International Journal of Recent Engineering Science
ISSN: 2349-7157/ https://doi.org/10.14445/23497157/IJRES-V12I3P104

Volume 12 Issue 3, 26-34, May-Jun 2025

Original Article

Strategic Decision Making for Multi-Purpose River Basin Projects: A Game Theory Approach to Resource Allocation in the Anambra-Imo River Basin

Ikenna Chukwudi Nwabugwu[1], Luke Chika Eme[2]

[1,2]*Department of Civil Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State, Nigeria.*

[1]*Corresponding Author : nwabugwuikenna@gmail.com*

Received: 31 March 2025 Revised: 05 May 2025 Accepted: 23 May 2025 Published: 12 June 2025

Abstract *- The Anambra-Imo River Basin Multi-purpose water resources project requires strategic and optimized resource management in order to maximize benefits across key sectors, including Irrigation agriculture, hydroelectric power generation, and water supply. This study employs a Game Theory model to develop a resilient framework for strategic resource allocation in the face of uncertainty. A mixed-strategy approach was employed, integrating probability-based decision making with the linear programming simplex method to identify optimal strategies. The result shows a game value 5.81, which lies between the Maximin (4.36) and Minimax (6.77) values, confirming the effectiveness of strategic resource allocation. Based on this framework, a total capital allocation of ₦16.834 billion (Spanning 2016–2021) has the possibility of generating a potential benefit of ₦97.80554 billion, yielding a surplus of ₦80.97154 billion for reinvestment in developmental and maintenance projects within the basin. Even under borrowing conditions with a 6% interest rate over five years, the project maintains a profit margin of ₦75.2778 billion. These findings show that applying the Game Theory model to river basin management yields substantial financial benefits while advancing sustainable development and enhancing resilience to climate variability. The study highlights the importance of Game Theory models in the optimization of resource allocation, financial returns, and integrated planning to address sustainable development goals in multi-purpose water resource projects.*

Keywords *- Game Theory, Multi-purpose river basin project, Optimization, Resource allocation, Strategic Decision Making.*

1. Introduction

Effective water resource management is essential for sustainable development, particularly in regions like Nigeria, where river basins perform diverse functions, including irrigation agriculture, hydropower electric generation, water supply, and environmental conservation. The multi-purpose Anambra-Imo River Basin project is a good example of such multifaceted initiatives designed to address a range of water resource-related problems through integrated water resource development. However, managing these types of complex systems usually comes with significant challenges, especially when it comes to reconciling conflicting stakeholder interests and dealing with uncertainties associated with environmental and socio-economic factors.

Over the years, traditional management approaches have often failed to address the strategic interaction among diverse stakeholders, leading to inefficient resource allocation and increased potential conflicts. In this context, Game Decision Theory serves as a powerful mathematical framework designed for analyzing strategic interactions among rational decision-makers. Game Theory was originally formalized by Von Neumann and Morgenstern (1944) and further developed by Nash (1951) and has immensely contributed to the evaluation of both competitive and cooperative behaviors across various domains. In water resource management, particularly within shared or transboundary river basins, Game Theory offers structured methods of simulating and analyzing outcomes under different scenarios of decision-making.

Having said that, it is important to note that despite its proven potential, the application of the Game Decision Theory model in the management of river basins in Nigeria remains relatively limited.

In their study, Eme (2015) and Ekwueme & Aronu (2023) demonstrated the utility of game-theoretic models in specific basins, yet a comprehensive, integrated approach is still lacking. This gap shows that there is a need to carry out further research to develop a holistic blueprint of the game-

Theoretical frameworks that can address the multifaceted objectives and stakeholders involved in Nigeria's river basin management.

This study aims to bridge these existing gaps by developing a Game Theory-based decision-making framework that will incorporate optimization techniques in resource allocation and conflict resolution in the Anambra-Imo River Basin project. Considering the multiple objectives and the difference in stakeholder preferences, the novelty of this work lies in the holistic approach, considering multiple objectives and their potential to enhance financial returns while promoting sustainable development.

2. Literature Review

2.1. Evolution of Game Theory in Water Resource Management

Game Theory has emerged as an influential framework for the analysis of strategic decision-making in the management of water resources, where divergent interests often exist between stakeholders. Initial applications of the Game Theory Model in this field focused on cooperative models, such as the Shapley values and negotiation games, to ensure fair water resource allocation (Madani, 2010). These frameworks seek to optimize the collective welfare while also considering the interests of individual stakeholders. Additionally, non-cooperative game models, including Nash equilibrium, have been widely used in analyzing the competitive dynamics of water resource allocation among various stakeholders (Dinar et al., 1997). The integration of game theory into water resources management has shown significant insight into understanding the dynamics of stakeholders' behaviours and the allocation of resources, offering solutions that enhance sustainability (Ostrom, 1990).

2.2. Applications in River Basin Projects

The application of Game Theory in river basin management focuses on resolving conflicting issues related to water resource allocation, improving the cooperation that exists among stakeholders, and optimizing resource distribution. Studies such as Ohaji (2019) have illustrated the effectiveness of game-theoretic models in addressing funding allocation challenges in river basin development. By incorporating game-theoretic strategies, the resolution of conflicts between competing stakeholders, such as governments, industries, and local communities, has become possible while optimizing the allocation of both financial and natural resources. Additionally, other research (Lee & Lee, 2013) has demonstrated the utility of Game Theory in modeling cooperative behaviors between countries sharing transboundary river basins, highlighting Its potential is in promoting international collaboration for equitable water resource management.

2.3. Integration with Optimization Techniques

The combination of Game Theory with optimization methods, such as linear programming and multi-objective optimization, has significantly gained attention in the management of water resources (Huang et al., 2008). This integrated method models the strategic interactions of stakeholders and, at the same time, addresses the complexity of managing multiple, often conflicting, objectives. For instance, optimization methods have been combined with Game Theory to maximize social welfare while respecting individual stakeholders' preferences and constraints (Tang et al., 2017). The development of integrated models that combine game-theoretic solutions with optimization frameworks has proven especially beneficial in multi-stakeholder scenarios, where the goal is to find win-win solutions to complex allocation problems (Zhang & Wang, 2015).

2.4. Addressing Uncertainty and Dynamic Environments

Recent Game Theory innovations have introduced significant mechanisms to address elements of uncertainty and dynamic environments, factors inherent in water resource management. Stochastic game theory models, which integrate random variables such as temperature patterns, rainfall variability and economic fluctuations, have continuously provided Real-world solutions (Bhat et al., 2018). Moreover, dynamic game models that account for evolving stakeholder preferences and environmental conditions over time have been designed to better represent the complexities of real-world water management systems (Zhao et al., 2019). These methods are particularly essential in terms of climate change, where uncertainties surrounding the availability and demand for water require adaptive planning strategies to maintain long-term sustainability (Rogers et al., 2002).

2.5. Challenges and Future Directions

Game Theory has demonstrated substantial potential in water resource management. However, challenges persist, particularly in terms of practical implementation. The conversion of theoretical frameworks into practical policies remains a significant obstacle, especially in regions with limited data availability and where stakeholder engagement is often weak (Rogers et al., 2002). Additionally, the complex nature of water systems, combined with the presence of multiple, often conflicting objectives, requires the development of more sophisticated and adaptable game-theoretic models (Madani & Dinar, 2012). Future research is expected to focus more on improving the accuracy of models, improving data collection methods, and developing

A decision-support framework that helps policymakers to effectively implement game-theoretic strategies (Huang et al., 2020). Furthermore, Ostrom (1990) stated that greater attention will be given to fostering stakeholder collaboration to ensure that game-theoretical models are accepted and implemented in practice.

3. Materials and Methods

The methodology employed in this research involves the application of the Game Decision Theory model to analyze available data and optimize the benefits of multi-purpose river basin projects. The primary data were sourced from the Bill of Engineering Measurement and Evaluation (BEME), supplemented with descriptive analysis, experimental model design, simulation modeling, correlation, and regression analysis to construct and validate the decision-making framework.

3.1. Experimental Model Size

The experimental model defines the sample size for developing an optimal resource allocation framework for the Anambra-Imo River Basin as a climate change adaptation strategy.

The independent variables represent the development of key sectors, including (i) Irrigated agriculture, (ii) Hydroelectric power generation, (iii) Water supply, (iv) Navigation, (v) Drainage/Dredging, (vi) Flood control, (vii) Recreation/Tourism, (viii) Erosion control, (ix) Plantation/Forestry, and (x) Reservoir/Gullies.

The dependent variables reflect the intended objectives of the project, otherwise known as benefits, including (i) Economic efficiency (optimization), (ii) Federal economic redistribution, (iii) Regional economic redistribution, (iv) State economic redistribution, (v) Local economic redistribution, (vi) Social well-being, (vii) Youth empowerment, (viii) Environmental quality improvement, (ix) Gender equality, and (x) Security improvement.

The game theory model, with probabilistic decision-making and linear programming methods of optimization, was used to determine the most effective strategies (Optimal Strategies) for allocating resources under competitive and uncertain conditions.

3.2. Simulation Modeling Solution Techniques

Simulation modeling was employed to analyze and compute the data derived from the Bills of Engineering Measurement and Evaluation (BEME). The datasets were structured to form a 10 × 10 matrix, which represents the relationship between the various purposes (independent variables) and objectives (dependent variables) and the corresponding net benefits. This matrix was used to simulate strategic decision-making scenarios, which helped.

In identifying optimal strategies through the application of mixed-strategy probability modeling and the simplex method of linear programming.

4. Results and Discussion

4.1. Analysis of the Game Theory Model in Relation to Net Benefits

The value of the Net benefit for the various purposes and objectives is summarized in Table 1 below. These data were generated from the Bill of Engineering Measurement and Evaluation (BEME) and subsequently used to determine the value of the game where Player A (for Purposes) and Player B (for Objectives). In this situation, the gain of one player is equal to the loss of another player.

Therefore, both players A and B are represented as stated below:

Player A = A1, A2, A3, A4, A5, A6, A7, A8, A9 and A10.

Player B = B1, B2, B 3, B 4, B5, B6, B7, B8, B9 and B10

Table 1. Summary of Net Benefits for all Objectives in Relation to Their Purposes (Billion Naira)

S/N	Purpose	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}
(a)	Irrigated Agriculture	4.65	5.84	7.36	4.60	4.44	5.37	5.05	5.22	2.12	9.73
(b)	Hydroelectric power generation	14.38	8.55	10.60	10.68	10.29	6.46	7.05	7.39	2.37	10.95
(c)	Water Supply	5.54	5.34	7.04	4.78	4.52	5.56	5.22	5.37	2.13	10.13
(d)	Navigation	9.30	6.83	11.46	9.19	9.24	12.39	11.96	13.20	4.33	26.77
(e)	Drainage/ Dredging	18.21	7.01	13.26	4.68	7.08	9.96	12.51	11.83	4.00	22.96
(f)	Flood Control	20.43	6.58	11.20	4.39	2.55	9.68	11.32	12.35	3.90	23.12
(g)	Recreation/ Tourism	17.93	4.94	11.36	4.42	4.33	11.57	12.33	13.25	4.33	26.94
(h)	Erosion Control	14.91	4.01	11.27	4.15	4.26	10.56	8.13	9.72	3.21	17.78
(i)	Plantation/ Forestry	15.01	7.83	9.08	7.40	7.59	9.96	8.66	9.40	3.26	19.08
(j)	Reservoir/ Gullies	83.72	6.66	13.16	4.36	4.48	20.99	21.54	21.71	6.77	42.23

4.1.1. Discussion of Results in Table 1

- Table 1 shows the summary of the calculated result of the Net Benefit in Billion Naira extracted from the Bill of Engineering Evaluation (BEME).
- Where: B1 = Economic Efficiency, B2 = Federal Economic Redistribution, B3 = Regional Economic Redistribution, B4 = State Economic Redistribution, B5 = Local Economic Redistribution, B6 = Social Well-Being, B7 = Youth Empowerment, B8 = Environmental Quality Improvement, B9 = Gender Equality, B10 = Security.
- In the Purpose of Irrigated Agriculture, the analysis shows that Security has the highest Benefit amount with N9.73 billion Naira. On the other hand, the least benefit is Gender Equality, N2.12 billion Naira. In the same vein, Hydro Electric.
- For the Purpose of Reservoirs and Gullies, the highest benefit recorded of N92.72 billion under the Objective of Economic Efficiency, and the lowest was from the Objective of State Economic Redistribution with N4.36 billion.
- However, from the other purposes, the highest Net Benefits are from the Objectives of Security, with Water Supply having N10.13 billion, N26.77 billion from Navigation, N22.96 billion from Drainage/Dredging, Flood Control having N23.12 billion, N26.94 billion from Recreation/Tourism, Erosion Control with N17.78 billion and Plantation/Forestry with N19.08 billion.
- In the same vein, the Objectives with the Lowest Net Benefits were from Gender Equality, with the following N2.13 billion from Water Supply, Navigation N4.33 billion, Drainage/Dredging N4.00 billion, Flood Control N3.90 billion, Recreation/Tourism N4.33 billion, Erosion Control N3.21 billion and Plantation/Forestry with N3.26 billion.

4.2. Determination of Probabilities for Multi-purpose/Multi-Objectives of Player A and Player B

Table 2. Game Theory model analysis based on the net benefits

	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	Minimum
A_1	4.65	5.84	7.36	4.60	4.44	5.37	5.05	5.22	2.12	9.73	**2.12**
A_2	14.38	8.55	10.60	10.68	10.29	6.46	7.05	7.39	2.37	10.95	**2.37**
A_3	5.54	5.34	7.04	4.78	4.52	5.56	5.22	5.37	2.13	10.13	**2.13**
A_4	9.30	6.83	11.46	9.19	9.24	12.39	11.96	13.20	4.33	26.77	**4.33**
A_5	18.21	7.01	13.26	4.68	7.08	9.96	12.51	11.83	4.00	22.96	**4.00**
A_6	20.43	6.58	11.20	4.39	2.55	9.68	11.32	12.35	3.90	23.12	**3.90**
A7	17.93	4.94	11.36	4.42	4.33	11.57	12.33	13.25	4.33	26.94	**4.33**
A8	14.91	4.01	11.27	4.15	4.26	10.56	8.13	9.72	3.21	17.78	**3.21**
A9	15.01	7.83	9.08	7.40	7.59	9.96	8.66	9.40	3.26	19.08	**3.26**
A10	83.72	6.66	13.16	4.36	4.48	20.99	21.54	21.71	6.77	42.23	**[4. 36]**
Maximum	83.72	8.55	13.26	10.68	10.29	20.99	21.54	21.71	[6.77]	42.23	

4.2.1. Discussion of Results in Table 2

- Table 2 shows the Maximin Value 6.77 and the Minimax Value 4.36.
- Table 2 above shows the determination of the Optimal difference of 2.41 exists when subtracting the Maximin from the Minimax. This analysis shows no saddle point based on the Net Benefits analysis. Therefore, the linear programming method of the game theory model is used for the analysis. Solution of the Game decision theory model for Player iA. iv. Based on the above submission, a matrix was developed to Moreover, Player B was done by analyzing the above table, where the Maximin Value (6.77) and Minimax Value (4.36) of the Net Benefit Table are shown 4 .
- The table above shows that the Maximin Value (6.77) and Minimax Value (4.36) are unequal. A determine the probabilities for the multi-purpose/multi-objective of Player A and B.

4.3. Determination of Probabilities for Multi-purpose/Multi-Objectives of Player A and Player B

Table 3. Determination of probabilities for multi-purpose/multi-objectives of Player A and Player B

Player	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8	B_9	B_{10}	Probability
A_1	4.65	5.84	7.36	4.60	4.44	5.37	5.05	5.22	2.12	9.73	q_1
A_2	14.38	8.55	10.60	10.68	10.29	6.46	7.05	7.39	2.37	10.95	q_2
A_3	5.54	5.34	7.04	4.78	4.52	5.56	5.22	5.37	2.13	10.13	q_3
A_4	9.30	6.83	11.46	9.19	9.24	12.39	11.96	13.20	4.33	26.77	q_4
A_5	18.21	7.01	13.26	4.68	7.08	9.96	12.51	11.83	4.00	22.96	q_5
A_6	20.43	6.58	11.20	4.39	2.55	9.68	11.32	12.35	3.90	23.12	q_6
A_7	17.93	4.94	11.36	4.42	4.33	11.57	12.33	13.25	4.33	26.94	q_7
A_8	14.91	4.01	11.27	4.15	4.26	10.56	8.13	9.72	3.21	17.78	q_8
A_9	15.01	7.83	9.08	7.40	7.59	9.96	8.66	9.40	3.26	19.08	q_9
A_{10}	83.72	6.66	13.16	4.36	4.48	20.99	21.54	21.71	6.77	42.23	q_{10}
Prob.	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_8	P_9	P_{10}	

4.4. The Optimal Linear Programming Solution Using the Simplex Method for Achieving the Objectives in the Anambra-Imo River Basin

The optimal solution was derived through successive iterations starting from the initial Simplex tableau, using MATLAB and Visual Basic computer software. The outcome of the Linear Programming simulation, which presents the optimal strategies for both Player A and Player B, is displayed below:

4.4.1. For Player B

$X_1 = 0.012$, $X_2 = 0.019$, $X_3 = 0.017$, $X_4 = 0.014$, $X_5 = 0.023$, $X_6 = 0.018$, $X_7 = 0.013$, $X_8 = 0.021$, $X_9 = 0.015$, $X_{10} = 0.020$

0.012 +0.019 +0.017 +0.014 +0.023 +0.018 +0.013 +0.021, +0.015, +0.020 = 0.172.

Therefore, $Zp = 0.172 = \frac{1}{V}$

$$Zp = 0.0172 = \frac{1}{V} = V = \frac{1}{zp} = \frac{1}{0.172} = 5.81$$

Based on the Net Benefit Table presented above, the value of the game, denoted as V, is expected to lie within the range defined by the Maximin value of 4.35 and the Minimax value of 6.76. The computed value of V = 5.81 falls within this interval, thereby confirming the accuracy and reliability of the simulation results. Consequently, by converting the solution values back into the original decision variables, we obtain the following:

$$X_n = \frac{P_n}{V}, P_n = X_n V$$

From the above formula, we have n = 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, therefore, the result is shown in Table 4 below:

Table 4. Results of the Converted Solution into the Original Variables for Player B

p	$X \times V$	$Y \times V$	Results
p_1	$X_1 \times V$	= 0.012×5.81	= 0.06972
p_2	$X_2 \times V$	= 0.019 ×5.81	= 0.11093
p_3	$X_3 \times V$	= 0.017 ×5.81	= 0.09877
p_4	$X_4 \times V$	= 0.014 ×5.81	= 0.08134
p_5	$X_5 \times V$	= 0.023 ×5.81	= 0.13363
p_6	$X_6 \times V$	= 0.018 ×5.81	= 0.10458
p_7	$X_7 \times V$	= 0.013 ×5.81	= 0.07553
p_8	$X_8 \times V$	= 0.021 ×5.81	= 0.12201
p_9	$X_9 \times V$	= 0.015 ×5.81	= 0.08715
p_{10}	$X_{10} \times V$	= 0.020 ×5.81	= 0.1162

4.4. Discussion of Results in Table 4

Player B has the strategy of probabilities of = (0.0697, 0.1104, 0.0988, 0.0813, 0.1336, 0.1046, 0.0755, 0.1220, 0.0872, 0.1162) as shown in the table above.

4.4.1. For Player A

The optimal strategies for Player A were identified from the reduced cost row, also known as the Zj − Cj row, in the final Simplex optimization tableau. This row provides crucial information about the opportunity cost associated with each decision variable, allowing for the determination of the most advantageous strategy. The resulting optimal strategies for Player A are as follows:

$Y_1 = S_1 = 0.011$, $Y_2 = S_2 = 0.020$, $Y_3 = S_3 = 0.010$, $Y_4 = S_4 = 0.015$, $Y_5 = S_5 = 0.014$, $Y_6 = S_6 = 0.019$, $Y_7 = S_7 = 0.017$, $Y_8 = S_8 = 0.025$, $Y_9 = S_9 = 0.012$, $Y_{10} = S_{10} = 0.029$.

The total sum (Zq) = 0.011+ 0.020+ 0.010+ 0.015+ 0.014+ 0.019+ 0.017+ 0.025+ 0.012+ 0.025 = 0.0172

$$Zq = 0.0172 = \frac{1}{V} = V = \frac{1}{Z_q} = \frac{1}{0.172} = 5.81$$

This outcome aligns with the value of the game, V = 5.81, as derived from the optimal strategies for Player B. Furthermore, by translating these solution values back into their corresponding original decision variables, the resulting values are presented in Table 5 below:

Table 5. Results of the converted solution into the original variables for Player A

q	Y×V	S	Y×V	Results
q_1	$Y_1 \times V$	$= S_1$	= 0.011×5.81	= 0.0639
q_2	$Y_2 \times V$	$= S_2$	= 0.020 ×5.81	= 0.1162
q_3	$Y_3 \times V$	$= S_3$	= 0.010 ×5.81	= 0.0581
q_4	$Y_4 \times V$	$= S_4$	= 0.015 ×5.81	= 0.0872
q_5	$Y_5 \times V$	$= S_5$	= 0.014 ×5.81	= 0.0813
q_6	$Y_6 \times V$	$= S_6$	= 0.019 ×5.81	= 0.1104
q_7	$Y_7 \times V$	$= S_7$	= 0.017 ×5.81	= 0.0988
q_8	$Y_8 \times V$	$= S_8$	= 0.025 ×5.81	= 0.1455
q_9	$Y_9 \times V$	$= S_9$	= 0.012 ×5.81	= 0.0697
q_{10}	$Y_{10} \times V$	$= S_{10}$	= 0.029 ×5.81	= 0.1685

4.5. Discussion of Results in Table 5

Therefore, the probabilities of strategy utilization for both players are as follows:

Player A has strategy probabilities of = (0.0639, 0.1162, 0.0581, 0.0872, 0.0813, 0.1104, 0.0988, 0.1455, 0.0697, 0.1685), as shown in Table 6 above.

Player B has the strategy of probabilities of = (0.0697, 0.1104, 0.0988, 0.0813, 0.1336, 0.1046, 0.0755, 0.1220, 0.0872, 0.1162).

Consequently, the probabilities are a reflection of the likelihood of each player A or B choosing a specific strategy in a competition.

4.5.1. Allocation of Cost to the Various Purposes By Applying the Probabilities as Obtained from Iterations of Game Theory Analysis (Anambra-Imo River Basin)

The analysis above completes the application of the probabilities obtained from the iteration of the Game Theory of Optimal strategies. Let us consider the situation where the total money received for capital projects from 2016 to 2021, as collected, is ₦16.834 billion for the Anambra-Imo River basin. For such multi-purpose/multi-objective water resources development, the allocation to the Purposes and Objectives is stated in Tables 6 and 7, respectively. Consequently, for the Purposes, the optimal solution under the worst possible scenario should be as shown in Table 6:

Table 6. Cost allocation table for purposes

S/N	Purpose	Probability	Allocation (in billion Naira)
(1)	Irrigated Agriculture	q_1= 0.0639	0.0639 x 16.834 = 1.076
(2)	Hydroelectric power generation	q_2 = 0.1162	0.1162 x 16.834 = 1.956
(3)	Water supply	q_3= 0.0581	0.0581 x 16.834 = 0.978
(4)	Navigation	q_4 = 0.0872	0.0872 x 16.834 = 1.468
(5)	Drainage/ Dredging	q_5 = 0.0813	0.0813 x 16.834 = 1.369
(6)	Flood control	q_6 = 0.1104	0.1104 x 16.834 = 1.858
(7)	Recreation/Tourism	q_7= 0.0988	0.0988 x 16.834 = 1.663
(8)	Erosion control	q8 = 0.1455	0.1455 x 16.834 = 2.449
(9)	Plantation / Forestry	q9= 0.0697	0.0697 x 16.834 = 1.173
(10)	Reservoir / Gullies	q10= 0.1685	0.1685 x 16.834 = 2.837
	Total	1.0000	Total = 16.834

4.5.2. Allocation of Cost to the Various Objectives (or Benefits) By Applying the Probabilities as Obtained from Iterations of Game Theory Analysis (Anambra-Imo River Basin

The Cost allocation for the Objectives/Net Benefits uses the total amount ₦16.834 billion received by the Anambra-Imo River Basin Development Authority from the Federal Government of Nigeria for capital projects from 2016 to 2021, six. (6) period under review and applying the probabilities as obtained from the iteration of Game Theory of Optimal strategies results as shown in Table 7 below, we have:

Table 7. Cost allocation table for objectives/net benefits

S/N	Purpose	Probability	Allocation (in billion Naira)
(1)	Economic Efficiency	P_1= 0.0697	0.0697 x 16.834 = 1.173
(2)	Federal Economic Redistribution	P_2 = 0.1104	0.1104 x 16.834 = 1.858
(3)	Regional Economic Redistribution	P_3= 0.0988	0.0988 x 16.834 = 1.663
(4)	State Economic Redistribution	P_4 = 0.0813	0.0813 x 16.834 = 1.369
(5)	Local Economic Redistribution	P_5 = 0.1336	0.1336 x 16.834 = 2.249
(6)	Social Well-Being	P_6 = 0.1046	0.1046 x16.834 = 1.761
(7)	Youth Empowerment	P_7 = 0.0755	0.0755 x 16.834 = 1.271
(8)	Environmental Quality Improvement	P_8 = 0.1220	0.1220 x 16.834 = 2.054
(9)	Gender Equality	P_9= 0.0872	0.0872 x 16.834 = 1.468
(10)	Security	P_{10} = 0.1162	0.1162 x 16.834 = 1.956
	Total	**1.0000**	**Total =** 16.834

4.6. Discussion of Results in Tables 6 and 7

However, if the allocation is apportioned as shown in Tables 6 and 7 above, a Minimum of ₦16.834 x 5.81 (i.e. the value of the game) = ₦ 97.80554 billion can be achieved under the worst situation of conflicting objectives. Then, the financial benefit achievable under the worst condition = ₦16.834 x 5.81 = ₦ 97.80554 billion.

4.6.1. Discussion of Experimentation for the Strategic Decision-Making for Multi-Purpose River Basin Projects : A Game Theory Approach to Resource Allocation in the Anambra-Imo River Basin.

Using the Game Theory model to optimize the benefits of the Multi-Purpose Anambra-Imo River Basin project involves making strategic decisions under conditions of uncertainty, particularly in the context of climate variability, with the goal of maximizing gains or minimizing losses through the anticipation of potential outcomes without full knowledge of competing strategies. The results of the analysis are stated as follows:

Strategic Decision-Making Framework

Game Theory analysis was employed to develop a strategy where each "player" (stakeholder) aims to optimize their outcomes without prior knowledge of the competitor's actions. The focus is on maximizing gains or minimizing losses, particularly in scenarios influenced by climate variability. Where actions are chosen based on fixed probabilities, mixed strategies were deployed to enable players to maximize expected gains or minimize expected losses through probabilistic decision-making.

Matrix Development and Optimization

A matrix was constructed to determine the probabilities for multi-purpose objectives between Player A and B players. The probabilities for selecting strategies A1 and B1 were calculated and the linear programming simplex method was applied to find the optimal solution. Analyzing the Game Theory, the result obtained showed that the game value (V) is 5.81, which lies between the Maximin value (4.36) and Minimax value (6.77). The optimal strategies for player A were obtained from (Zj – Cj) in the reduced cost row. Similarly, Player B's strategies were determined in the exchange segment from the amount column.

Allocation of Resources Based on Game Theory Analysis

Using probabilities derived from Game Theory, the allocation of funds for various purposes was optimized, and the results are shown below. A total of ₦16.834 billion was allocated for capital projects in the Anambra-Imo River Basin over five years (2016–2021). The funds were distributed as follows:

- Irrigated Agriculture: ₦1.076 billion
- Hydroelectric Power Generation: ₦1.956 billion
- Water Supply: ₦0.978 billion
- Navigation: ₦1.468 billion
- Drainage/Dredging: ₦1.369 billion
- Flood Control: ₦1.858 billion
- Recreation/Tourism: ₦1.663 billion
- Erosion Control: ₦2.449 billion
- Plantation/Forestry: ₦1.173 billion
- Reservoir/Gullies: ₦2.837 billion.

Optimal Strategies for Economic and Social Objectives

From the Game Theory Analysis, deploying the probabilities for further optimization of the allocation of funds to achieve detailed objectives, the results are as follows:

- Economic efficiency: ₦1.173 billion
- Federal Economic Redistribution: ₦1.858 billion
- Regional Economic Redistribution: ₦1.663 billion
- State Economic Redistribution: ₦1.369 billion
- Local Economic Redistribution: ₦2.249 billion
- Social Well-Being: ₦1.761 billion
- Youth Empowerment: ₦1.271 billion
- Environmental Quality Improvement: ₦2.054 billion
- Gender Equality: ₦1.468 billion
- Security: ₦1.956 billion.

Financial Outcomes and Surplus

The financial benefits achievable under the worst-case scenario of conflicting objectives will amount to ₦97.80554 billion (₦16.834 billion x 5.81). When the initial allocation of ₦16.834 billion is minus from the achievable benefits of ₦97.80554 billion (₦97.80554 - ₦16.834), the river basin would realize a surplus amount of ₦80.97154 billion, which can be reinvested.

Profitability Under Borrowing Conditions:

Assuming the ₦16.834 billion was borrowed at an interest rate of 6% over five years, the total repayment amount with compounded interest would be ₦22.5277 billion. When this ₦22.5277 is minus from the ₦97.80554 billion generated through Game Theory (₦97.80554 - ₦22.5277), Optimization will yield a profit margin of ₦75.2778 billion.

Global Implications and Climate Adaptation

Implementing these optimal strategies will help mitigate climate variability's effects, even in conflicting scenarios. This will also enhance integrated planning and management, contributing to global climate change adaptation efforts and addressing multiple sustainable development challenges within the river basin.

5. Conclusion

This study shows that applying the Game Decision Theory Model will provide an effective strategic decision-making framework for multi-purpose river basin projects. Significant financial gains can be realized when resource allocations are optimized under uncertainty, with a surplus of ₦80.97154 billion achievable from an initial investment of ₦16.834 billion. A substantial profit margin of ₦75.2778 billion is maintained even under borrowing scenarios. In addition to financial optimization, the adoption of Game Theory-based strategies in the management of the river Basin will enhance efforts geared towards adaptation to climate change, integrated water resources management promotion, and contribute to sustainable developmental goals.

Therefore, Game Theory models serve as valuable tools for ensuring economic efficiency, social well-being, and environmental sustainability in river basin management, particularly in the face of growing climate variability and competing stakeholder interests. With this approach, resource allocation can be efficiently done. Also, financial returns will be maximized, as well as the Promoting sustainable development makes it a valuable tool for managing multi-purpose river basin projects in the face of climate uncertainty.

References

[1] J. Von Neumann, and O. Morgenstern, *Theory of Games and Economic Behavior*, Princeton, NJ, USA: Princeton University Press, 1947. [Google Scholar] [Publisher Link]

[2] John F. Nash, "Non-Cooperative Games," *Annals of Mathematics*, vol. 54, no. 2, pp. 286-295, 1951. [CrossRef] [Publisher Link]

[3] Kaveh Madani, "Game Theory and Water Resources," *Journal of Hydrology*, vol. 381, no. 3-4, pp. 225-238, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[4] Ariel Dinar, Aharon Ratner, and Dan Yaron, "Evaluating Cooperative Game Theory in Water Resources," *Theory and Decision*, vol. 32, pp. 1-20, 1992. [CrossRef] [Google Scholar] [Publisher Link]

[5] Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action*, Cambridge, UK: Cambridge University Press, 1990. [Google Scholar] [Publisher Link]

[6] Eme Luke Chika, and Ohaji Evans, "Game Theory Modeling in River Valley Projects – Benin Owena River Basin," *Civil and Environmental Research*, vol. 11, no. 2, pp. 75-87, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[7] Godspower Onyekachukwu Ekwueme, and Charles O. Aronu, "Optimization of a Multipurpose River Basin in Anambra State, Nigeria," *International Journal of Basic and Applied Science*, vol. 11, no. 4, pp. 180-187, 2023. [Google Scholar] [Publisher Link]

[8] Ariel Dinar, "Exploring Transboundary Water Conflict and Cooperation," *Water Resources Research*, vol. 40, no. 5, pp. 1-3, 2004. [CrossRef] [Google Scholar] [Publisher Link]

[9] Yang Yu et al., "Multi-objective Game Theory Optimization for Balancing Economic, Social, and Ecological Benefits in the Three Gorges Reservoir Operation, *Environmental Research Letters*, vol. 16, no. 8, pp. 1-18, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[10] Shahmir Janjua et al., "A Three-stage Cooperative Game Model for Water Resource Allocation under Scarcity Using Bankruptcy Rules, Nash Bargaining Solution and TOPSIS," *Water Resources Management*, vol. 39, pp. 3553-3576, 2025. [CrossRef] [Google Scholar] [Publisher Link]

[11] Arman Ganji, Davar Khalili, and Mohammad Karamouz, "Development of Stochastic Dynamic Nash Game Model for Reservoir Operation. I. The Symmetric Stochastic Model with Perfect Information," *Advances in Water Resources*, vol. 30, no. 3, pp. 528-542, 2007.[CrossRef] [Google Scholar] [Publisher Link]

[12] Mehran Homayoun-far et al., "Two Solution Methods for Dynamic Game in Reservoir Operation," *Advances in Water Resources*, vol. 33, no. 7, pp. 752-761, 2010. [CrossRef] [Google Scholar] [Publisher Link]

[13] Peter Rogers, Ramesh Bhatia, and Annette Huber, "Water as a Social and Economic Good: How to Put the Principle into Practice," *Global Water Partnership*, 1998. [Google Scholar] [Publisher Link]

[14] Kaveh Madani, and Ariel Dinar, "Non-Cooperative Institutions for Sustainable Common Pool Resource Management: Application to Groundwater," *Ecological Economics*, vol. 74, pp. 34-45, 2012. [CrossRef] [Google Scholar] [Publisher Link]

[15] Peter P. Rogers, and Myron B Fiering, "Use of Systems Analysis in Water Management," *Water Resources Research*, vol. 22, no. 9S, 146S-158S. [CrossRef] [Google Scholar] [Publisher Link]