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Optimization of Resource Allocations to Maximize Benefit Cost Ratio of the Irrigation System

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Abstract: Water resources projects are very complex in nature, requires huge financial investment and requires to consider socioeconomic, political, environmental aspects apart from technical aspects. There are many techniques evolved over the years to solve complex water resource problems. Pimpalgaon Dhale medium irrigation project system is considered in this project is located in Barshi taluka of Solapur district. It is planned to irrigate an ICA of 2400 ha of 6 villages namely Pimpalgaon, Pangaon, Yawali, Sakat, Undegaon and Irle. Dam is completed in 2008 however distribution system is still incomplete. The system is optimized to calculate maximize net benefit from the crops subjected to various constraints (viz. water availability, land availability, male and female labour availability, capital availability etc,). Single objective linear programming model is formulated and constraints are written and solver program of MS excel is used to derive maximum net benefit from the irrigation system under consideration. Benefit Cost ratio is calculated and compared it with that calculated adopting conventional methodology. The data required for model formulation is adopted from various sources such as Government reports/ documents, reports available on websites, research papers etc. The constraints such as capital availability within irrigation system during kharif and rabi season, female labour hours availability during kharif and rabi season limits the area under crops as well as net benefits however there is substantial increase in area under irrigation and net benefits from the irrigation system. The Solver program of MS Excel is very useful and convenient to use for solving linear programming.
Keywords: Water Resource Projects, Maximize net benefit, Benefit Cost Ratio, Linear programming.,

I. INTRODUCTION

Rainfall in the Maharashtra State is highly variable with respect to space and time. More than 50 % area of the state is drought prone and more than 50% population in the state is depend on Agriculture for their livelihood.

Due to variation in rainfall pattern, topographical limitations, various tribunal awards in relation to sharing of interstate river water etc, out of 225 lakh hectare cultivable command area, only 85 Lakh hectare area can be brought under irrigation through surface water. Since formation of State substantial progress has been made by the state in irrigation and hydropower. Large number of major, medium, minor irrigation projects are constructed in the State. As per CWC guidelines (2010), Benefit Cost Ratio of Irrigation projects is calculated to check viability of project (It shall be greater than 1.5 except for drought prone area, where it is 1). Net incremental benefits from Agricultural produce, hydropower, fishery, tourism, etc are benefits whereas capital cost, interest thereon, administrative charges, operation and maintenance charges etc. are the cost components. Agricultural produce is the main benefit from irrigation system based on cropping pattern (type of crops and their percentages indifferent seasons) recommended by Agricultural department. Maximum benefits from the irrigation system and Maximum area under each crop are the main objectives and needs to be worked out considering various constrains viz. available water, cost of seeds, fertilizers, pesticides, labour availability etc. Linear programming model is one of the simplest model that can be formulated and serves the purpose. Solver in Microsoft Excel can be used to solve the linear programming model.

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II. PROBLEM STATEMENT

Plan formulation involves finding the values of the decision variables which satisfy all constraints and which best meet the 'objectives'. One of the most important advances made in the field of water resources engineering is the development and adoption of optimization techniques for planning, design and management of complex water resources systems. Algorithm or solution procedure most appropriate for a particular constrained optimization model depends on the characteristics of the problem that is being studied and the mathematical form of the objective function and constrained equations. Any mathematical model is only an approximate description of the real water resource system.

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Linear Programming model with single objective function is used to Optimize the net benefit from the Pimpalgaon Dhale Irrigation project (Medium Irrigation Project benefitting 6 villages) located on Sira nalla, tributary of River Bhogavati- a left bank tributary of River Sina in Krishna Basin located at village Pimpalgaon, Tal. Barshi, Dist. Solapur. in satisfying the different constraints (viz. available resources, capital inputs etc.)

III. OBJECTIVES

1) To maximize net benefit from Pimpalgaon Dhale irrigation project comprising area under six villages in project command is considered.
2) To maximize area under various crops so that net benefit from the irrigation system is maximum.
3) To formulate the Linear programming model and used to finalize optimum cropping pattern to be used for the project which will give maximum benefit and hence higher BC ratio.

IV. CASE STUDY OF PIMPALGON DHALE IRRIGATION PROJECT

Pimpalgaon Dhale Irrigation project (Medium Irrigation Project benefitting 6 villages) is located on Sira nalla, tributary of River Bhogavati- a left bank tributary of River Sina in Krishna Basin located at village Pimpalgaon, Tal. Barshi, Dist. Solapur. Total catchment area upto dam site is 288 SqKm. Maximum annual rainfall is 1007 mm and minimum is 204 mm. Average annual rainfall is 609.8 mm. Reservoir having gross storage capacity 12.66 Mcum and live storage is 9.86 Mcum. Annual utilization is proposed is 14.82 Mcum. Project consists of 315 meter masonary dam and 1985 meter Earthen Dam. Ungated ogee spillway is provided. Maximum flood discharge is 2250 cumecs. Area under submergence is 623 hectare. Gross Command Area (GCA) 3323 hectare, Culturable Command Area (CCA) is 2824 hectare and Irrigable Command Area (ICA) is 2400 hectare. Project is benefiting the Drought Prone Area Developing Programme (DPAP). The project will benefit the villages namely Pimpalgaon, Sakat, Undegaon, Pangaon, Irle and Yawali.

Pimpalgaon Dhale is an ongoing project, dam is completed in 2008 and since then water is stored in the reservoir. The canal having length of 23 km is nearly completed and distribution system consisting of 12 distributaries is under construction. Rehabilitation works related to project are also nearing to completion. At present water is utilized by beneficiaries/farmers by lifting water from the reservoir. After completion of a distribution system benefits of projects will get extended to farmers by irrigating 2400 ha ICA in the command area. Proposed cropping pattern in command area is approved by Agricultural department and crops and their percentage.

In this project considering the percentage of area prescribed under different crops by an Agricultural department, area under the recommended crops is maximized and net benefit for the crops recommended is maximized considering the various constraints viz. quantum consumed in lifting water from the reservoir, constraints of reservoir capacity, canal capacity, maximum area of command available, and considering benefits for drinking water, use of water for industry etc. The results are compared with benefits estimated. Linear programming model is formulated considering two objective functions and constraints and solved using solver in Microsoft Excel.

V. LITERATURES

Since the end of world war II, operations research developed fastly and was used for investigating operational problems in many fields such as management sciences, systems analysis, water resource, transportation engineering, military science and industrial engineering. Many introductory OR textbooks, such as the one by Werner (1975), and Liberman (1990) provide good descriptions of a wide variety of OR techniques. In the field of water resources, technical papers on the application of OR techniques appear regularly in journals such as Water Resources Bulletin, Water Resources Planning and Management, Water Resources Research, Advances in Water Resources, and Water Research. Authors who have written books on the employmentof OR in water resources include Mass et al. [1962], Hall and Dracup [1970], Haimes et al. [1975], Cohon [1978], Louck et al. [1981], Chankong and Haimes [1983] and Hipel and McLeod [1992].

A. Plan Formulation

Water resources planning involves identification or development of possible water resources, systems design or management plans and evaluation of their economic, ecological, environmental, and social impacts. Mathematical model are used to identify the management plans which best meet the objectives of the community. For this purpose economic andother objectives are expressed mathematically. An important criterion for plan formulation is the economic benefit and cost. The management plan involves selection of any engineering design and operating variables called decision variables. The values that the decision variables may assume are always restricted.

Physicial, technical, legal, financial and other restrictions on the values of the decision variables can be expressed by equations known as ‘constraints’.

Plan formulation involves finding the values of the decision variables which satisfy all constraints and which best meet the ‘objectives’. This exercise is known as ‘decision making’.

Mathematical programming algorithms are used for solving constrained optimization models. During the last three decades, one of the most important advances made in the field of water resources engineering is the development and adoption of optimization techniques for planning, design and management of complex water resources systems. Algorithm or solution procedure most appropriate for a particular constrained optimization model depends on the characteristics of theproblem that is being studied and the mathematical form of the objective function and constrained equations. Any mathematical model is only an approximate description of the real water resource system.

The approximate description of the system is optimal only with respect to the particular model, not necessarily with respect to the real problem.

B. *Single-Objective Optimization Techniques:-Linear Programming Models:*

LP has been one of the most widely used techniques in water resources management. It is concerned with solvinga special type of problem: one in which all relations among the variables are linear, both in the constraints and in the objective function to be optimized.

A typical LP model isMax $z = cx$

s.t.

$(Ax)\ I \leq b_i\ x \geq 0$

In which c is a n-dimensional vector of objective function coefficients.x is n- dimensional vector of decision variables b is m- dimensional vector of the right hand sideA is m x n matrix of constraint coefficients

C. *Reservoir Management and Operations Models: A State-of-the-Art ReviewWilliam W-G. Yeh (Dec 1985)*

The objective of this paper is to review the state-of-the-art of mathematical models developed for reservoir operations, including simulation. Algorithms and methods surveyed include linear programming (LP), dynamic programming (DP), nonliner programming (NLP), and simulation. A general overview is first presented. The historical development of each key model is critically reviewed. Conclusions and recommendations for future research are presented.

D. *Optimization of Cropping pattern using Linear Programming Model for Markandeya Command AreaInternational Journal of Scientific and Engineering Research (Sep 2015)*

Proper water management is becoming a must since shortage started to cause serious problems. The United Nations is stressing on the need to gradually produce more output andtor value per unit of water. The main purpose of this study is to improve water productivity. An optimization model was developed solved by linear programming utilizing the General Algebraic Modeling System to obtain the optimum cropping pattern that maximizes revenue per unit water taking into account crop evapotranspiration, land, market and water availability as constraints. A case study was conducted in Lebanon on an area of 6700 Hectares located in South Bekaa.

E. *Optimization of resources with the aid of linear programming model in Steve Shoe production centre, Enugu, Nigeria. Osagie, Godwin Nosakhare Ph.D ,Icheme, Monday Ojochide Department of Business Administration, Ambrose Alli University, Ekpoma, Nigeria (2018)*

This paper studied the optimization of resources with the aid of linear' programming model in Steve Shoe Production Centre (SSPC), Enugu. The Linear programming model is a complex mathematical tool used for solving managerial decision problems. From the researcher's observation, Steve Shoe Production Centre depended completely on trial and error method of decision making which often yielded suboptimal results. This gap brought about the need to amongst others demonstrate how the linear programming model developed in this study can assist SSPC Enugu to optimize its resources for effective output decisions.

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VI. FORMULATION OF MODEL

In this section a linear programming model is formulated to optimize net profit/benefit from the Pimpalgaon Dhale Irrigation system and to find the benefit cost ratio for the system subjected to availability of scarce resource inputs. Model also gives the area under different crops. As the conventional cropping pattern (before and after project) given is of year 1985 just before 1st administrative approval to project, and lot of change has been observed in cropping pattern of Project before completion of reservoir; now cropping pattern adopted for study (before and after project) is of Barshi LIS located in the same area.

A. *Resource Available for after Irrigation Condition*

For net benefits after irrigation condition, data regarding availability of resources such as water, capital, labour hours for kharif season is presented in table 1. and for rabi season is presented in table 2.

Table 1. Resource availability for kharif season:

Season	Water availability ha.m	Capital availability Rs.	Male labour hours available hrs.	Female labour hours available hrs.
Kharif	1197.572	191745978.5	44040	32160

Table 2. Resource availability for Rabi season:

Season	Water availability ha.m	Capital availability Rs.	Male labour hours available hrs.	Female labour hours available hrs.
Rabi	665.379	234356195.9	51408	38080

B. *Resource Requirement per Hecatre of crops is Presented as below*

Table 3. For kharif season:

Crop	Water ha. M	Capital input Rs.	Male labour hours	Female labour hours
Chillies	0.35507	65304	31.01	33.09
Hybrid jowar	0.27197	31603	21.17	19.33
Maize	0.26678	35124	21.17	19.33
Groundnut	0.2485	82458	11.33	12.58
Vegetables	0.08954	242527	31.01	33.09
Kharif sunflower	0.23225	32882	21.17	19.33
Tur	0.22856	42658	11.33	12.58

Table 4. For Rabi season:

Crop	Water ha. M	Capital input Rs.	Male labour hours	Female labour hours
Rabi Jowar	0.239	31603	21.17	19.33
Gram	0.252	34913	11.33	12.58
Rabi sunflower	0.282	36691	21.17	19.33
Vegetables	0.285	242527	31.01	33.09

Table 5 . Excel Sheet of Solver Program : (After Irrigation Condition)

Variables	
x1(Hy. Jowar)	0
x2(Maize)	0
x3(Fodder)	472.2978516
x4(Tur)	0
x5(Moog)	0
x6(Vegetables)	0
x7(Sunflower)	0
x8(Groundnut)	0
x9(Bajara)	0
x10(Paddy)	0
x11(Wheat)	0
x12(R Jowar)	0
x13(Gram)	0
x14(Sunflower)	0
x15(Vegeatbles)	698.5152018

Objective	
Maximize	₹ 30,66,69,924.89

Constraints				
1	141.6893555	<=	996.872	Water Availability in Kharif Season
2	199.3744	<=	199.3744	Water Availability in Rabi Season
3	102401731	<=	102401731	Capital Availability in Kharif season
4	89891921.32	<=	125157671	Capital Availability in Rabi season
5	14645.95638	<=	56040	Male Labour Available in Kharif Season
6	21660.95641	<=	87600	Male Labour Available in Rabi Season
7	15628.33591	<=	40320	Female Labour Available in Kharif Season
8	23113.86803	<=	63150	Female Labour Available in Rabi Season
9	1170.813053	<=	2824	Area Availability
10	0	>=	0	Non Negativity Constraints
11	0	>=	0	Non Negativity Constraints
12	472.2978516	>=	0	Non Negativity Constraints
13	0	>=	0	Non Negativity Constraints
14	0	>=	0	Non Negativity Constraints
15	0	>=	0	Non Negativity Constraints
16	0	>=	0	Non Negativity Constraints
17	0	>=	0	Non Negativity Constraints
18	0	>=	0	Non Negativity Constraints
19	0	>=	0	Non Negativity Constraints
20	0	>=	0	Non Negativity Constraints
21	0	>=	0	Non Negativity Constraints
22	0	>=	0	Non Negativity Constraints
23	0	>=	0	Non Negativity Constraints
24	698.5152018	>=	0	Non Negativity Constraints

(Solver MS Excel solution)

Model is run using solver program in MS excel and results of net benefit from the system and area under crops is presented in table 5.

Net benefit from the system = Rs. 657,932,482.12

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F. Optimal Cropping Pattern

Table 5. For Kharif season:

Area allocated in ha.						
Chillies	Hybrid jowar	Maize	Groundnut	Vegetables	Kharif sunflower	Tur
-	399.42	-	-	738.57	-	-

Table 6: For Rabi season:

Area allocated in ha.			
Rabi jowar	Gram	Rabi sunflower	Vegetables
406.50	-	-	913.34

For before irrigation condition, data regarding availability of resources such as water, capital, labour hours for kharif season is presented in Table 7 and for rabi season is presented in Table 8.

G. Resource Available for before Irrigation Condition

Table 7: For kharif season:

Season	Water availability ha.m	Capital availability Rs.	Male labour hours available hrs.	Female labour hours available hrs.
Kharif	996.872	102401731	56040	40320

Table 8 : For Rabi Season

Season	Water availability ha.m	Capital availability Rs.	Male labour hours available hrs.	Female labour hours available hrs.
Rabi	199.3744	125157671	87600	63150

H. Resource Requirement per hecatre of Crops

Table 9: For kharif season

Crop	WaterHa. M	Capital inputRs	Male labourHrs	Female labourhrs
Jowar	0.27197	17852	21.17	19.33
Maize	0.26678	17009	21.17	19.33
Fodder	0.3000	216816	31.01	33.09
Tur	0.22856	17692	11.33	12.58
Moong	0.22856	24913	11.33	12.58
Vegetables	0.08954	128690	31.01	33.09
Sunflower	0.09025	22128	21.17	19.33
Groundnut	0.2485	22669	11.33	12.58
Bajara	0.3800	10234	21.17	19.33
Paddy	0.6000	14393	21.17	19.33

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Table 10: For Rabi Season

Crop	Waterha. m	Capital inputRs.	Male labourHrs	Female labourhrs
Wheat	0.500	16377	21.17	19.33
Rabi jowar	0.239	17221	21.17	19.33
Gram	0.252	22658	11.33	12.58
Sunflower	0.282	22128	21.17	19.33
Vegetables	0.285	128690	31.01	33.09

Table 11. Excel Sheet of Solver Program : (After Irrigation Condition)

Variables	
x1(Hy. Jowar)	0
x2(Maize)	0
x3(Fodder)	472.2978516
x4(Tur)	0
x5(Moog)	0
x6(Vegetables)	0
x7(Sunflower)	0
x8(Groundnut)	0
x9(Bajara)	0
x10(Paddy)	0
x11(Wheat)	0
x12(R Jowar)	0
x13(Gram)	0
x14(Sunflower)	0
x15(Vegeatbles)	698.5152018

Objective	
Maximize	₹ 30,66,69,924.89

Constraints				
1	141.6893555	<=	996.872	Water Availability in Kharif Season
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20	0	>=	0	Non Negativity Constraints
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I. Optimal Cropping Pattern

Table 12: For Kharif season crops

Area allocated in ha									
Jowar	Maize	Fodder	Tur	Moong	Vegetables	Sunflower	Groundnut	Bajara	Paddy
-	-	472.30	-	-	-	-	-	-	-

Table 13: For Rabi season crops

Area allocated in ha				
Wheat	Rabi jowar	Gram	Sunflower	Vegetables
-	-	-	-	698.52

VII. CALCULATION OF BENEFIT COST RATIO FOR IRRIGATION SYSTEM:

Table 14: BC Ratio Calculations

Sr no.	Particulars	Amount in Rs.	Remarks
A	Total Cost of the project (2021-22)	Rs. 1713280000	-
B	Annual Benefits		-
	Gross Value of produce under irrigated condition	Rs. 657,932,482.12	-
	Deductions		-
	Gross Value of produce under non irrigated condition	Rs. 306,669,924.90	-
	Annual Benefits	Rs. 351,262,557.22	-
C	Annual Cost of the project		-
	a) Simple Interest @ 10% of capital cost	Rs. 171328000	-
	b) Depreciation Charges 1%	Rs. 17132800	-
	c) Administrative charges @ Rs. 300/ Ha	Rs. 720000	-
	d) Maintenance charges 1% of headwork	Rs. 12241385.6	-
	Total Annual Cost	Rs.201422185.6	-
			-
	B.C. Ratio = Annual Benefit/ Annual Cost =	1.74	-

Net annual benefit from the system = Net annual benefit after irrigation – Net annual benefit before irrigation =Rs.351,262,557.22
Annual cost of the project = Rs. 201,422,185.6
Benefit Cost ratio = Annual beneft/Annual cost = 351262557.22 / 201422185.6 = 1.74

VIII. RESULT AND DISCUSSION

1) Pimpalgaon Dhale medium irrigation project system is considered in this project is located in Barshi taluka of Solapur district. It is planned to irrigate an ICA of 2400 ha of 6 villages namely Pimpalgaon , Pangaon, Yawali, Sakat, Undegaon and Irle. Dam is completed in 2008 however distribution system is still incomplete.
2) The system is optimized to calculate maximize net benefit from the crops subjected to various constaints (viz. water availability, land availability, male and female labour availability, capital availability).
3) Single objective linear programming model is formulated and constraints are written and solver program of MS excelis used to optimize (maximize benefit).
4) The various coefficients used in the objective function are taken from study material of water resource department of GoM.
5) The coefficients of constraints and resource availability is obtained through Government documents/ Reports, Researchpapers available on websites.

6) Two scenarios viz., net benefits of the system before irrigation project and after irrigation project are considered both conventially (as documented in the report) as well as obtained through model formulation and solving it using Solver program of MS excel.
7) The cost of the project (based on 2017-18 price) documented in the project report is escalated @ 6% per annum to bring it to the price of 2020-21. The depreciation, administrative charges, maintenance charges , simple interest etc are considered for calculating annual cost.
8) Benefit Cost ratio calculated for project by adopting conventional approach is 1.18. The BC ratio calculated by formulating model and linking it to resources is 1.74.
9) In conventional approach, 9 different crops with their percentages amounting total area 2400 ha were considered in calculating net benefit before irrigation project by authority in their report. Under irrigation condition 16 different crops with their percentages amounting total area 1410 were considerd in calculating benefits. The BC ratio works out to be 1.18 by authority.
10) Single objective linear programming model formulated in this project with cropping patterns before and after irrigation from other scheme(Barshi LIS) are considered. The 15 different crops were considered in the model formulation to obtain net benefit before irrigation . The 2824 ha land availability(CCA) was considered for land constraint. Model output gives 1170 ha area under two crops (Fodder – 472.30 ha kharif crop and vegetables – 698.52 ha rabi crop) by satisfying all the resource availability constraints. Thus number of crops and overall area under the crops is decreased however benefits are increased. Under irrigation condition 11 different crops were considered in the model formulationto obtain net benefit after irrigation. The 2824 ha land availability (CCA) was considered for land constraint. Model output gives 2457ha (ICA) area under four crops (Hybrid Jowar-399.42 ha, Vegetables- 738.57 ha in kharif season and Rabi Jowar-406.50 ha , Vegetables- 913.34 ha in rabi season) by satisfying all the resource availability constraints. Thus number of crops were reduced from 16 to 4,however area under the crops were increased to 2457 ha against 1410 ha.There is substaintial increase in net benefits. The BC ratio works out to be 1.74.
11) Model output also shows that there is a shortage of water during rabi season and also shows shortage of capital during kharif season for maximizing benefits before irrigation. This puts limitations on area and benefits derived. Model output shows considerable increase in area under the crops due to reservoir/ assured water during kharif and rabi i.e. scenario after irrigation. However entire CCA of 2824 ha cannot be brought under irrigation due to limited capital availability with farmers/ within system during both kharif and rabi season and also less number of female labour hours availability during both seasons.
12) The model formulation do not consider reservoir balance equation , canal capacity constraints fortnight requirements of area during rotations etc. due to non availability of data and considers model formulation as a resource allocation formulation. This is a limitation of the study.

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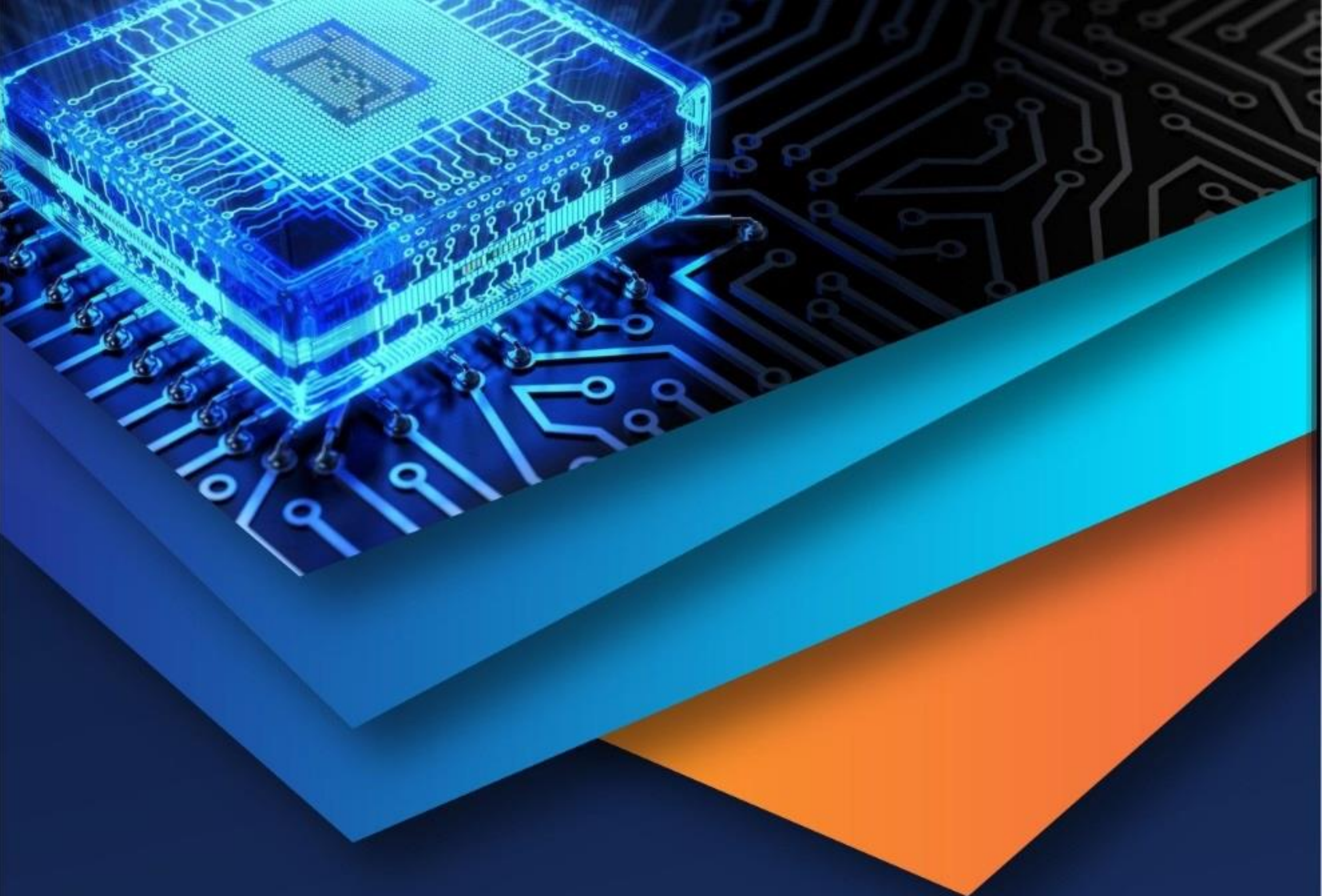

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ISRA JIF IMPACT FACTOR: 7.129

SJIFactor TOGETHER WE REACH THE GOAL IMPACT FACTOR: 7.429

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