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OPTIMIZATION OF THE RESERVIOR OPERATION OF INDRA SAGAR DAM USING CELLULAR AUTOMATA APPROACH

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ABSTRACT

A novel Cellular Automata approach is developed in this paper for the optimal solution of largescale reservoir operation problems. The aim of this paper is to show how the Cellular Automata can be used for the solution of reservoir operation problems, and more importantly to demonstrate that the method is extra-ordinarily much more efficient and effective than conventional methods. The cells are defined as the discrete points chosen on the operation horizon of the problem and storage volumes are taken as the cell states. The optimization objective functions of the problems are used to derive the updating rule of the problems. The proposed methods are used to optimally solve the problem of water supply and hydropower operation of "Indra-Sagar" reservoir in India. The results are presented and compared with those obtained using three heuristic search methods namely MOPSO, EMMOPSO and TV-EMMOPSO algorithms. The results show that the Cellular Automata approach is much more efficient and effective than most powerful search methods for the reservoir operation problems.

1. INTRODUCTION

Among the various components of water resources systems, reservoirs are the most important. A reservoir is created by constructing dam across a stream. The principal function of a reservoir is regulation of natural stream flow by storing surplus water in the wet season and releasing the stored water in a future dry season to supplement the reduction in river flow. In short, the purpose of a reservoir is to equalize the natural stream flow and to change the temporal and spatial availability of water. The water stored in a reservoir may be diverted to far away places by means of pipes or canals resulting in spatial changes or it may be stored in the reservoir and released later for beneficial uses giving rise to temporal changes.

Depending upon the magnitude of natural inflows and demands at a particular time, water is either Stored in the reservoir or supplied from the storage. As a result of storing water, a reservoir provides head of water which can be used for generation of electric power. In case of flood control projects, it provides empty space for storage of water thereby attenuating the hydrograph peaks. A reservoir also provides pool for navigation to negotiate rapids, habitat for aqua life and facilities for recreation and sports. It enhances scenic beauty, promotes a forestation and wild life.

Once the structured facilities like dams, barrages, hydropower plants etc. come into being, the benefits that could be reaped depend to a large extent upon how these facilities are managed. The efficient use of water resources requires not only judicious design but also proper management after construction. Reservoir operation forms a very important part of planning and management of water resources system. Once a reservoir has been developed, detailed guidelines are to be given to the operator which enables him to take appropriate management decisions.

The reservoirs are commonly built in India for conservation and flood control purposes. The climate experienced in Indian subcontinent is of monsoon type in which most of the water is received during the monsoon period from June to September. The conservation demands are best served when the reservoir is as much full as possible at the end of the filling period. The flood control purpose, on the other hand, requires empty storage space so that the incoming floods can be absorbed and moderated to permissible limits.

A reservoir operation policy specifies the amount of water to be released from the storage at any time depending upon the state of the reservoir, level of demands and any information about the likely inflow in the reservoir. The operation problem for a single purpose reservoir is to decide about the releases to be made from the reservoir so that the benefits for that purpose are maximized. For a multipurpose reservoir, in addition to the above, it is also required to optimally allocate the release among several purposes.

CELLULAR AUTOMATA APPROACH (Ce-A)

Informally, a CA (Cellular Automata) is a set of identical elements, called cells, each one of which consists of a regular, discrete, infinite spatial network. Each cell can assume a state from a finite set, and the automaton evolves in discrete time steps, changing the state of all its cells according to a local rule, homogeneously applied at every step. The new state of a cell depends on the previous state of a set of cells, which can include the cell itself and its neighborhood. The next state of a cell is defined using an update rule, sometimes referred to as a transition rule, which is a function of its current state and the current state of its neighbors. The collective state of all of the cells in the model at any given point is known as the global state.

These rules and states are normally dependent on the problem being solved. There is no limit to the number of dimensions that can be used, but it has a large affect on the communication network among cells, known as the cellular neighborhood. An important nature of the method is that CA updates its state depending on those surrounding it in the previous iteration. CAs does not have an objective function and are concerned only with the execution of rules at a local level.

From an optimization point of view, CAs possess three additional key properties in their execution:

- **Parallelism**: updates of each cell state are completed in parallel, and each of the changes to cell states occurs at once.
- **Localist_representation**: Determines that when a cell is updated, its new state is based solely on the old state of cell and those of its neighbors. Localism is the mechanism by which parallelism can benefit performance in combinatorial optimization problems.
- **Homogeneity**: Requires that each cell is updated according to the same rule. This is important for treating each part of the system with the same degree of importance as any other. This homogeneity is in fact present in other search algorithms such as GAs due to their lack of problem-specific knowledge.

The concept of Cellular Automata (CA) theory is able to model systems with many objects that interact with each other. The systems are divided into discrete units, or cells that act autonomously. The advantage of using CA is that the behaviour of same complex systems can be captured using relatively simple rules for each cell. Attempting to reproduce this behaviour without breaking those systems into autonomous units, even if possible, would be complicated. Each cell in a CA model can be in a single state at any given point in the simulation. The number of states the cell may be in, depends on the problem being solved. Some set of rules on which the transition of cells is based upon are stated below:

A. If cell is alive (output set to 1)
   a. Neighbors < 2 **Cell Dies** because of loneliness
   b. Neighbors > 3 **Cell Dies** because of overcrowding
B. If cell is dead (output set to 0)
   a. But have 3 neighbors. These three neighbors get together and produce a new cell.

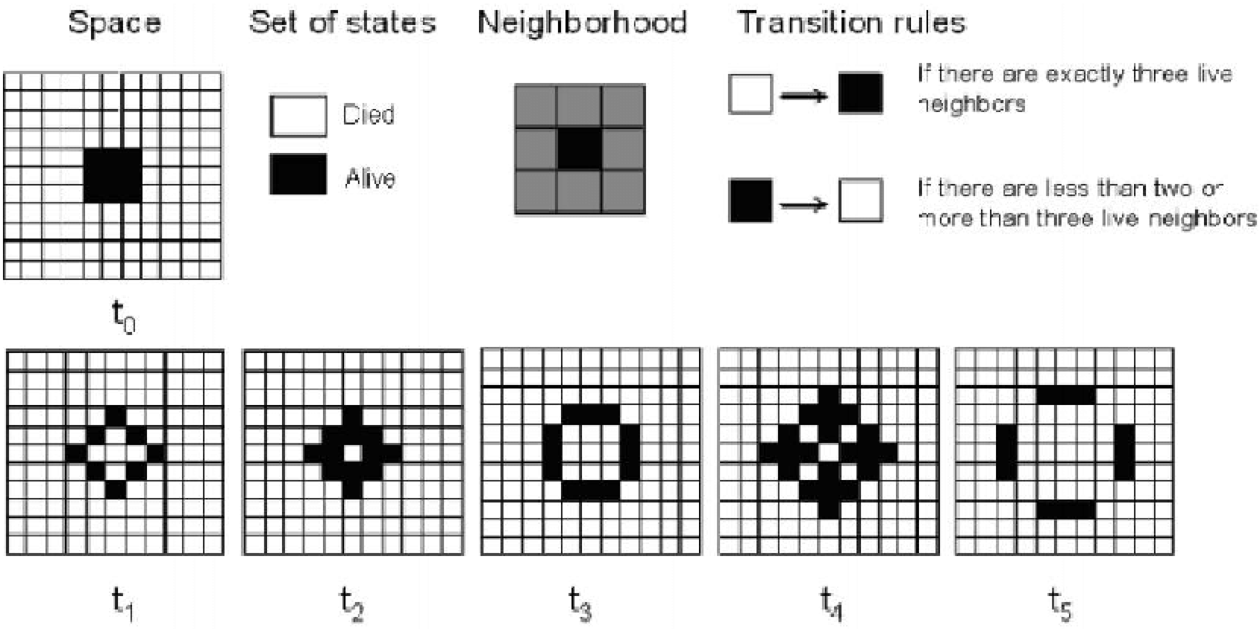

Fig:- CELLULAR AUTOMATA

CA FORMULATION

Application of CA to any optimization problem requires 4 basic components of method:-Cells, Its neighborhood, Cell state and transition rule.

Cell state represents decision variables. In reservoir operation problems, two set of decision variables – storage volume & release volume are considered as decision variables.

The objective function can be mathematically expressed as-

$$\text{Min F} = \sum_{t=1}^{n} \left(1 - \frac{Pt}{Icap}\right) \quad \text{...eq-1}$$

Where,

F= objective function

N= no. of periods

Pt= power generated at period t (MW)

I_{cap}= installed capacity of hydropower plant (MW).

OPTIMIZATION APPROACH

In this study, the cellular automata (Ce-A) based optimization approach was proposed for optimal hydropower operation and flood control of the Indra Sagar Reservoir. The Ce-A is composed of a regular grid of cells. Each cell can carry one of the finite numbers of states, which is described for the system. Then, the grid can be formed by joining various sets of cells that identify the dimensions of the grid cells. The initial values of cells describe the initial state of the grid cells. The new generation of solutions at the next time step can be developed by introducing fixed rules (generally, a mathematical function) that estimate the new state of each cell. The rules can be described based on the previous state of the specified cell and the states of neighborhood cells. Generally, the rules are kept the same for all the cells within a grid and do not change over time. Therefore, in order to use the concept of Ce-A for any optimization problem, four components of the Ce-A should be defined including the cell, cell state, cell neighbors, and updating rule. For this particular problem, the cells are taken as discrete points in time representing the start and the end of each period of the operation. In the Ce-A optimization approach, the cell state represents the decision variable of the optimization problem, which in this study was taken as the reservoir storage. The surrounding cells are considered as the neighborhood cells.

To derive updating rule for arbitrary cell 'j' the local objective function should be defined based on the objective function of problem defined in eqn-1,

Therefore, the local objective function is:

$$\textbf{Min } F_j = (I_{cap} - P_{j-1}^{\;k+1})^2 + (I_{cap} - P_j^{\;k+1})^2 + \alpha(CV)_j^2$$

j= cell number, k= Iteration level, α= Penalty Parameter, CV= Constraint Violation.

where j and k denote the cell number and iteration level, respectively.

Final equation is derived with respect to cell state S_j, while all other cell states are kept constant. It leads to an updating rule in the form of-

$$\Delta sj = \partial P_{j-1}/\partial S_j \,(I_{cap} - P_{j-1}^{\,k}) + \partial P_j/\partial Sj \,(I_{cap} - P_j^{\,k}) + (\alpha\,(CV)_j^{\,2} + (CV)_{j-1}^{\,i})^2 \,/\, (\partial P_{j-1}/\partial S_j) + (\partial P_j/\partial S_j)(2B\alpha)$$

$\Delta s_j = S_j^{k+1} - S_j^k$ and B is a binary parameter with the value of 1 if the solution in the cell j is feasible, and 0 if otherwise. The optimization framework and the Ce-A approach to solve it was all coded in MATLAB and is accessible on GitHub.

DESCRIPTION OF THE STUDY AREA

Introduction: The Narmada is a river in central India. It is the third longest river that flows entirely within India, after the Godavari, and the Krishna. River Narmada, with flow length of 1,312 km originates from Amarkantak in Anuppur district of Madhya Pradesh. Narmada flows south westward and after passing through Madhya Pradesh, Gujarat, and a small stretch in Maharashtra, it drains into Arabian Sea near Gulf of Cambay. It is also known as "Life Line of Madhya Pradesh" for its huge contribution to the state of Madhya Pradesh in many ways.

Located at 32km from Mundi in the Khandwa district of Madhya Pradesh in India. Foundation stone was laid by Smt. Indira Gandhi, former Prime Minister of India on 23rd Oct. 1984. Construction started on 1993 and commissioned on 31st March, 2005. The Dam was built as a joint venture between Madhya Pradesh irrigation and National Hydro-electric Power Corporation. The Power house of NHDC is the largest surface Power house in Madhya Pradesh.

Physical Features:

River	**Narmada**
Length of Dam	**654 m**
Height	**91.4 m**

Designed Discharge	**83543 m^3/s**
No. of Radial gates	**20 (20m x 17m)**
Spillway Length	**495 m**
Type of Turbine	**Francis**
Installed Power generation capacity	**1000 MW**
Catchment Area at site	**61,642 km^2**
Land Irrigated	**1,69,000 Hectare**
Supplies Drinking water	**2.61 TMC (thousand million cubic feet)**
Latitude / Longitude	**22’ 17’ 00 / 76’ 28’ 00**

Table-1

DATA ACQUISITION

The following heads describing the various data which has been acquired for conducting the study and developing the Monthly Release Policy for optimal operation of Indira Sagar Reservoir.

- Monthly inflow series to the reservoir site
- Details of Indira Sagar reservoir
- Demand pattern of the region

Monthly inflow series to the reservoir site:

The monthly inflow series to the reservoir site were acquired from NARMADA CONTROL AUTHORITY (NCA) OFFICE INDORE (M.P.).

Details of Indira Sagar reservoir:

1. **Reservoir Levels**

1. Top Bund Level (m)	267.00
2. MWL(m)	263.35
3. FRL (m)	262.13
4. MDL (m)	243.23
5. Crest level of spillway (m)	245.13
6. Water Spread Area at FRL (Sq.km)	913.48

Table-2

2. Storage Capacity

Gross Storage [Bm^3]	12.220
Live Storage [Bm^3]	9.750
Dead Storage [Bm^3]	2.450

Table-3

Demand pattern of the region: The monthly demand data to the reservoir site were generated and cropping pattern data & hydropower demand data acquired from NARMADA CONTROL AUTHORITY (NCA) OFFICE INDORE (M.P.), NVDA OFFICE INDORE and NHDC OFFICE KHANDWA DISTRICT

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Discharge:

Annual Maximum / Minimum discharge with corresponding Water Level (m.s.l)						
	Maximum			Minimum		
Year	Q (cumecs)	WL (m)	Date	Q (cumecs)	WL (m)	Date
1970-1971	0	139.235	23/05/1971	0	139.235	23/05/1971
1971-1972	13019	148.610	07/09/1971	30.9	139.185	30/05/1972
1972-1973	18973.7	149.713	02/09/1972	26.5	139.135	28/05/1973
1973-1974	44900	157.100	31/08/1973	28.2	139.225	25/05/1974
1974-1975	31454	153.215	20/08/1974	32.4	139.140	30/05/1975
1975-1976	32213.6	152.685	12/09/1975	19.1	139.186	16/06/1975
1976-1977	12927.9	147.073	06/08/1976	11	139.505	30/12/1976
1977-1978	24844	150.100	15/09/1977	55.4	139.245	26/05/1978
1978-1979	27373.4	150.575	30/08/1978	49.9	139.215	08/06/1978
1979-1980	32084.3	151.600	10/08/1979	34.5	139.090	26/05/1980
1980-1981	21843.6	149.750	30/08/1980	37.5	139.260	02/06/1980
1981-1982	27983.8	151.905	10/08/1981	39.2	139.275	17/05/1982
1982-1983	17050	147.935	23/08/1982	36.3	139.235	28/05/1983
1983-1984	19420	148.970	11/09/1983	24.6	139.160	10/06/1983
1984-1985	46000	155.550	19/08/1984	33.9	139.190	31/05/1985
1985-1986	13850	147.710	10/08/1985	30.2	139.235	26/05/1986
1986-1987	32600	152.550	15/08/1986	31.8	139.220	11/06/1986
1987-1988	21313	149.190	28/08/1987	16.43	139.120	31/05/1988
1988-1989	21400	149.200	05/08/1988	11.92	139.080	06/06/1988
1989-1990	13650	147.070	08/08/1989	16	139.100	04/06/1989
1990-1991	37750	153.200	23/08/1990	108	139.500	14/06/1990
1991-1992	21750	149.200	31/07/1991	22.6	139.770	08/06/1991
1992-1993	9900	145.680	18/08/1992	40	139.400	09/06/1992
1993-1994	29000	151.800	17/07/1993	47.15	139.290	14/06/1993
1994-1995	48200	157.230	06/09/1994	118.2	139.660	19/05/1995
1995-1996	12500	147.000	25/07/1995	58	139.370	26/05/1996
1996-1997	31025	152.000	28/07/1996	69.48	139.420	26/06/1996
1997-1998	33500	153.150	26/07/1997	70	139.370	12/06/1997
1998-1999	27900	151.150	15/09/1998	54.14	139.290	31/05/1999
1999-2000	30150	151.660	21/09/1999	39.91	139.290	10/06/1999
2000-2001	5790	143.980	31/07/2000	55.15	139.390	05/05/2001
2001-2002	11725	146.000	16/08/2001	51.69	139.360	04/06/2001
2002-2003	14950	147.980	03/09/2002	57	139.420	25/05/2003
2003-2004	11905	146.660	29/07/2003	3.46	138.820	27/11/2003
2004-2005	12100	146.740	25/08/2004	12	139.030	14/04/2005
2005-2006	8793.7	145.300	04/08/2005	51.53	139.380	30/03/2006

2006-2007	18482.74	148.550	20/08/2006	15.3	139.300	22/04/2007
2007-2008	10691.59	145.820	08/08/2007	69.9	139.400	20/06/2007
2008-2009	1583.65	141.650	20/07/2008	149.81	139.780	09/06/2008
2009-2010	15828.13	147.750	12/09/2009	82.57	139.780	12/11/2009
2010-2011	10257.83	145.990	09/09/2010	84.86	139.520	23/06/2010
2011-2012	17698.74	148.750	27/08/2011	266.55	139.940	08/05/2012
2012-2013	33479.3	153.150	06/09/2012	46.27	139.490	17/02/2013
2013-2014	46398.29	154.575	24/08/2013	214.02	139.575	12/05/2014
2014-2015	10407.92	145.750	08/09/2014	3.17	139.090	11/07/2014
2015-2016	2311.07	142.120	17/08/2015	138.94	139.420	30/05/2016
2016-2017	10200	146.070	09/08/2016	106.3	139.510	29/06/2016
2017-2018	2620.52	142.290	15/09/2017	21	139.15	02/03/2018
2018-2019	4856.07	143.28	17/08/2018	29.3	139.19	05/08/2018
2019-2020	21150	150.300	13/09/2019	89	139.440	30/06/2019

Table-4

The data pertaining to physical features have been collected from various reports on ISP system planning and operation. The rainfall data, stream flow data and the data of inflow and demand data into the Reservoirs were collected from the NARMADA CONTROL AUTHORITY OFFICE INDORE, NHDC OFFICE NARMADA NAGAR KHANDWA, and NVDA OFFICE INDORE.

HYDROGRAPH FOR WATER YEAR: 2019-20 (DATA CONSIDERED : 1972-2020)

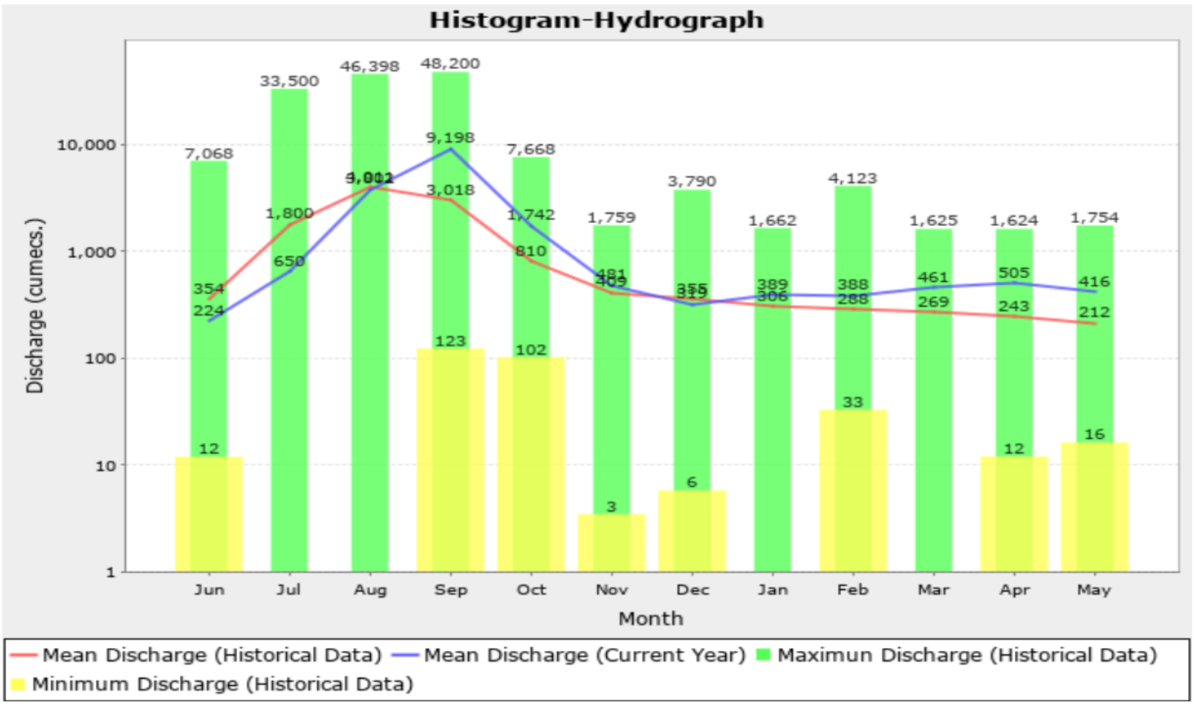


Fig-1

ANNUAL RUNOFF VALUES FOR THE PERIOD (2000 – 2020):

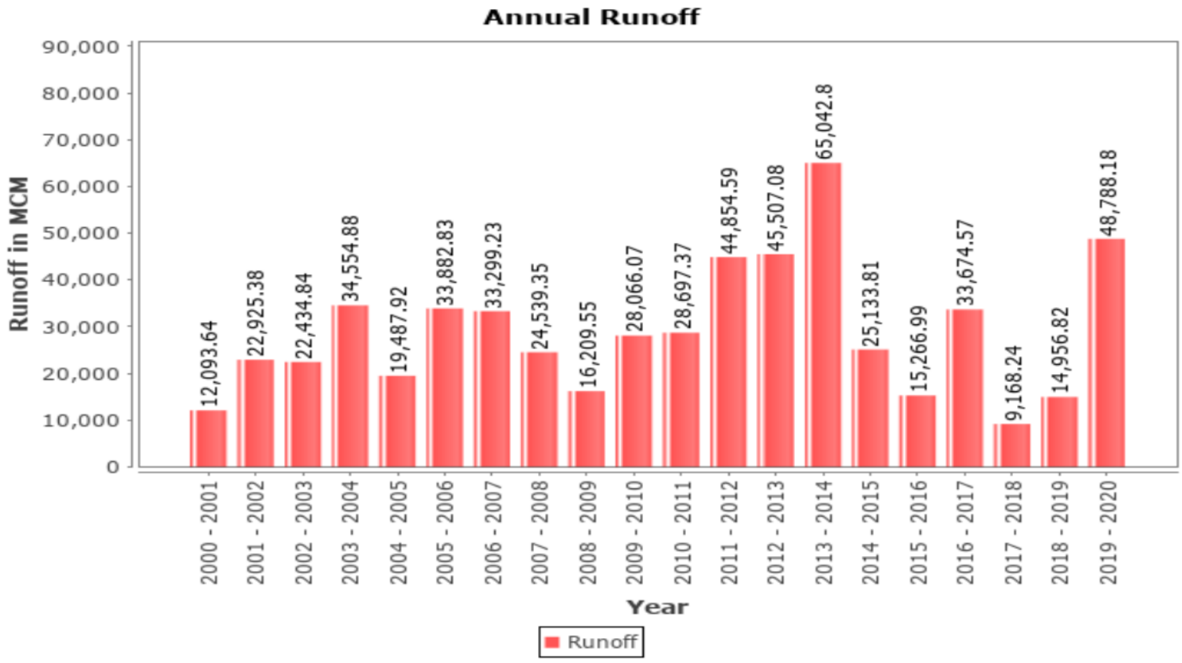
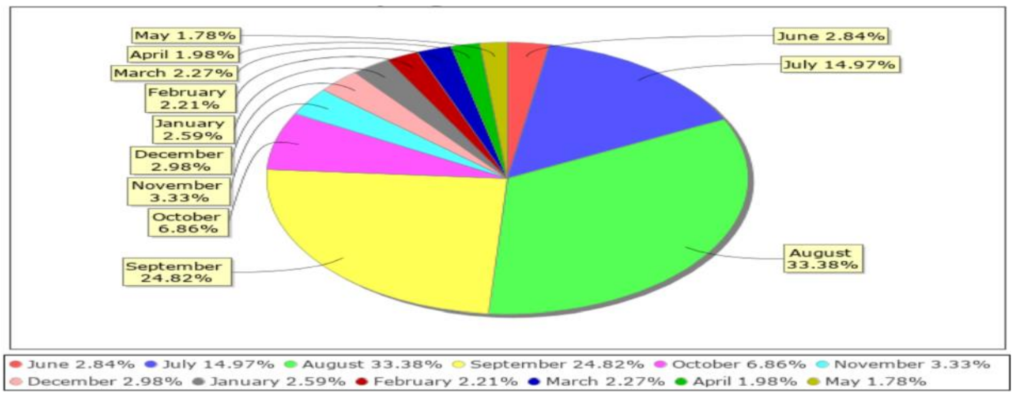


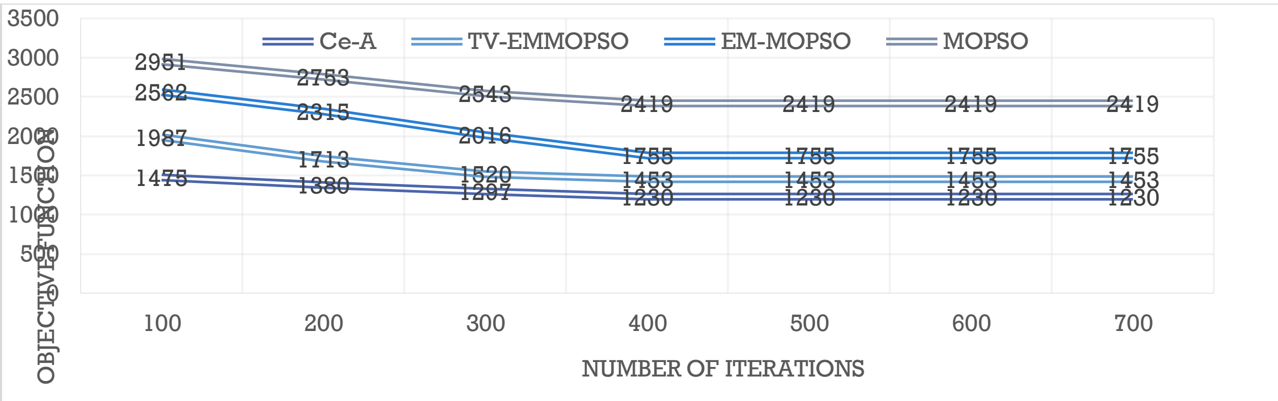
Fig-2

MONTHLY AVERAGE RUNOFF BASED ON PERIOD (1972 – 2020):

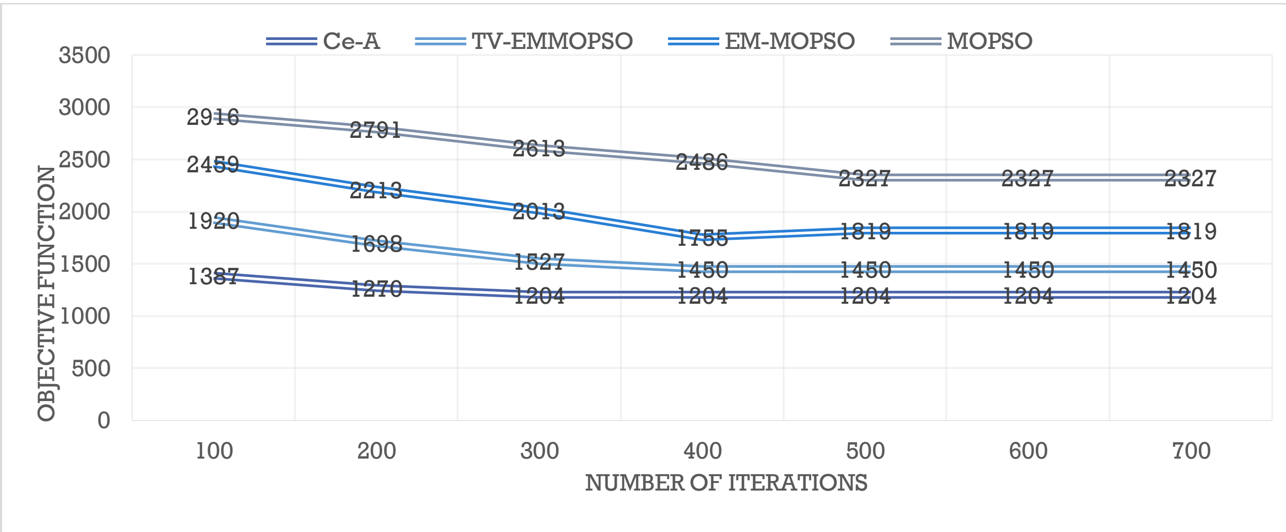


2. RESULTS AND CONCLUSION

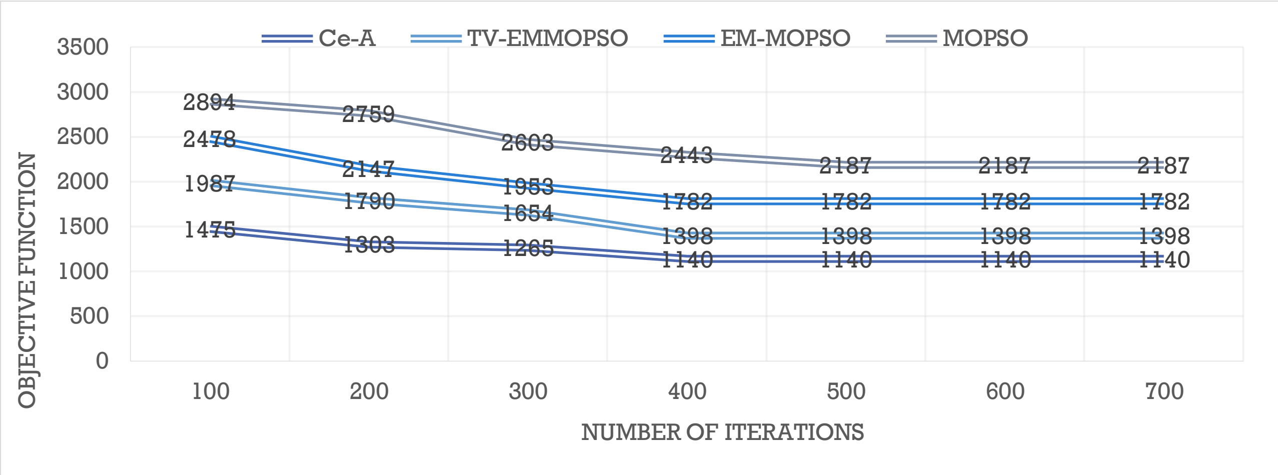
YEAR	MOPSO	EMMOPSO	TV-EMMOPSO	CELLULAR AUTOMATA	CONTINUTY EQUATION	%REDUCED			
						MOPSO	EMMOPSO	TV-EMMOPSO	CELLULAR AUTOMATA
2016-17	2419	1755	1453	1230	11446	78.86	84.66	87.30	89.25
2018-19	2327	1819	1450	1204	10408	77.64	82.52	86.06	88.43
2020-21	2187	1782	1398	1140	10408	78.98	82.89	86.56	89.04



PLOT BETWEEN OBJECTIVE FUNCTION AND NO. OF ITERATIONS FOR 2016-17



PLOT BETWEEN OBJECTIVE FUNCTION AND NO. OF ITERATIONS FOR 2018-2019



PLOT BETWEEN OBJECTIVE FUNCTION AND NO. OF ITERATIONS FOR 2020-2021

REFERENCES

[1] (PDF) optimal solution of large-scale reservoir-operation problems: cellular-automata versus heuristic-search methods (researchgate.Net)

[2] Https://ieeexplore.Ieee.Org/abstract/document/9335575

[3] Https://ascelibrary.Org/doi/abs/10.1061/(asce)wr.1943-5452.0001312

[4] Sreenevasan, K. R. and Vedula, S. (1995). “Reservoir operation for hydropower optimization:A chance constrained approach.” Department of Civil Engineering, Indian Institute of Science Banglore, Vol.21, part4, pp. 503-510.

[5] Liu, B. and Odanaka, T. (2000). “Dynamic Fuzzy criterion model for Reservoir Operations: A case study.” Computers and Mathematics with Applications, Vol. 37, pp. 65-75.

[6] Ndiritu, J.G. (2003). “Reservoir system optimization using a penalty approach and a multi-population genetic algorithm.” Vol. 29,pp. 273-280.

[7] Kumar, D.N. and Reddy, M.J. (2006). “Ant Colony Optimization for Multi-Purpose reservoir Operation.” Water resources Management, Vol. 20, pp.879-898.

[8] Jana, N. D. Si, T. &Sil, J. (2012). “Particle Swarm Optimization with Adaptive in Mutation in Local Best of Particles.” International congress on Informatics, Environment, Energy and Applications, Vol. 38.

[9] Using cellular automata approach to optimize the hydropower reservoir operation of folsom dam erfan goharian 1,2, *, mohammad azizipour 3, samuel sandoval-solis 2 and graham fogg 2

[10] Daraine, A.B., and Moradi, A.M. (2009). “Reservoir Operating by Ant Colony Optimization for Continuous Domain (ACOR) Case Study: Dez Reservoir.” International Journal of Engineering and Applied Sciences, Vol.5, pp. 406-410.

[11] Cheng, C.T., Wang, W.C. and Chau, K.W. (2008). “Optimizing Hydropower reservoir Operation using Hybrid Genetic Algorithm and Chaos.” Water Resources management, Vol.22, pp. 895-909.