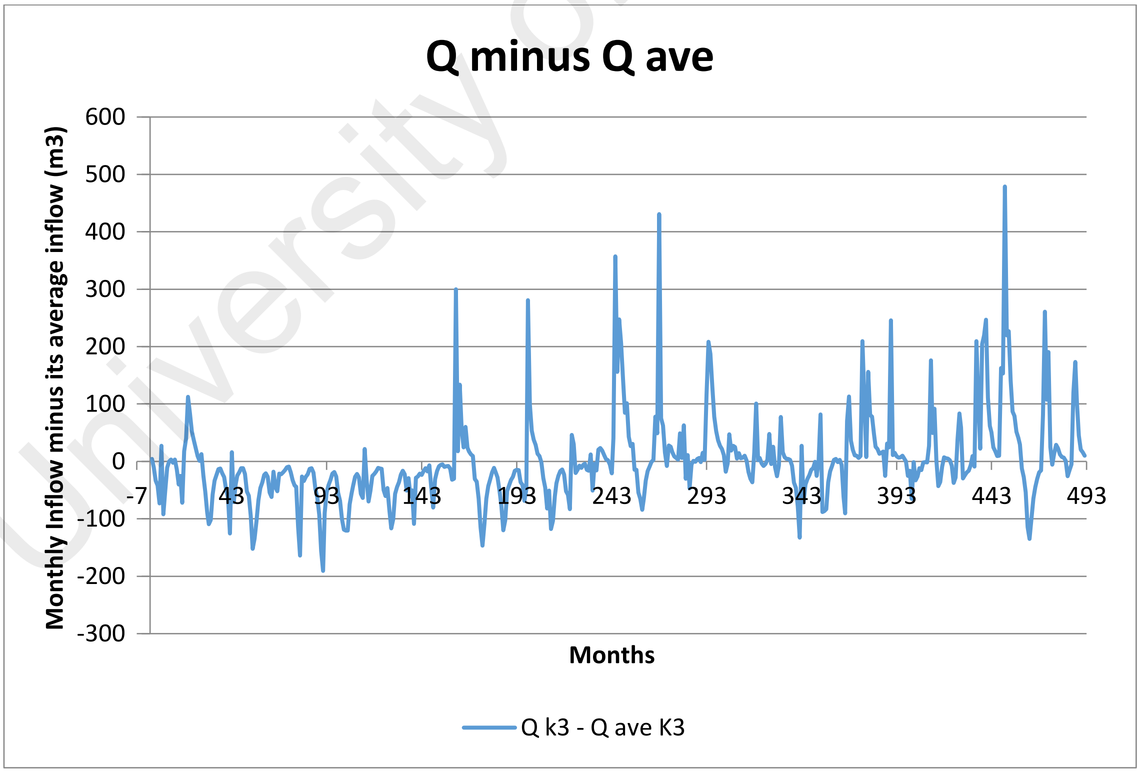


Figure 4.33: The difference between the inflow and average inflow in Karun III

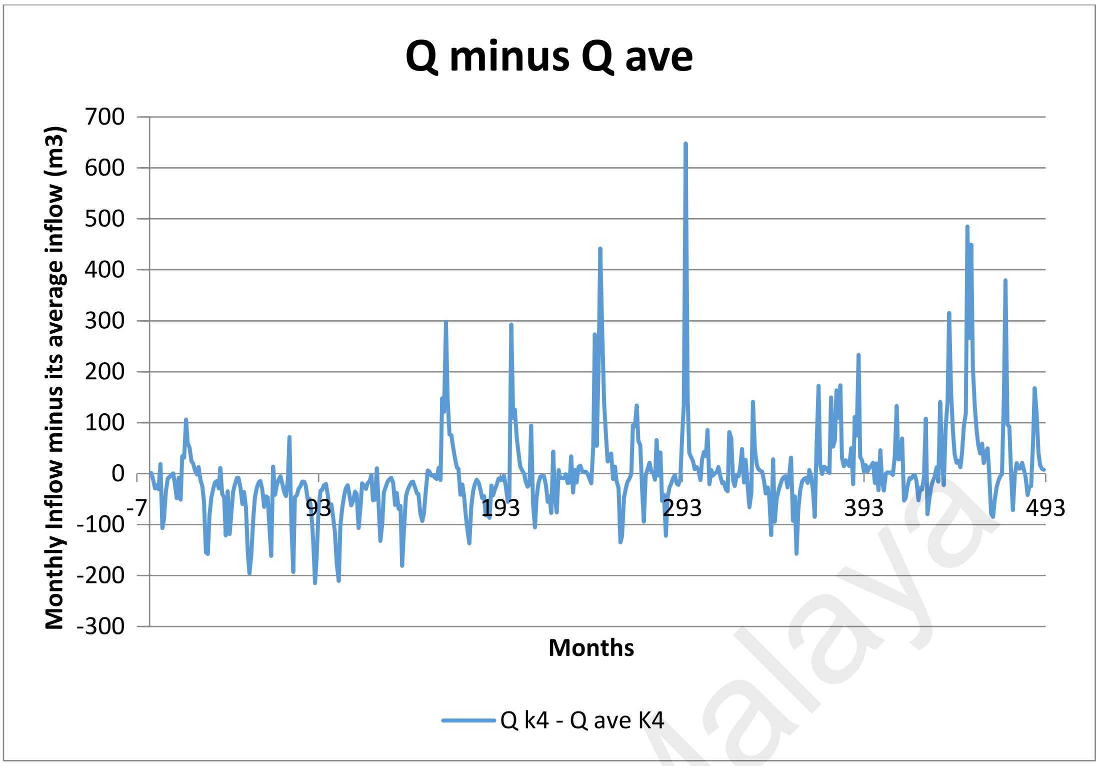


Figure 4.34: The difference between the inflow and average inflow in Karun IV

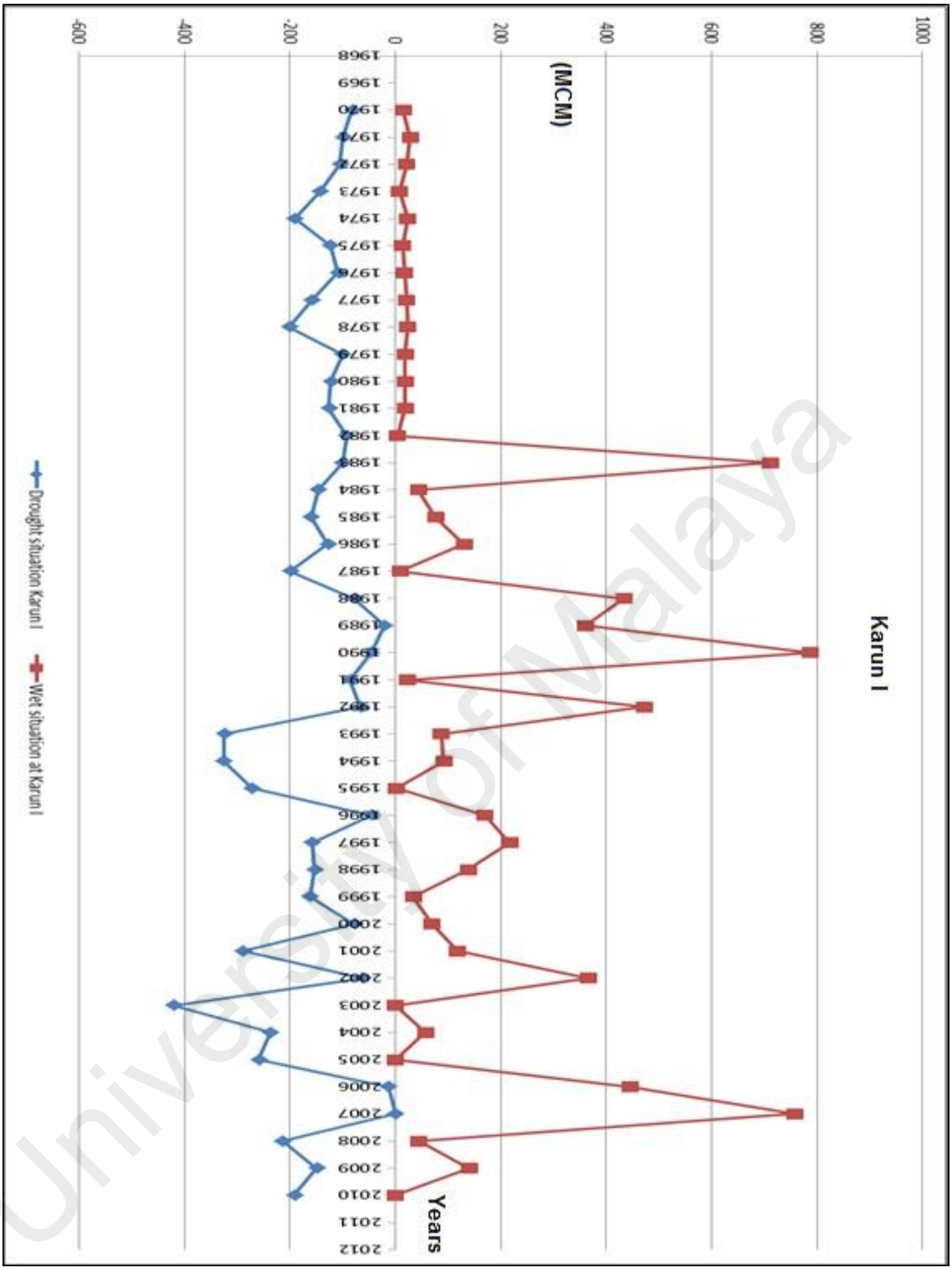


Figure 4.35: The difference between the drought and wet situation in Karun 1 dam

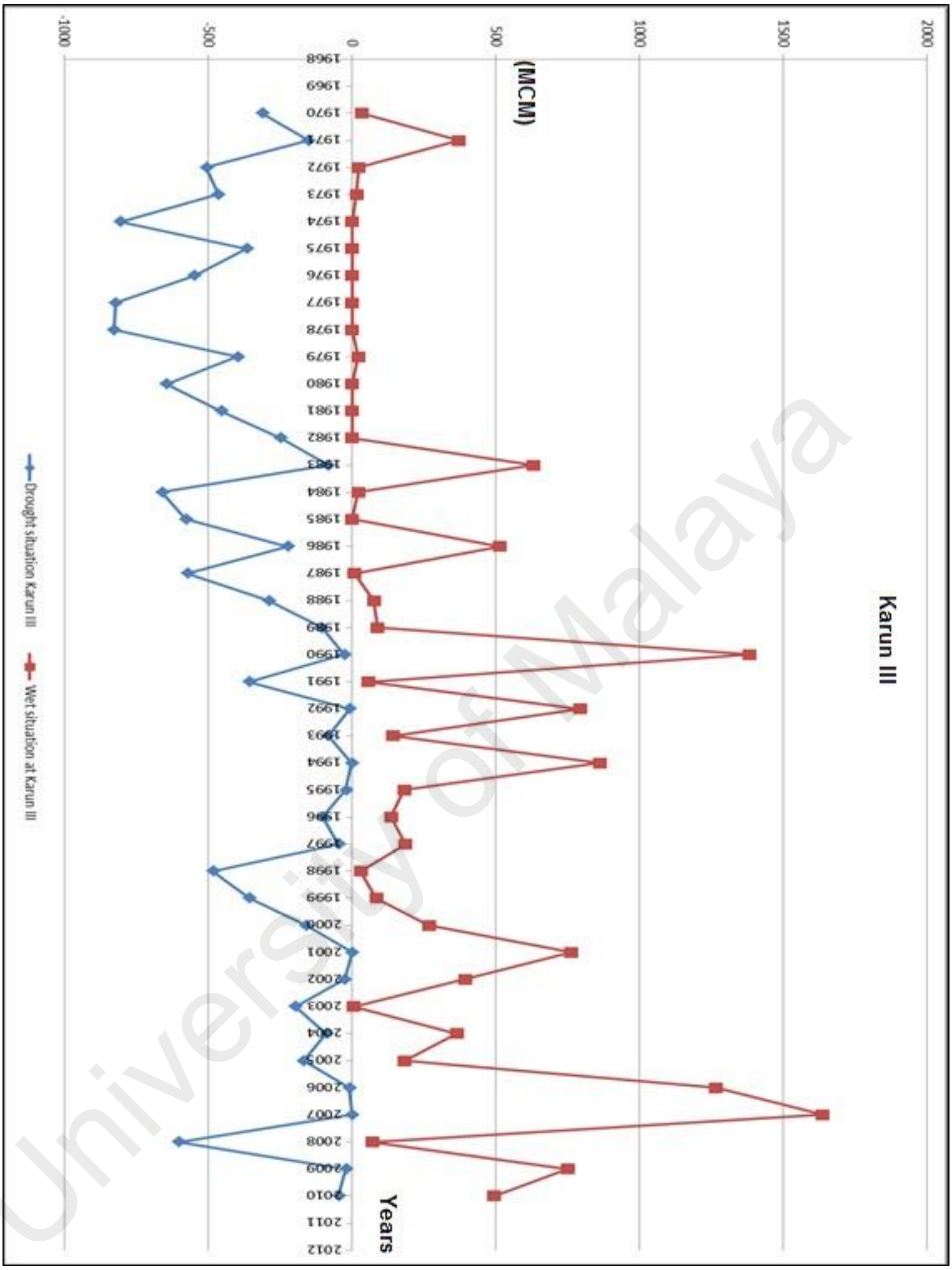


Figure 4.36: The difference between the drought and wet situation in Karun III dam

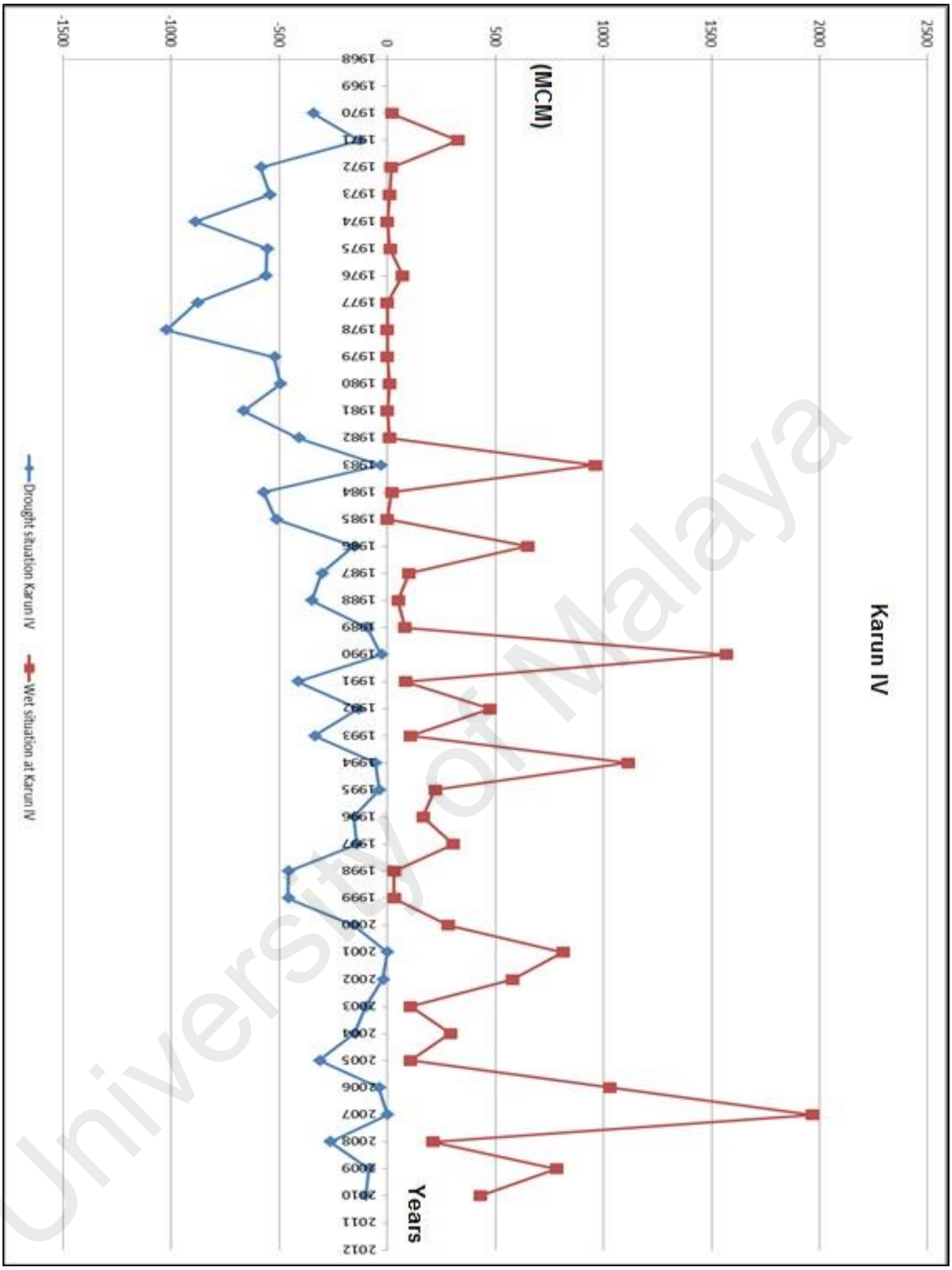


Figure 4.37: The difference between the drought and wet situation in Karun IV dam

Table 4.27 shows a drought year with the most severity year of historical data. Figure 4.38 shows the graph that belongs to this period.

Table 4.27: The difference between the average inflow and inflow in during the drought condition (MCM) for Karun IV

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Inflow	0.7	1.8	5	2.2	1.9	1.7	5.9	1.4	2.2	1	2.1	0.9
Monthly average inflow	3.4	4.6	6.1	7.6	7.9	10.3	12.5	12.4	9.4	5.8	4.8	3.4
Inflow minus average inflow	-2.7	-2.8	-1.1	-5.4	-6	-8.6	-6.6	-11	-7.2	-4.8	-2.7	-2.5

This means that, we consider this year as the base year for finding maximum storage in drought period and similarly, we can do this for the wettest year to achieve the lowest level of reservoir storage.

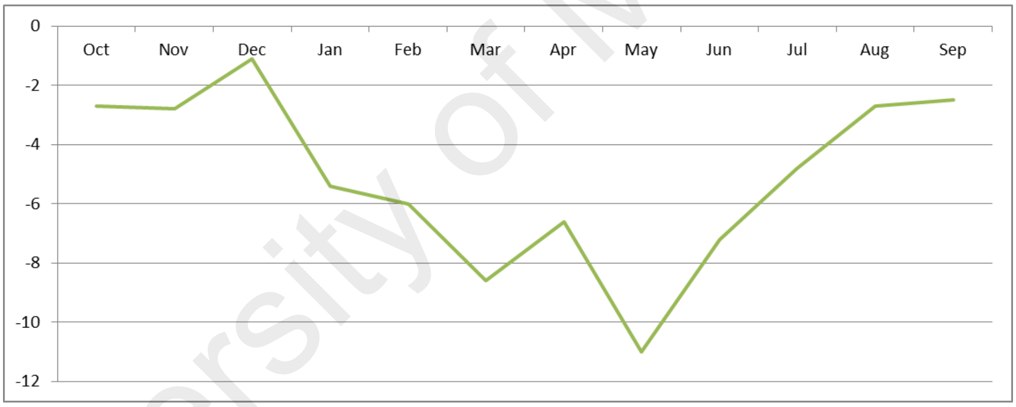


Figure 4.38: The difference between the average inflow and inflow in during the drought condition (MCM) for Karun IV

The next step is to find the maximum storage of the reservoir, then a linear model which is modelled in LINGO is used to calculate the maximum volume of the reservoir. The gained values can validate the obtained results

Maximum Storage in drought period:

In this model the maximum amount of outflow is obtained for constant volume of the reservoir ((4.7).

$$\text{Minimize } Z = C \tag{4.7}$$

Subject to (4.8)

$S_{t+1} = S_t + i_t - q_t - w_t$ (4.9)

$S_t \leq K$ (constant reservoir volume) (4.10)

$S_t \geq S_1$ (4.11)

Where, C is the reservoir capacity, S_t Storage of the month t, it inflow in month t, w_t the amount of overflow in month t and q is the constant monthly need of downstream. The coding of the written model is in appendix F:

Table 4.28: The details of Karun reservoirs storages

A	Karun IV	Karun III	Karun I
Reservoir Storage	2192	2970	2993
Dead Storage	1097	1250	1864
Storage Area	29.23	48.2	54.8
Dead Storage Area	19.55	27.38	38.57

Modelling the evaporation losses in Karun reservoirs:

In order to calculate the amount of evaporation, the reservoir surface must be calculated. The reservoir surface is a function of its volume (Figure 4.39).The specific of this curve is convexity.

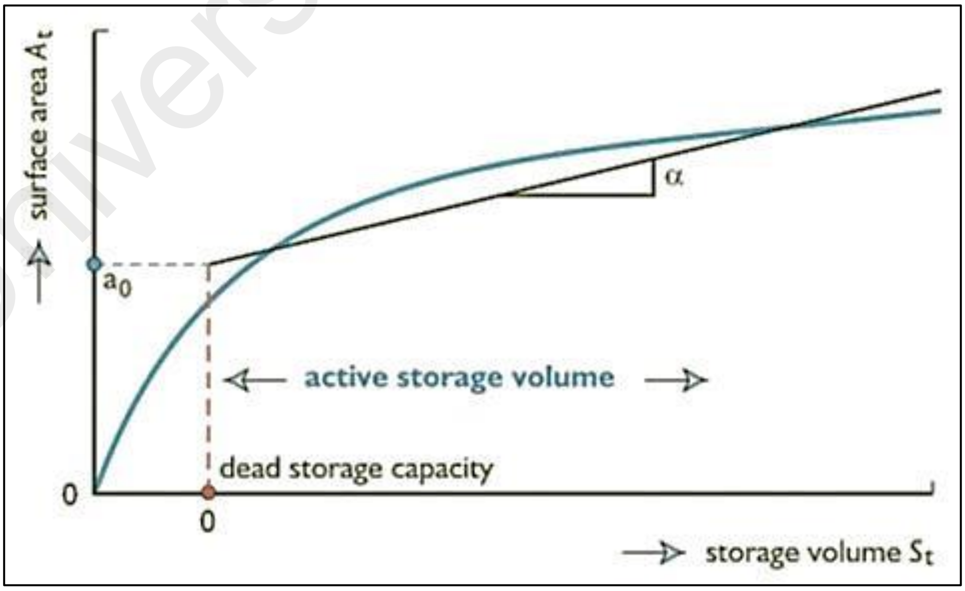


Figure 4.39: Evaporation relationship with the area and volume of reservoir (Loucks, Stedinger, & Haith, 1981)

Apart from, surface-volume curve, the depth of seasonal evaporation from reservoirs' surface (εt) must be given. As it is shown in the picture α_0 is the dead storage of the reservoir.

For example in Karun IV reservoir, for a volume of 2190 MCM a surface equivalent 29.23 km^2 is available. Also for a dead storage capacity (1097 MCM) we have a surface of 19.55 km^2. So by writing a linear relation "α" slope can be calculated.

The average amounts of evaporation in reservoir are shown in Table 4.29 in terms of mm.

Table 4.29: The average amount of evaporation in Karun reservoirs in mm

ε_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0	0	0	47.6	137.2	263.2	324.8	330.4	277.2	184.8	56	0
Karun III	0	0	0	30.8	134.4	280	364	378	324.8	210	67.2	0
Karun I	0	0	0	56	137.2	266	344.4	333.2	268.8	170.8	47.6	0

So the amount of monthly evaporation volume for the reservoir is attained by following equation ((4.12):

$$Lt = \varepsilon t * a_0 \qquad (4.12)$$

Where, εt is average monthly evaporation (mm), a_0 is dead storage amount, Lt value is according to the Table 4.30:

Table 4.30: The average of Lt value in Karun reservoirs

L_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0.0	0.0	0.0	52.2	150.5	288.7	356.3	362.4	304.1	202.7	61.4	0.0
Karun III	0.0	0.0	0.0	38.5	168.0	350.0	455.0	472.5	406.0	262.5	84.0	0.0
Karun I	0.0	0.0	0.0	104.4	255.7	495.8	642.0	621.1	501.0	318.4	88.7	0.0

α as a non-dimensional quantity is defined by the (4.13) that will be used in continuity equation of the reservoir:

$$a_t = \frac{\alpha \varepsilon t}{2} \tag{4.13}$$

Table 4.31: The average of "a_t" value in Karun reservoirs

a_t	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Karun IV	0	0	0	0.0210	0.0606	0.1163	0.1436	0.1460	0.1225	0.0817	0.0248	0
Karun III	0	0	0	0.0186	0.0813	0.1695	0.2203	0.2288	0.1966	0.1271	0.0407	0
Karun I	0	0	0	0.0403	0.0986	0.1912	0.2475	0.2395	0.1932	0.1228	0.0342	0

Noting the all mentioned above, the optimization model can be defined as follows ((4.14) to ((4.18):

Maximize Z = q (4.14)

Subject to (4.15)

$(1+a_t)S_{t+1} = (1-a_t)S_t + i_t - q - w_t - L_t$ (4.16)

$S_t \leq C$ (4.17)

$S_t \geq S_1$ (4.18)

The Lingo Coding is in the Appendix F.

4.4 The release rule curves figures

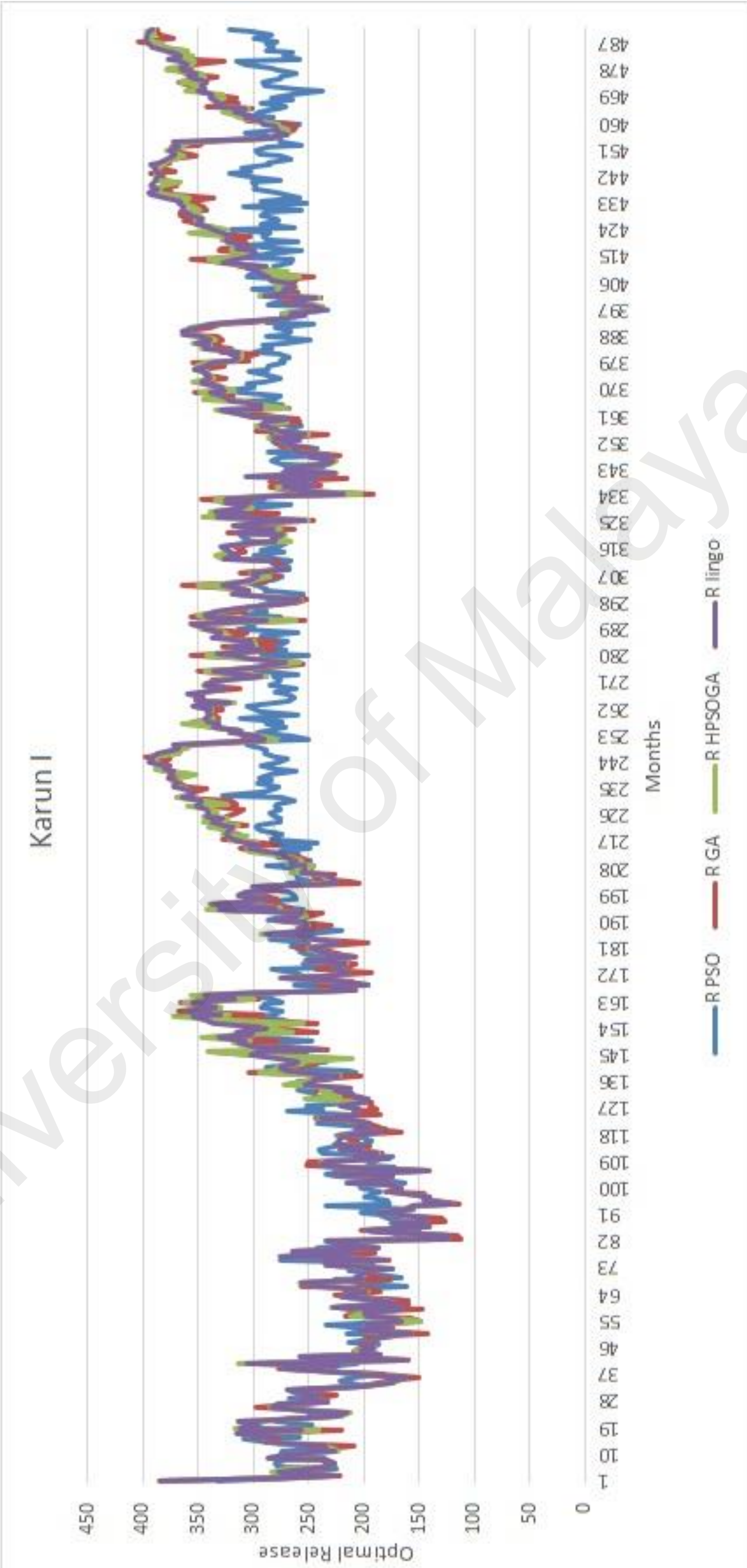


Figure 4.40: Results of optimal release details for Karun I reservoir

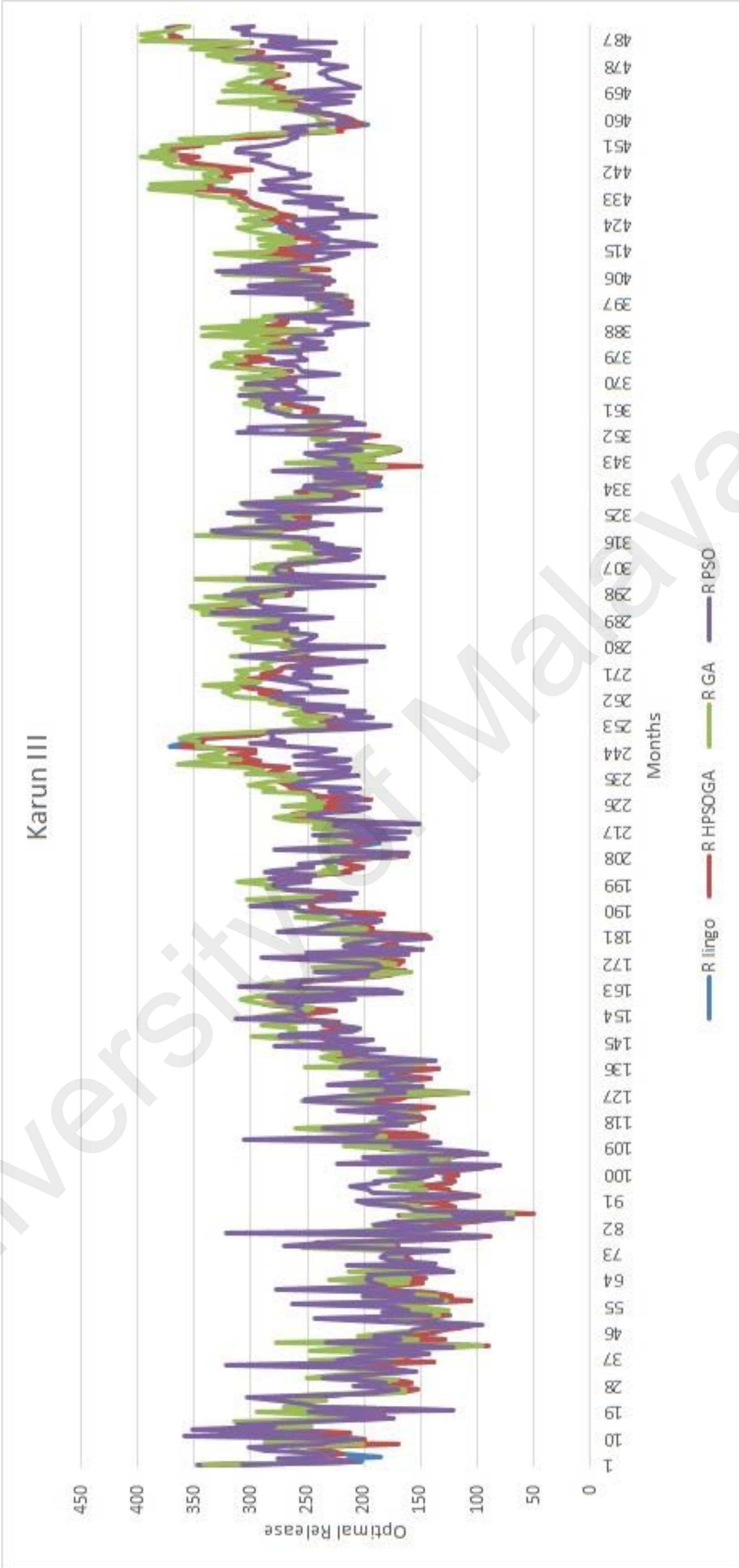


Figure 4.41: Results of optimal release details for Karun III reservoir

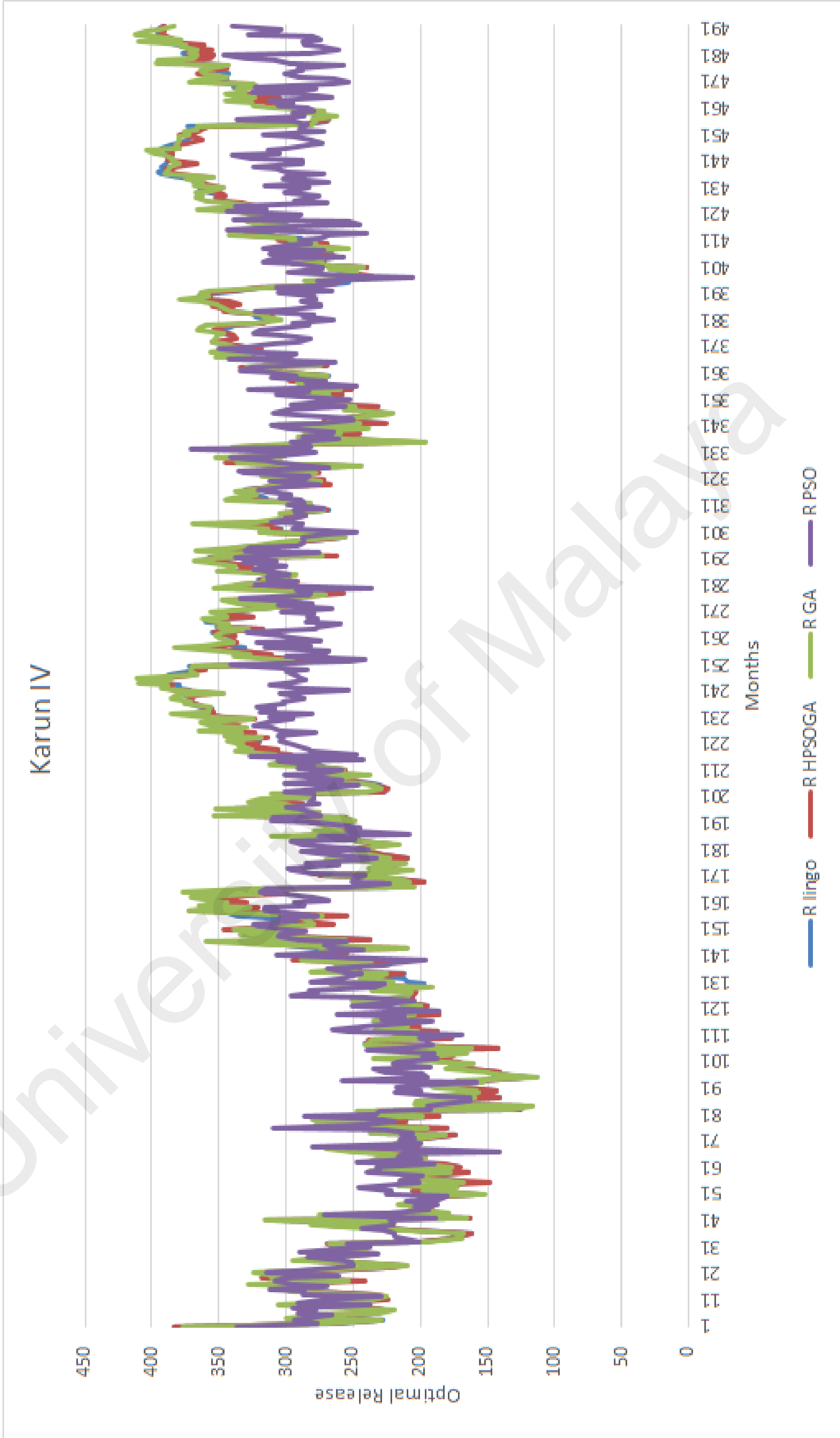


Figure 4.42: Results of optimal release details for Karun IV reservoir

Table 4.32: Validation results for optimal release amount

	Karun I	Karun III	Karun IV
RMSE (MCM)	10.048	9.959	4.139
NRMSE	0.036	0.0314	0.057
CV(RMSE)	0.035	0.043	0.033

4.5 Optimal Cropping Pattern

The optimization problem was solved using linear programming method and evolutionary algorithm in Excel Solver. The results of both methods were completely coincided. The details of the evolutionary algorithm solver engine are shown in Table 4.35. Table 4.33 shows the optimal dedicated amount of land to the cropping pattern of the mentioned seventeen agricultural products in the possession of six MCM water. The objective function is the ultimate value of optimal cultivation pattern, which its value obtained by sum of the multiplying the value per hectare (Toman) in the amount of optimal allocated acres (ha). The optimal objective value in this problem for both methods (LP and Evolutionary Algorithm) was exactly same and it is equal to 5,820,787,814 Toman.

Table 4.33: The optimal area of agricultural land for production (hectares) (The data in this table is calculated only for the problem constraints and conditions)

	Final Value (ha)		Final Value (ha)
Wheat	377	Sugar beet	30
Barley	185	Watermelon	40
Husks	40	Cucumber	40
Corn	20	Potato	40
Pea	57	Onions	40
Lentil	59	Tomatoes	40
Cotton	8	Canola	72
Beans	60	Rice	110
Soy spring	60		

As shown in Table 4.34, in total, about 208.5 tons of phosphate fertilizer, 288.7 tons of nitrogen fertilizer and 271 tons of potassium fertilizer are needed for these products. Nitrogen, phosphate and potassium have the most consumption for all the products respectively. Due to high demand the maximum amount of fertilizer belongs to wheat, barley and rice respectively. As can be seen in Table 4.34, the lowest amount of the required fertilizer belongs to cotton with the value of 3.8 tons. Table 4.47, shows the cost estimation of fertilizer used in an optimal crop pattern.

Table 4.34: The amount of consumed fertilizer in acre in optimum cropping pattern (Weight unit: Kg)

	Phosphate Fertilizer	Nitrate fertilizer	Potash fertilizer	Other	Total
Wheat	57072	87381	6886	3043	154381
Barley	28107	33213	1705	1603	64629
Husks	9948	15906	898	458	27210
Corn	2882	6628	383	139	10032
Pea	2727	2851	323	22	5924
Lentil	5240	5768	331	1	11024
Cotton	1614	2059	120	21	3813
Sugar beet	7374	8250	1361	697	17682
Watermelon	7471	7769	636	1833	17708
Cucumber	10170	16443	2234	2796	31642
Potato	10778	14455	2808	478	28518
Onions	9325	13311	1132	1142	24910
Tomatoes	9531	15177	636	1339	27492
Canola	13239	16248	1374	369	31230
Beans	8879	9676	588	311	19453
Soya bean	6401	9390	2676	171	18639
Rice	17766	24142	2994	369	45272
Sum	208522	288667	27088	14791	539560

As shown in Figure 4.43, the wheat has highest water consumption compared to other agricultural products (1622429.91 m^3). In fact, four agricultural products with high consumption (including wheat, rice, barley and canola) are used about 75 percent of the water needed for seventeen crops (Equivalent 3626952 m^3). The reason behind it is a high demand for these products.

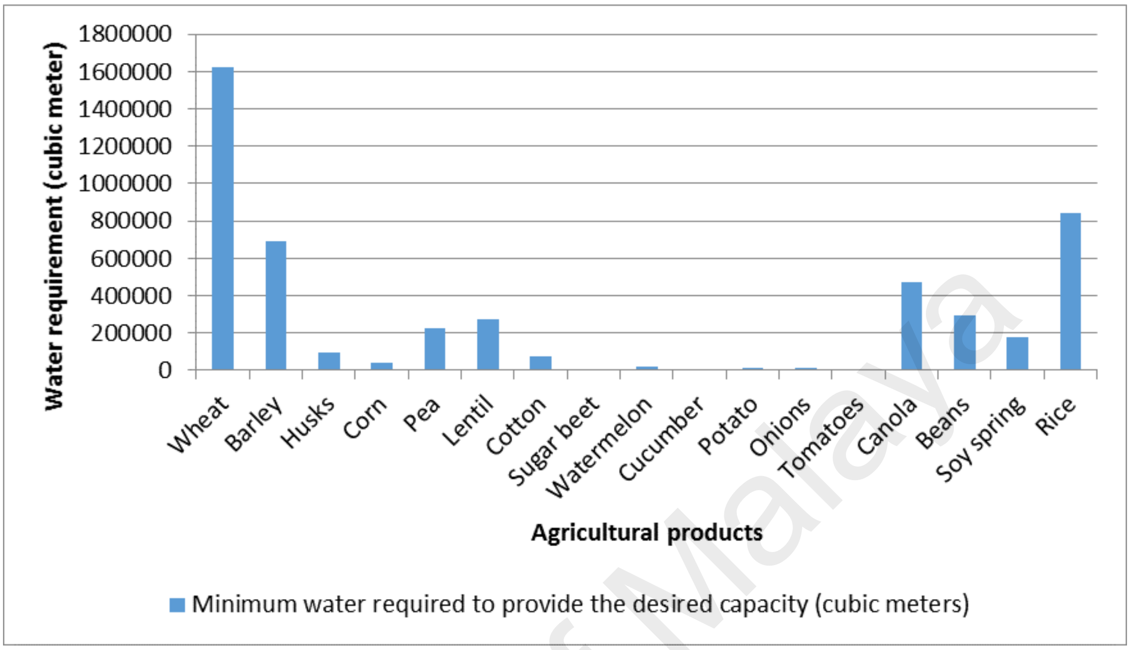


Figure 4.43: The minimum water required to provide the desired capacity (m^3)

Figure 4.44 shows the difference between the minimum amount of agricultural land required for production (ha) and the optimal amount of agricultural land (ha) for each agricultural product. As clearly seen, in the figure, the allocated area in optimal case completely satisfies the minimum required farmland. In other words, Figure 4.44 testifies that the result is optimal. The optimum crop pattern for Barley, Pea, Lentil, Cotton, Canola and Beans is equal to minimum required farmland based on minimum demand. However, for Cucumber, Onions, Watermelon, Potato there is a difference more than 35 hectares between minimum required farmlands and optimal conditions.

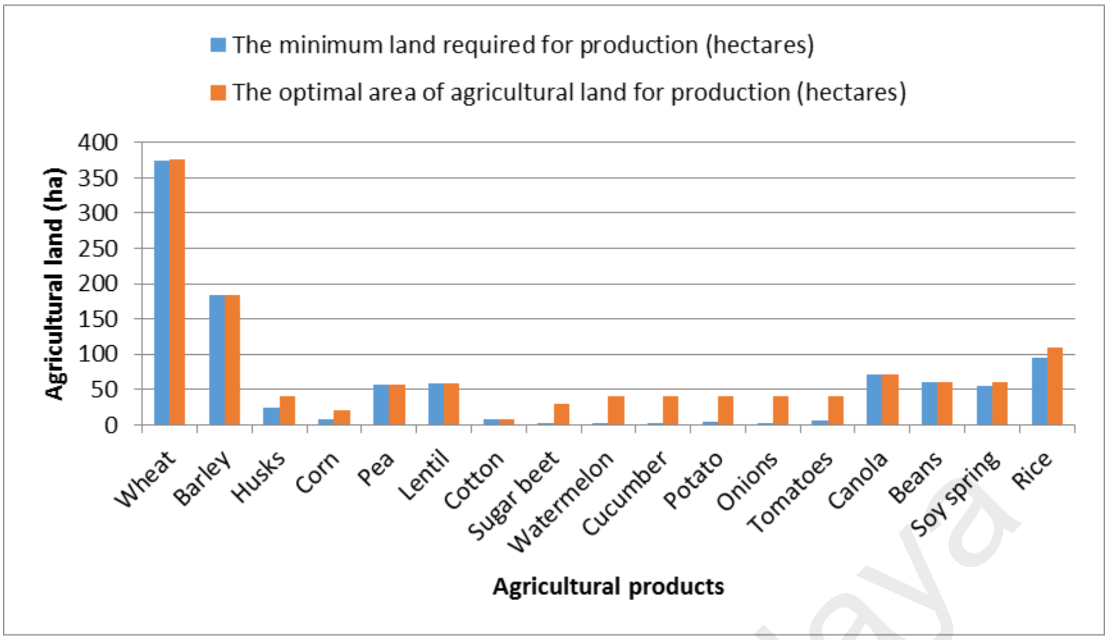


Figure 4.44: The difference between the minimum amount of agricultural land and the optimal amount of agricultural land (ha) for each agricultural product.

4.5.1 Calibration test by Linear Programming (Solver-Excel)

Table 4.35: Solver option for evolutionary algorithm

Engine:	Evolutionary
Solution Time:	40.375 Seconds
Sub problems:	618
Precision	0.000001
Convergence	0.0001
Mutation Rate	0.075
Time w/o Improve	30 sec
Integer Tolerance	1%,

4.5.2 Validation test by sensitivity analysis:

Table 4.36: The optimal area of agricultural land for production (hectares) and sensitivity report of linear programming

	Final Value (ha)	Reduced Cost	Objective Coefficient	Allowable Increase	Allowable Decrease
Wheat	376.65	0	2808750	945557.6555	162494.4219
Barley	184.50	-300171.7742	2113800	300171.7742	1E+30
Husks	40.00	910698.3871	3615900	1E+30	910698.3871
Corn	20.00	2281102.258	5555820	1E+30	2281102.258
Pea	57.14	-554879.0323	1995000	554879.0323	1E+30
Lentil	58.58	-606431.4516	2390000	606431.4516	1E+30
Cotton	8.44	-716345.1613	5211800	716345.1613	1E+30
Sugar beet	30.00	5775994.355	8824200	1E+30	5775994.355
Watermelon	40.00	6568202.097	10354190	1E+30	6568202.097
Cucumber	40.00	3384725.806	5844000	1E+30	3384725.806
Potato	40.00	6788083.065	8710200	1E+30	6788083.065
Onions	40.00	4503286.29	7435000	1E+30	4503286.29
Tomatoes	40.00	6469357.258	7537200	1E+30	6469357.258
Canola	72.15	-314799.1935	3950100	314799.1935	1E+30
Beans	59.88	-184584.6774	3006000	184584.6774	1E+30
Soy spring	60.00	1885588.71	3969500	1E+30	1885588.71
Rice	110.00	5664892.742	11418300	1E+30	5664892.742

4.6 Accuracy of optimization algorithms (PSO, GA and HPSOGA)

As discussed in the methodology section, Particle Swarm Optimization (PSO), Genetic Algorithms (GA) and the hybrid model of the two models (HPSOGA) are used to obtain optimal release, optimal storage and the amount of hydro electric energy produced for the three dams (Karun I, III, IV). In order to calibrate the results, a linear programming method was used in the Lingo software. To compare the accuracy of the results, three criteria were used for RMSE, NRMSD and CV (as mentioned in the previous chapter).

4.6.1 Optimal hydroelectric generation

Karun 1 reservoir results: As seen in the Table 4.37, The RMSE errors obtained from the PSO and GA method have the difference of 162.042 and 13.413 units compared to HPSOGA algorithm result respectively. The calculated error rate according to the NRMSD criteria, using the PSO and GA method has respectively 0.190 and 0.010 units of error difference, compared to the combined method of the them (HPSOGA). The error difference between the CV method for both PSO and GA algorithms are 0.119 and 0.009 units, respectively (Figure 4.45). These results confirm the better performance of the HPSOGA algorithm compared to other two algorithms.

Table 4.37: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun I reservoir

Karun I	Power (HPSOGA)	Power(GA)	Power(PSO)
RMSE	50/194	63/607	212/235
NRMSD	0/037	0/047	0/227
CV	0/033	0/043	0/152

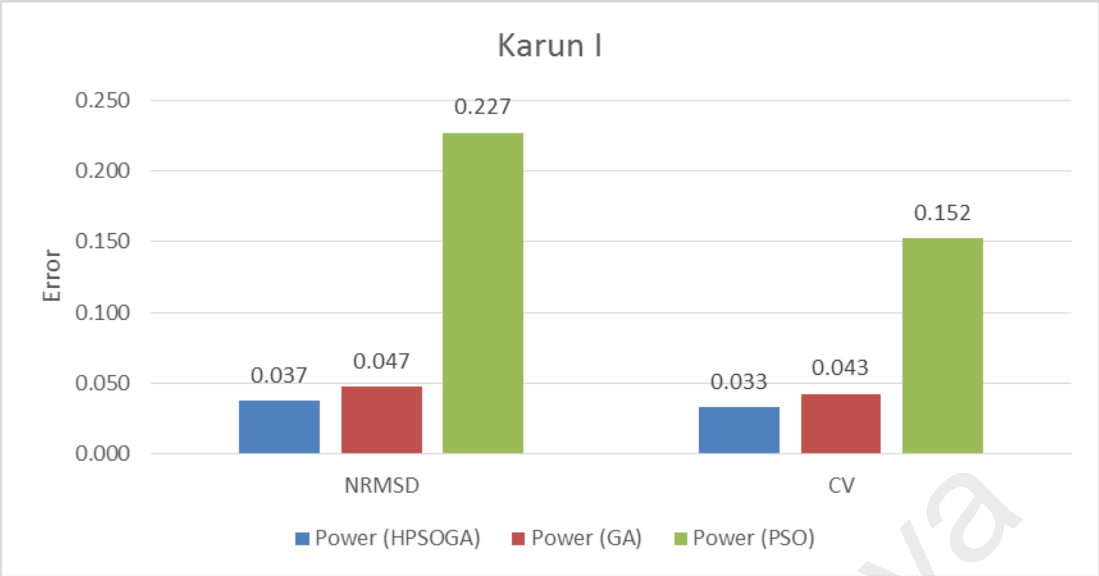


Figure 4.45: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun I reservoir

Karun III reservoir results: Similarly, the RMSE error was compared to PSO and GA optimization methods using HPSOGA algorithm (Table 4.38). This comparison showed a difference of 163,993 and 19,63 of the mentioned methods compared to the HPSOGA combination method. The NRMSD results showed 0.098 less precision for the PSO method, and showed 0.011 less accuracy for GA method. Moreover, the CV results for both PSO and GA showed 0.140 and 0.017 units of error compared to HPSOGA, respectively (Figure 4.46).

Table 4.38: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun III reservoir

Karun III	Power (HPSOGA)	Power (GA)	Power (PSO)
RMSE	55/236	74/868	219/229
NRMSD	0/033	0/044	0/131
CV	0/042	0/058	0/182

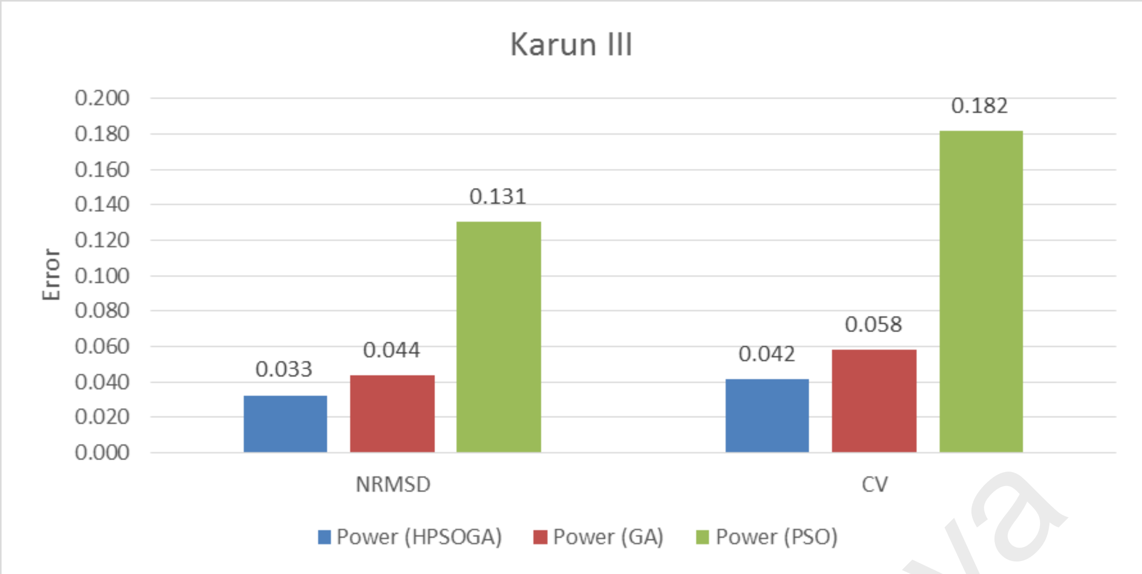


Figure 4.46: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun III reservoir

Karun IV reservoir results: The above process was similar to Karun IV dam. The RMSE error rate of the PSO and GA optimization methods compared to the HPSOGA hybrid optimization method indicate an error difference of 167.733 and 7.954, respectively (Table 4.39). The difference in error rate generated by the NRMSD for both PSO and GA methods is 0.124 and 0.006, respectively, compared to HPSOGA algorithm. The last criterion or CV, also fully reflects the greater error of the PSO method (equivalent to 0.109), and then the GA algorithm (or 0.05) compared to the HPSOGA (Figure 4.47).

Table 4.39: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun IV reservoir

Karun IV	Power (HPSOGA)	Power (GA)	Power (PSO)
RMSE	50/194	58/147	214/926
NRMSD	0/038	0/044	0/162
CV	0/033	0/039	0/143

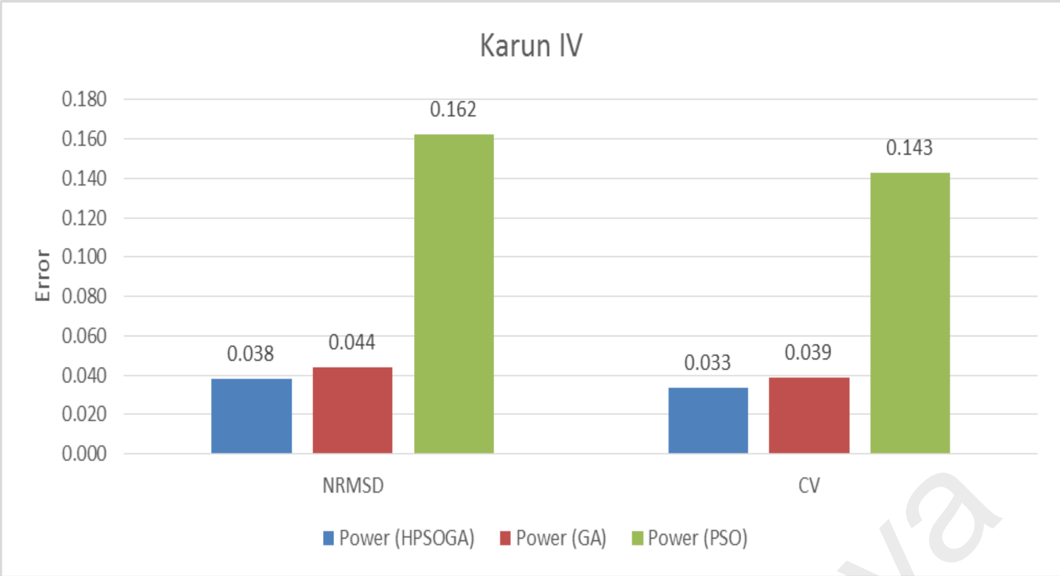


Figure 4.47: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of hydroelectric power generated in Karun IV reservoir

The results generally indicate the lower accuracy of PSO and GA compared to HPSOGA. Meanwhile, the results of the Genetic Algorithm (GA) are far better than the Particle Swarm Algorithm (PSO).

4.6.2 Optimal release

Karun I reservoir results: According to Table 4.40 The error rate from the RMSE criteria for PSO and GA algorithms compared to HPSOGA shows that their performance is 4.893 times and 1.525 times worse. The NRMSD benchmark also is 7.353 times and 1.438 times greater in error compared to the HPSOGA model. As expected the third criteria (CV) also indicates the better performance of the Genetic Algorithm (GA) compared to the Particle Swarm Algorithm (PSO). (The PSO method error is about 5.335 times more than HPSOGA and for GA algorithm error is 1.544 times more than HPSOGA algorithm.)(Figure 4.48)

Table 4.40: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun I reservoir

Karun I	Release (HPSOGA)	Release (GA)	Release (PSO)
RMSE	10/048	15/327	49/162
NRMSD	0/036	0/052	0/268
CV	0/035	0/055	0/188

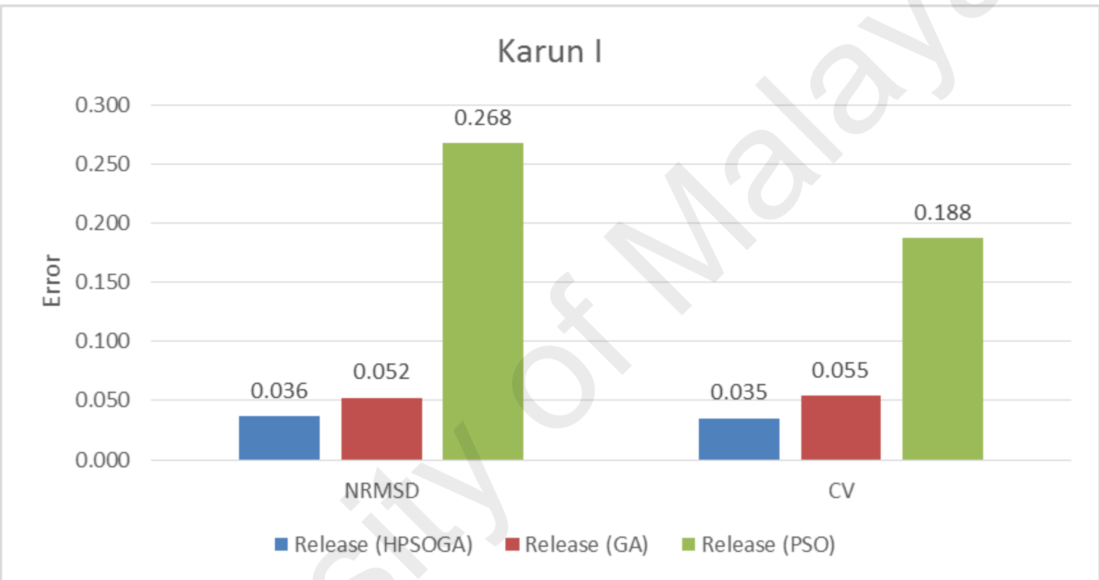


Figure 4.48: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun I reservoir

Karun III reservoir results: According to the Table 4.41 by dividing the obtained error from PSO and GA methods into HPSOGA results using the RMSE criteria is can be seen that the PSO is 4.141 times and the GA is 2.794 times worse. Using the same method but this time under NRMSD criteria, the error rate for PSO method is for 4.721 worse and for GA method is 2.819 worse than HPSOGA results. The CV criteria results also fully support the above results (Figure 4.49).

Table 4.41: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun III reservoir

Karun III	Release (HPSOGA)	Release (GA)	Release (PSO)
RMSE	9/959	27/820	41/237
NRMSD	0/030	0/085	0/142
CV	0/043	0/110	0/179

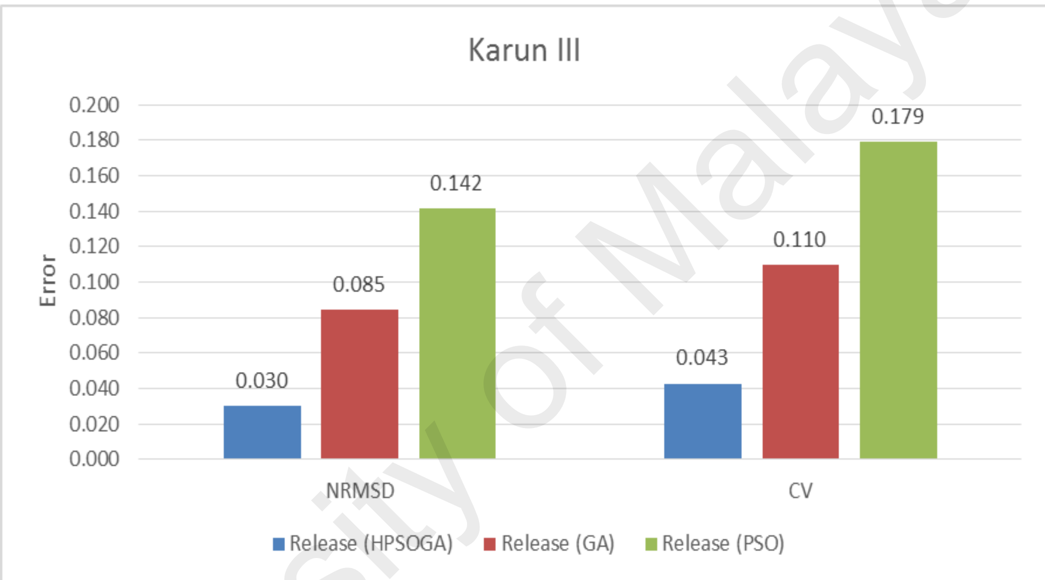


Figure 4.49: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun III reservoir

Karun IV reservoir results: Similarly, the RMSE error ratio for PSO and GA optimization methods compared to HPSOGA was 4.752 and 1.426, respectively (Table 4.42). These results also indicate highest accuracy of HPSOGA, then GA and eventually PSO (Figure 4.50).

Table 4.42: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun IV reservoir

Karun IV	Release (HPSOGA)	Release (GA)	Release (PSO)
RMSE	10/048	14/329	47/747
NRMSD	0/036	0/052	0/173
CV	0/035	0/050	0/167

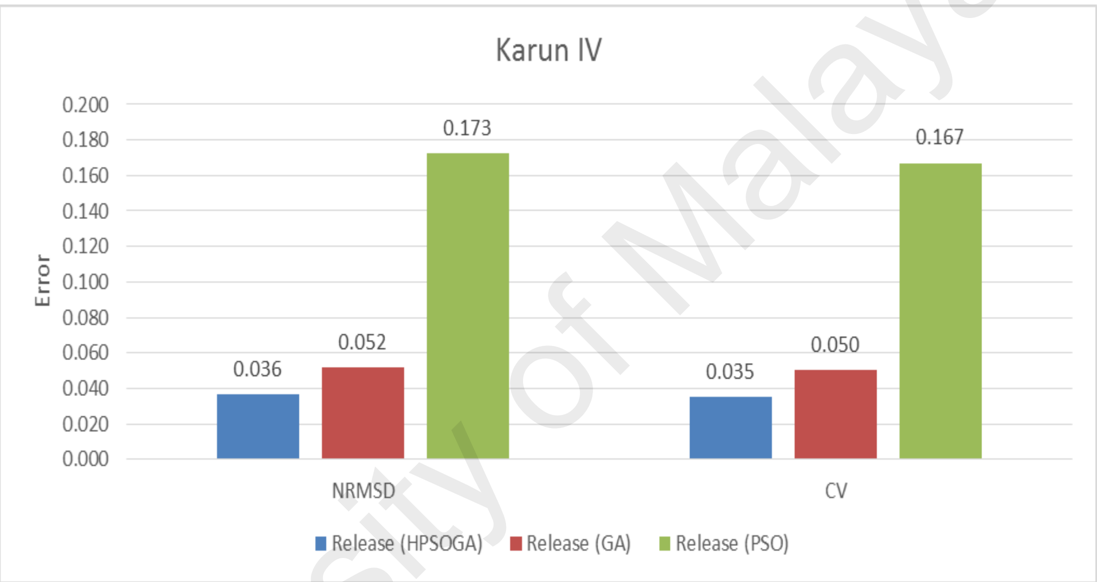


Figure 4.50: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal release in Karun IV reservoir

4.6.3 Optimal storage

Karun I reservoir results: The accuracy of the PSO results compared to HPSOGA has a difference of approximately 275 units difference in RMSE, 0.311 in NRMSD and 0.119 units in CV (Table 4.43). It should be noted that the accuracy of GA results is far better than PSO (Figure 4.51).

Table 4.43: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun I reservoir

Karun I	Storage (HPSOGA)	Storage (GA)	Storage (PSO)
RMSE	37/231	44/275	312/129
NRMSD	0/037	0/043	0/348
CV	0/016	0/019	0/135

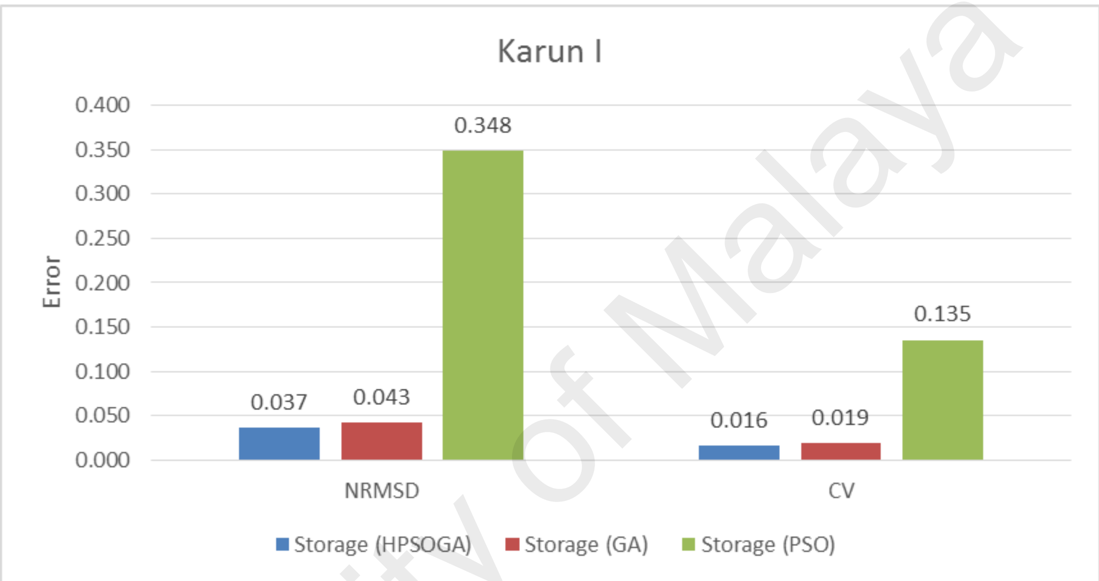


Figure 4.51: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun I reservoir

Karun III reservoir results: According to the Table 4.44 comparison of the accuracy of the results indicates a better performance of the GA than the PSO. (About 7 times better in terms of criteria RMSE and CV and 8.2 times better in terms of criteria NRMSD) (Figure 4.52)

Table 4.44: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun III reservoir

Karun III	Storage (HPSOGA)	Storage (GA)	Storage (PSO)
RMSE	24/222	33/669	271/936
NRMSD	0/024	0/033	0/244
CV	0/012	0/017	0/133

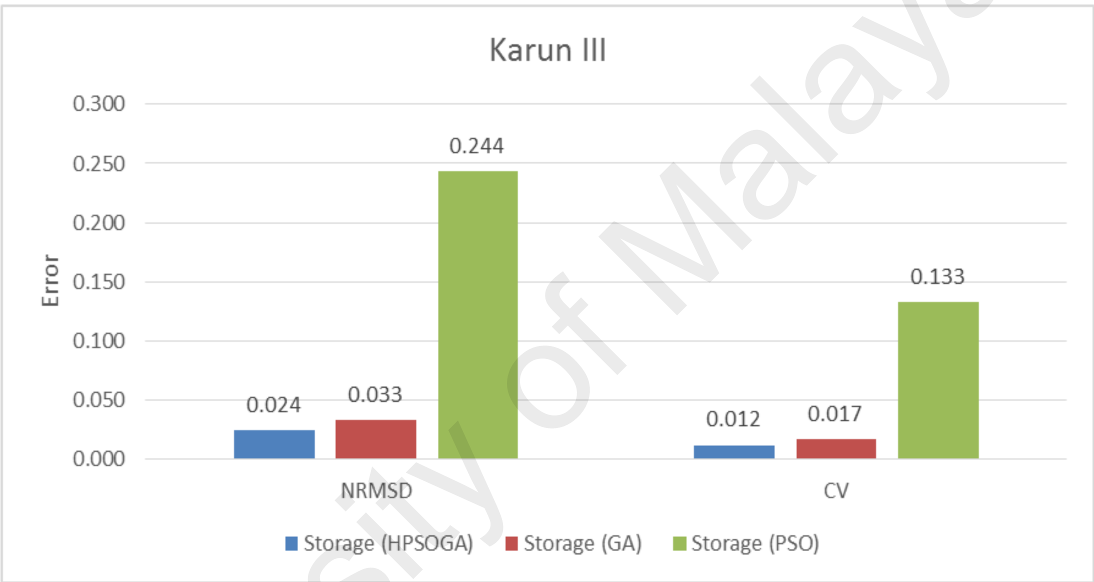


Figure 4.52: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun III reservoir

Karun IV reservoir results: In all the obtained results, i.e. release, optimum storage and the produced energy, for all dams, the accuracy of HPSOGA was better than GA and GA accuracy was remarkably better than PSO (

Table **4.45**). However, exceptionally, the accuracy of the GA algorithm was approximately 34% better than the HPSOGA algorithm for only the optimal storage capacity at Karun IV Dam (Figure 4.53).

Table 4.45: Comparison of the error of the optimization methods (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun IV reservoir

Karun IV	Storage (HPSOGA)	Storage (GA)	Storage(PSO)
RMSE	37/231	12/824	312/129
NRMSD	0/037	0/013	0/309
CV	0/016	0/006	0/137

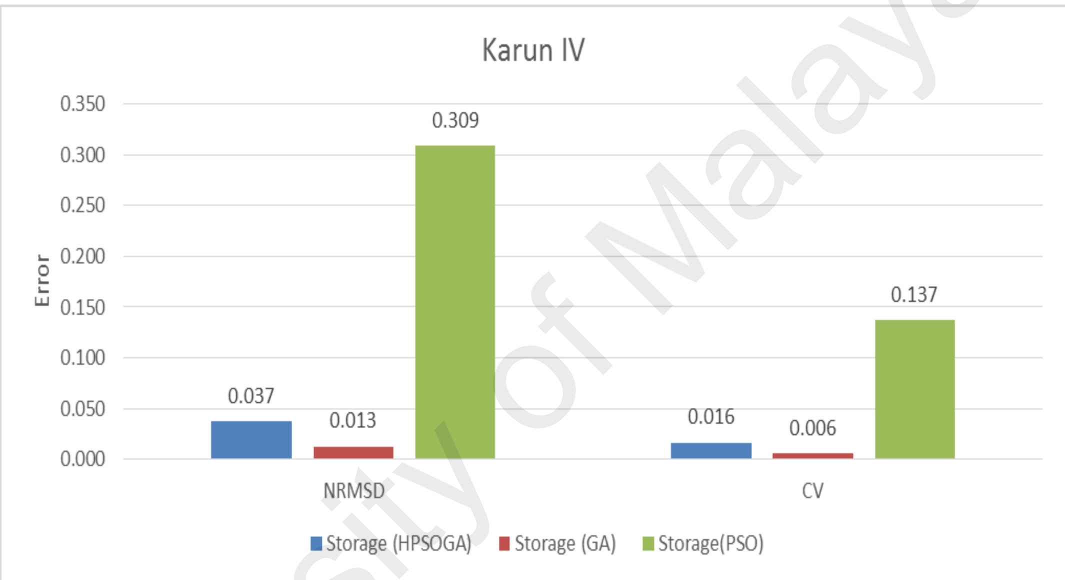


Figure 4.53: Comparison of the NRMSD & CV errors for the optimization algorithms (PSO, GA and HPSOGA) which are used to calculate the amount of optimal storage in Karun IV reservoir

4.7 Predicting the Cost of agricultural products

After determining the optimal amount of agricultural land for these 17 agricultural products per hectare (Table 4.33), the cost of land preparation, planting, crop processing are easily calculated, by using the costs set by the Ministry of Agriculture in different stages of farming (Table 3.13). Table 4.46 shows the breakdown cost for these 17 crops.

Table 4.46: The estimated cost of planting, maintenance and harvesting

	Total Cost	Farmland Cost	Harvesting Cost	Maintenance Cost	Planting Cost	Farmland Preparation Cost
Wheat	240544.2	73027.0	27228.8	67771.3	46101.0	26416.0
Barley	102704.8	26421.2	12793.4	31230.1	19093.5	13166.6
Husks	99711.8	26883.0	12392.7	28701.9	21136.0	10598.2
Corn	17515.7	5692.5	1738.3	6240.6	2300.8	1543.4
Pea	20667.9	4707.3	4583.1	5766.2	3288.9	2322.4
Lentil	36784.4	8011.9	9858.5	9776.5	5646.5	3491.0
Cotton	9767.5	1474.9	2104.7	4487.9	1044.0	656.1
Sugar beet	42557.8	6033.0	10358.0	17877.8	5983.7	2305.3
Watermelon	47632.3	7984.5	12447.4	13301.8	9262.4	4636.2
Cucumber	103530.1	13291.1	33046.4	29873.7	20865.8	6453.1
Potato	111293.4	14211.4	19136.6	25501.1	48560.8	3883.4
Onions	105382.4	14439.3	33913.2	33735.4	16906.6	6388.0
Tomatoes	118586.8	15512.3	47480.9	33382.9	17207.2	5003.5
Canola	54515.9	18350.5	5366.5	19052.2	6126.3	5620.4
Beans	71285.3	16433.9	13747.6	24337.8	11887.7	4878.3
Soya bean	43528.0	17170.8	5080.2	11832.5	4245.6	5198.9
Rice	276330.3	81065.6	40048.6	66200.2	60037.9	28978.1

Table 4.47: The cost estimation of consumed fertilizer in acre in optimum cropping pattern (Currency unit: TOMAN)

	Phosphate Fertilizer	Nitrate fertilizer	Potash fertilizer	Other
Wheat	29379	24859	22976	47458
Barley	13838	11070	11808	22140
Husks	4360	1720	3680	13960
Corn	1660	1460	1540	5720
Pea	4514	3543	3086	10228
Lentil	4686	4335	3163	87870
Cotton	675	549	532	5165
Sugar beet	2820	2190	1980	3840
Watermelon	3640	3000	3240	7360
Cucumber	3680	3160	3280	8200
Potato	3560	3240	2760	12640
Onions	3960	3760	2680	7400
Tomatoes	4080	3760	3240	9280
Canola	5988	4762	4834	24603
Beans	5569	4671	4731	9401
Soya bean	3720	2760	4020	94920
Rice	14960	11220	7810	20790
Sum	111089	90058	85359	390976

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Introduction

Achieving optimal operation rules in multi-reservoir systems is an important topic that has received lots of attention from water resource planners. It is obvious that, a slight improvement in the performance of these systems will lead to noticeable economic income.

There is not any comprehensive approach to solve all the optimization models, efficiently. Therefore, we tend to model the economical and physical aspects of water resources systems with one or more efficient optimization algorithms. Modelling the optimal utilization system in the reservoirs is of important factors that should be considered. Therefore, in this study, the following items were considered as much as possible:

1. Models should be as simple as they were described by terms and be understandable by non-specialists, those who have no scientific background.

2. If the model is developed in the real world, it should be adaptable enough to be able to unify the rapid changes that may be experienced in the current or future world.

3. The model should include all aspects of the problem, not only some details of it.

4. Models should be user friendly as much as possible.

The best method for solving constrained optimization model depends on the specified mathematical form of the objective function and equations. There is not any comprehensive method for efficient solving of all the optimization models. Thus, every mathematical programming model in its best way is only an approximate description of the actual water resources system. The obtained answer is only optimized to the prepared model not to the real problem.

The present study has used evolutionary algorithms and linear programming techniques. Control curves in storage system show the optimum or the appropriate amount of system's delivery water for the storage reservoir condition and input to the reservoir during different months.

In this study, we aimed to maximize hydroelectric power production, water supply for agricultural needs and control seasonal flooding by using multi-objective programming, which has been modelled and optimized, regarding the operation of the set of Karun reservoir dams, which are the main system of reservoir dams in Iran. From evaluation of optimization time due to its high dimensions regarding the number of limitations and decision variables in a 40-year period, it was identified that implementation of the matrix structure and using evolutionary algorithms are appropriate tools to optimize linear and nonlinear models with large dimensions. Then, computational results were obtained by solving the model using different scenarios for combinations of the objective functions. After reviewing these results, it was found that the impact of hydroelectric power is quite impressive in the determination of the optimum solution in comparison with the function of providing water demand. These results provide a useful means to decide for the optimal amount of flow passing through the turbines, the rate of water flowing and the amount of water supply for agricultural and industrial purposes in the short term and long term planning for executives and decision-makers. (Heydari et al., 2016).

This study has two new innovations for optimizing the reservoir operation:

Planning for present and future using regression analysis and artificial neural networks (in situations of data insufficiency or data generation for the future)

Integrated and optimal resource management, from planning to operation. (Connecting the optimizer model to optimal water allocation for agricultural land and estimate the amount of agricultural products and predict the cost before implementation.

5.2 Conclusion

5.2.1 System release rule and reservoir balancing functions

In a real-world situation, release decisions are continuously being made. The operator is continuously assessing the storage levels at every reservoir, estimating the current inflow rates, forecasting future hydrological conditions and deciding if the current release rates need to be revised.

The operating rules are used to compute the rate of release from each reservoir. Knowing the total amount of water in storage in the system, the operator uses the release rule of the current season to determine the rate of release from the system. Next, the operator has to decide which reservoirs has to be used to meet the determined rate of release. The balancing functions for the current season are used to compute the ideal storage level for each reservoir given the current amount of water in storage in the system. If the system storage is balanced according to the ideal storage levels, the operator should release at the release rate specified by the release rule while attempting to maintain the ideal balance. If the system storage is not perfectly in balance, the operator should release at the release rate specified by the release rule and try to achieve the ideal balance as soon as possible. The operator has some freedom on how to achieve the ideal storage balance, but as a rule reservoirs with a storage level above their ideal level will release more than reservoirs with storage levels below their ideal level. The decisions of the operator have to take into consideration the physical limitations of the system structures and equipment, and the short-term operational requirements such as water and energy demand schedules. Note that the long-term operational requirements are being implicitly considered by the operating rules.

Simulating this continuous decision process is not straightforward, since a simulation model uses a discrete time-step. A key issue the model builder has to decide is whether the inflow of the next immediate simulation period is considered available for use during that period. In this case, the inflow is assumed known at the time of the decision, i.e. the beginning of the period.

In real-world situations, although the operator does not know with certainty the future inflows, he or she knows the past and current inflow rates and may have reliable short-term forecasts of future inflows. The operator is continuously making release decisions that are revised as soon as new information about the inflows becomes available. This situation is better represented by assuming the inflow for the next immediate simulation period is known at the time of the decision. Therefore, in this study, in addition to conventional operational planning, Artificial Neural Networks and Regression Analysis were used for future behaviors of the reservoir.

5.2.2 Cropping pattern

One of the most practical objectives of this study is to develop a mathematical programming model for optimal allocation of resources in agricultural field in Khuzestan region. For designing an optimal cropping pattern in an irrigation and drainage network that has defined resources and restrictions, different methods are available for managers and researchers.

The optimal use of natural and human resources is an important objective of economic and social aspects that in this case, fundamental and sweeping changes in the structure of agriculture, the extensive involvement of staff and favorable management factors of production, are necessary to develop the agricultural sector in the country. In this communication, design and adjusting the cropping pattern to determine the amount of cultivated area and the right combination of products, is utmost important and should be done in such way that in addition to the optimal use of existing capacities and access, considering regional and national needs. Design cultivated and process are influenced by many varied factors that are studied that force the designer pattern to collect a wealth of data and information.

Performing appropriate cropping pattern guarantees food security, production stability, reduction in the adverse effects of drought it is necessary to protect natural resources and increase efficiency production factors. But, for performing appropriate cropping pattern we require common intrinsic county planning, coordination and cooperation of power ministries, agriculture and commercial institutions.

Design and adjustment of the cropping pattern is utmost important to determine the amount of cultivated area and the right combination of products. It should be done in such way that in addition to achieve the optimal use of existing capacities and access, regional and national needs are being considered.

Cultivated design and process are influenced by many varied factors that force the designer to collect a wealth of data and information. It is crucial to pay particular attention to the projects' effective operation to obtain the utmost benefits and satisfaction from all the goals set earlier (Heydari et al., 2015).

In general, the results obtained from this study show that the farmers do not use the available resources efficiently. Implementation of optimization models indicates that the use of arable land in different seasons can lead to done in a better way. Therefore, if the limits of the region, including water, reduced, there will be a possibility of increasing the area under cultivation and profitability. The development of infrastructural services play an immense role in reducing resource constraints, and optimal use of resources can be effective to achieve the desired profitability of farming activities.

According to estimations of water's shadow price, it can be stated with certainty that water is the most limiting factor in the region's agriculture. Therefore increasing the accessibility of farmers to water can be increased acreage and farmers' incomes.

If we consider several watershed areas, we can divide the watersheds to different general arena based on water resources and raining rate .In each arena, the general policies of reaching to an appropriate cropping pattern with the focus on water resources are similar to each other (even in different climates), these arenas include:

Arena that has severe water restriction

At the present, policies based on indiscriminate consumption of underground water resources are dominated; therefore, it is necessary that production policies are for optimal consumption and high efficiency and non-reduction of production as much as possible. For performing this policy the following methods should be considered:

1. Giving priority to fall plants for using annual fall, winter and spring rains.

2. Increasing the cultivation area in controlled environments such as greenhouse, cultivation under plastic

3. In spring cultivation using plants that their growing period is short and have more adaptation with rainfall distribution of the area.

4. Establishment of Conservation tillage systems

5. Establishment of pressurized irrigation lands, especially drip irrigation in agricultural lands and garden

6. Reduction of water consumption and increasing economic efficiency and preserving basic resources

7. Plants with low water needs and cultivation kinds of yielding precocious plants

Arenas that have no water restriction

In these areas, agricultural operation policies should go toward maximum utilization of land for production and the following methods are considered:

1- Moving toward multi-cultivation methods

2- Maximum utilization of water resources with the aim of keeping the potential of production resources

3- Proper utilization of tail water of reservoirs that includes optimization of cropping pattern and proper exploiting of production resources.

5.2.3 Hydropower generation

Since, the production of hydroelectric energy is a function of the reservoir volume and release rate, the objective function for energy production is in contrast with the objective function for agricultural and industrial needs and for flood control. Therefore, large amounts of water cannot stored behind the dam exit from the turbines. On the other hand, the increased volume of water stored behind the dam will increase the amount of energy produced per month. Hydroelectric power production is the function of the height of the water stored behind the dam and the volume of water passing through the turbine. However, increasing the water release rate for hydroelectric power production is relatively more effective than increasing the height of water stored behind the dam because of the physical structure of reservoir dams and location of turbines. When the volume of water stored behind the dam is close to its maximum and it is not possible to drain the water from the tunnel, there will be an overflow throw out-lets. With the increased volume of water passing through the turbines, the water level increases in the tailwater. Increasing water height in the tailwater will decrease hydroelectric power production. For this reason, it is not so often possible to release the water to the extent of the water capacity of the tunnels. A comparison between the results of the evolutionary algorithms optimization model and mathematical programming methods for implementing the best scenario showed that there is a good match between them.

The results also showed that the volume of seasonal flooding increases solely in the spring, and overflows through sub-outlets and the discharged water volume is very low through these sub-outlets in the other months. The percentage of consumption needs of an area is estimated at 35-40%, which has the lowest value of 26% in September and the highest value of 56% in December. Hydroelectric energy is produced to the highest and lowest level, in the months of June and January with a production value of 327242 (MWh) and 160070 (MWh) energy, respectively (Heydari et al., 2016).

5.2.4 Flood control

In the catchments under study, generally high flow is observed in two distinct periods, from November to February (winter) and from March to May (spring). Heavy precipitation is responsible for winter floods, whereas the combined effects of rainfall and snowmelt produce the spring floods.

5.3 Recommendation

5.3.1 Reservoir rule curves considerations

The majority of reservoir systems is still managed through fixed and pre-defined operating rules that indicate with varying detail the actions to be taken by the system operators as a function of small number of variables, such as the time of the year, state of the system and hydrological conditions. These pre-defined rules are usually presented in the form of charts or tables that are very easy to understand, and constitute a good working tool for negotiations on reservoir systems operations. Since the operating rules are easily readable, little modelling or scientific background is required to take part in the discussion. In our view, this possibility for discussion and modification is the main reason why the great majority of reservoir systems is still managed by these type of rules. Simulation models are very useful at this stage of discussion and included in these models to represent the actual operating decisions taken by the operator of the system being simulated, and they can quickly be modified to meet suggestions that arise during the discussions.

5.3.2 Cropping pattern suggestions

Suggestions for future studies

1. It is recommended to calculate the actual performance of the product and the actual evaporation-transpiration more accurately by using a nonlinear programming model and considering the soil moisture balance (at ten-day irrigation intervals obtained from the local information) and also considering the dynamic aspects of root growth, therefore the results would be more desirable.

2. It is suggested to link the provided model with the geographical information system software (GIS) and add the zoning capabilities of cultivation pattern

to this model. This will cause to obtain the optimal cultivated area of each product from the surface and underground water resources of the plain.

3. It is recommended to link the provided model with Modflow to be able to carry out analyses related to the drop in the water table aquifer and accurately calculate the changes in aquifer volume.

Suggestions for managers:

1. Developing the regional cultivation patterns based on reducing the use of scarce water resources.

2. Using the water markets in order to change the process of utilizing water resources.

3. Noticing the effects of government policies on local products because of the exchange relationship between numerous objectives such as intervention in products' market.

5.3.3 Suggestions for hydropower generation modelling

Suggestions for future studies

If researchers wish to continue research on the optimal production of hydroelectric power, it is recommended to consider the following hydroelectric schemes parameters in their model.

Parameters for Hydroelectric Schemes in desired model:

1. Year of commissioning (for existing or committed plant);
2. Earliest allowable year of commissioning (for candidate plant);
3. Normal life expectancy;

4. Plant displaced by this station;
5. Reservoir storage capacity (GWh of energy);
6. Number of generating units;
7. Nominal installed capacity of units (MW);
8. Station internal demand (% of installed capacity);
9. Loss in interconnector to the grid (%);
10. Minimum power output (MW);
11. Firm power and average power in each month of year (MW);
12. Firm energy and average energy in each month of year (GWh);
13. % available storage for each month of firm year and in average year (% of live storage capacity);
14. station availability in each month (% time/capacity);
15. forced outage rate in each month (% of time);
16. minimum generation level (MW) in each month of year (to allow for programmed releases for other water users);
17. fixed operating costs (currency unit per MW per annum);
18. variable operating costs (currency unit per MWh);

5.3.4 Suggestions for flood control

Flood control

We need flood frequency analysis to identify the flood magnitude for every return period. Hence, a thorough flood frequency analysis has to be carried out for the upper and intermediate catchment. The initial condition of the reservoirs and flood hydrograph combination of the catchment determine how critical the situation is. So, the calculated hydrograph in upstream indicates the maximum possible flood based on the river system features. The hydrodynamic simulation is needed to obtain flood inundation depth in the flood plain. To achieve this, the HEC—RAS model (or any relevant models) can be used by applying available data from Dez and Karun rivers.

A very important aspect of flood studies is estimating the flood damage in inundated regions. In order to figure out an accurate damage amount, gathering historical data of damage and having the result of a flood damage survey are necessary.

The results obtained from the survey and the maps are applied to build a GIS database. In some conditions and mitigation plan alternatives, the hydraulic model will run to forecast discharges as well as water levels for various return periods of flood the damage in different return periods are evaluated.

To analyse the cost/benefit of various mitigation alternatives HEC-FDA software can be used. To calculate the annual benefits of a specific mitigation alternative a risk-based damage analysis is carried out. Moreover, in order to opt the most desirable alternative an economic assessment will be done based on cost-benefit analysis.

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