



Optimization of a multipurpose river basin in anambra state, Nigeria

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Article Info

Article history:

Received Dec 19, 2022

Revised Feb 16, 2023

Accepted Mar 30, 2023

Keywords:

Economic efficiency;

Net benefits;

Optimization;

River basin;

Youth Empowerment.

ABSTRACT

In this study, the multipurpose objective of development in the Anambra River basin was examined. The study's goals are to determine the net benefits of the various objectives under each purpose currently carried out by the Anambra River Basin, to identify the best way to achieve the goals, and to show, through logical and mathematical reasoning, how money could be allocated to the various goals of a dam project in Anambra State effectively. Economic Efficiency (EE), Regional Economic Redistribution (RER), Social Well-Being (SW), Youth Empowerment (YE), and Environmental Quality Improvement are the objectives taken into account in the study (EQI). The optimization problem in the multipurpose-objective development of the Anambra State river basin was solved utilizing the multi-start optimization method. The study showed that the basin would achieve enormous financial benefits if it used its N15.0 billion strategic development budget over four years for various purposes as illustrated. The results showed that the following allocation of the five purposes should be optimized simultaneously for an N15.0 billion four-year strategic development fund: EE should receive No.762 billion, RER should receive No.594 billion, SW should receive No.649 billion, YE should receive No.683 billion, and environmental quality improvement should receive N4.768 billion. It was found that Environmental Quality Improvement was allocated the higher amount while Regional Economic Redistribution was allocated the least amount for the development. The study's findings recommended that the management of the basin stop the practice of allocating funds to various uses at their discretion, which has led to significant oversight and the improper distribution of scarce resources. As a result, every fund distribution must be justified using logic and mathematics. To increase the accuracy of the data, the Anambra State River Basin Development Authorities must intensify record-keeping activities.

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1. INTRODUCTION

Because water supports a wide range of ecosystem services and because civilization depends on a steady supply of water for drinking, food production, waste treatment, industry, and recreation, watershed management stands at the convergence of environmental and social sciences [1]. According

to their scope and objectives, watershed models can be divided into four groups: multi-criteria (multi-objective) decision-making models, hydro-economic models, engineering-based watershed process models, and others. It would be difficult to choose an appropriate solution among the available alternatives in terms of managing the watershed [2]. Naturally, the criteria are incongruous and incommensurable, and these choices can be contentious because it is frequently challenging to please all parties involved given their disparate interests, values, and viewpoints. The dichotomy between environmental goals and economic gains from land-use development (wood harvesting, agricultural land development, and recreational activities) has been made clear in watershed management challenges (water and soil conservation and reduction of eutrophication) [3]. The majority of decision-makers have achieved equilibrium as a result of the conflict between the economic approach of local residents living in the basins and the environmental approach of government decision-makers in the Anambra State River Basin Development Authority [4]. A thorough analysis, using, for example, a river basin with several uses, can demonstrate that each of the aims can result in real advantages. It is also appropriate to regard each purpose's benefit to varying in relation to each objective. Given the foregoing, it is essential to take into account not just the economic efficiency but also any other objectives that may be deemed relevant at the planning stage in order to make decisions that are explicit, thorough, and efficient. It is not news that the burden of economic austerity has had a significant impact on water resources assessment through inadequate budget allocation and various forms of infrastructure neglect [5]. Therefore, the main obstacles affecting this investigation are: water resources development in the area has been hampered by two issues: the Anambra State River Basin Authority's insufficient budgetary allocation; and the inconsistent allocation of costs to the various goals of water resources development and the resulting waste of financial resources [6]. Consequently, an empirical study is urgently needed to aid in solving the current problem, the river basin's failure to generate revenue for the state and federal governments. As a result, the goal of development in the Anambra River basin is to be maximized on the basis of full capacity utilization [7]. The multipurpose goal of development in the Anambra River basin is to be optimized on the basis of full capacity utilization. The study's particular goals are to ascertain the net benefit of the numerous goals under each purpose now pursued by the Anambra River Basin, to identify the best way to achieve the goals and purposes, and to demonstrate how funds can be adequately allocated the various purposes for the optimum benefits [8], [9].

Looking at some relevant works associated with present study, the study by [10] took into account composite water samples obtained from the Owena multipurpose dam in Ondo State, southwest Nigeria. Natural water, according to the authors, is never completely pure since it often contains residues of other elements that affect its physical, chemical, and bacterial features. According to the water sources, these compounds known as contaminants vary in type and quantity. Even though surface water is the most easily accessible type of water, it only makes up roughly 0.02% of the total amount of water on earth [11]. This modest portion of the world's water supply, if properly distributed and maintained, would be adequate for human requirements. In order to sustainably use their water resources, most nations currently have water management policies that safeguard and enhance their quality while preserving economic and social development [12]. Most of the studied metrics exhibited substantial seasonal fluctuations (p -value < 0.05), and a few also showed significant regional variations. When compared to criteria for drinking water and water quality for aquaculture, the water characteristics of the dam lake showed an acceptable quality for the majority of parameters measured with a low load of chemical contaminants [13]. However, in comparison to drinking water requirements, which call for proper water treatment before distribution for public use, excessive values for turbidity, colour, iron, manganese, and microbial load, were found. The degree to which a certain water source might satisfy the needs of these communities, according to [14], relies on the water's quality. The phrase "water quality" refers to the chemical, physical, and biological aspects of water in relation to all other hydrological properties, typically in terms of its usefulness for a certain purpose [15]. Any aspect of the water that affects the transportability, survival, reproduction, growth, and output of aquaculture species, shapes management choices, has an impact on the environment or

degrades the product's quality and safety can be regarded as a variable of the water's quality [16]. The values or concentrations assigned to parameters relating to water quality can be used to describe the pollution state of the source, and its biotic state, or to forecast the likelihood of the presence of specific organisms. In order to manage the water source, restore it if polluted, and foresee the impacts of anthropogenic changes on the dam lake, it is required to study the water quality features of the multi-purpose dam in Africa [17].

According to a study by [18], infrastructure in water-energy-food-environment systems, including dams, can help support the production of hydroelectric power and control the fluctuation of river flow. However, these advantages frequently have detrimental environmental effects on wildlife, have an adverse financial impact on other economic sectors, and can harm ecosystems near rivers (e.g. wetlands, floodplains, river forests and mangroves). Methods for system-scale option assessment that simultaneously take into account a number of pertinent problems aid in the discovery of operational and infrastructure policy designs that strike an appropriate balance between prospective benefits and drawbacks [19]. While balanced outcomes across performance indicators can be achieved by optimizing model-based assessments, this depends on the necessity of strong collaboration between sectors and between upstream and downstream developments [20]. Comparing the energy, agricultural, and conservation trade-offs implied by various levels of development can aid in the design of future systems (for example, building various reservoirs and irrigation schemes) [21]. The Rufi River Basin in Tanzania was the subject of their study, which employed a computer-assisted multi-sectorial spatial planning approach and took into account the connections between the water, energy, food, and environment sectors. The findings highlighted significant sectorial trade-offs particularly how downstream performance indicators are impacted by the cumulative effects upstream of the expansion of informal irrigation, something that may be challenging to change in the future [22]. The results showed significant potential for infrastructure development in the basin. The upper basin of the Blue Nile River in Ethiopia, which has significant potential for producing hydroelectric power and irrigating crops, was the subject of research by [23]. The study makes an effort to assess the functionality of infrastructures, particularly the High Aswan Dam and the artificial reservoirs that have been proposed for Ethiopia, as well as the economic advantages and disadvantages of storage infrastructures in Ethiopia and their spatial and temporal distribution [24]. An integrated hydro-economic model was created at the basin level to achieve this. To examine the hydrological and economic effects of the various policy alternatives and anticipated infrastructure developments, the model incorporates crucial institutional, economic, and hydrological aspects of the river basin [25]. According to the study by [26], water shortage is a significant problem in many nations, necessitating more efficiency and equity in water allocation for decision-makers. From the viewpoint of a leader-follower connection between the agents (stakeholders) of a river basin in their study, a two-level optimization model based on game theory (GT) is constructed, consisting of a GT-based optimization model. A multi-agent cooperative model based on GT and a single agent of shared interest. Sri Lanka's 25,500 km² Mahaweli multipurpose water system was evaluated in the study by [27]. To satisfy various, frequently incompatible water demands, the authors created a model that may be used to assess water management solutions to the functioning of cascading water basins. The Mahaweli project was primarily administered for irrigation-based agriculture and the production of hydroelectric electricity. By taking into account the exchanges between hydroelectricity and agricultural produce, the study assesses the effectiveness of alternative water management strategies [28]. In light of the study's finding that more water being diverted for paddy irrigation results in less hydroelectricity produced, commercial decisions must be made when water supplies are scarce. During times of water constraint, decisions concerning how much arable land to plant also influence risk factors that relate to rice productivity [29]. The study's findings demonstrate that the existing infrastructure restricts the quantity of water diverted for irrigation that can be used effectively. It also causes geographic variability in risk measures, which improves at the expense of a decrease in expected return across the basin [30].

2. RESEARCH METHOD

2.1 Study area.

One of the notable states in the southeast of Nigeria is Anambra. The Anambra River's indigenous name is "Oma Mbala," which is also its original name. Awka serves as its capital. The largest industrial cities and commercial hubs in the State are Nnewi, Onitsha, and Ekwulobia. Delta State, Imo State, Rivers State, Enugu State, and Kogi State are all neighbours of the state. The Igbo make up 98% of the population of Anambra State's original ethnic groupings, while the Igala makes up 2%. After Lagos State, Anambra is one of Nigeria's most populous and densely populated states. It runs across 45 kilometres between Amorka and Oba, with an estimated population density of 1,500–2,000 people per square kilometre. More than 60% of the state's population lives in urban areas, with a population growth rate of 2.83% annually.

One of Nigeria's most energetically dense inland sedimentary basins is the Anambra Basin. It is a roughly triangular embankment with a total sediment thickness of around 9 km, spanning an area of about 3000 km². The Anambra Basin is frequently the youngest formation in the Benue Trough and is situated west of the Lower Benue Trough. The Niger Delta Basin's hinge line forms the southern boundary of the basin. It extends into the Niger Valley in the northwest, the Jos Mountains in the north, and Lafia in the northeast. The Abakaliki Anticlinorium and the Ibadan Mountains, respectively, mark the eastern and western limits of the basin. Nigeria's major lignite and coal reserves were located in the basin. In the basin, Enugu saw the beginning of Nigeria's coal mining. At Enugu's Udi Ridge, Albert Kitson discovered coal in 1909, turning the area into a key location for British trade. In Enugu, there were coal mines in Ogbete, Ribadu, Onyema, Okaba, and Okpara, among others.

There are two primary seasons: the rainy season (April - September/October) and the dry season (October/November to March), which roughly correspond to the dry and flood phases of the hydrological regime, respectively. The Anambra River Basin Development Authority was one of the 12 river basins established in 1976 by Decree No. 25 of the Military Government of President Olusegun Obasanjo under the Federal Ministry of Agriculture and Water Resources, according to the Federal Military Government (1976) and the Federal Ministry of water resources (2010). Based on the amended Decree No. 35 of 1987, the Authority's mandate was to develop the water resource potential of its catchments. However, it was discovered that the majority of those in charge at the time the basin authority was established lacked official training or genuine expertise in watershed management.



Figure 1. Map of Anambra river basin showing various locations [31]

2.2 Method of data collection and method of data analysis.

The data for the study was obtained from the Anambra River Basin Development Authority

(ARBDA), Anambra State, Ministries, and Parastatals. The data cover five years, from 2015 to 2019, and include capital projects and benefits of water resource projects. The information gathered includes the following: (a) Economic efficiency data, (b) Regional economic redistribution data, (c) Social well-being data, (d) Youth employment data, (e) Environmental quality improvement data.

The data obtained was preprocessed to obtain the net benefit of the various purposes/objectives of the study. The analysis of the pre-processed data was based on linear programming method. For the present study, the objectives considered comprises of economic efficiency, regional economic redistribution, social wellbeing, youth employment, environmental quality improvement, under purposes such as irrigation, hydropower, water supply, flood control and erosion control. The solution will be to obtain the optimal value for the various purposes mentioned above.

However, to obtain an adequate solution to the model, the study shall employ the Multi-Start Optimization method. Multistart methods combine a global strategy for sampling the search space with a local strategy for improving the sampled solutions. The `r` console function `BBoptim` from multiple starting points to obtain multiple solutions was used for the analysis [32] This type of optimization or root-finder is usually run with each row of `par` indicating initial guesses. The normal distribution will be used to randomly generate 200 initial guesses for the five objectives under study.

3. RESULTS AND DISCUSSIONS

Taking into account a 15 billion plan development based on the money allotted for the development involving irrigation, hydropower, water supply, flood control, and erosion management. In order to develop the basin, it was necessary to maximize goals like economic efficiency (EE), regional economic redistribution (RER), social well-being (SW), youth empowerment (YE), and environmental quality improvement (EQI). On the basis of a Bill of Engineering Measurement and Evaluation (BEME) on the benefit distribution in relation to the objectives, the net benefits of the various purposes were provided in Table 1. The outcome shown in Table 1 demonstrates the net advantages of the various purposes relative to the goals. The results shown in Figure 1 also revealed that Environmental Quality Improvement had the lowest net benefit, at ₦1.9624 billion, followed by Social Well-Being with a net benefit of ₦2.095 billion. Economic Efficiency had the highest net benefit, at ₦2.6418 billion.

Table 1. Summary of the Net Benefits (in Billion Naira) of all the objectives under consideration in this study

PURPOSE (A ₁₋₅)	Objective (B ₁₋₅)				
	Economic Efficiency (B ₁)	Regional Economic Redistribution (B ₂)	Social Well-being (B ₃)	Youth Empowerment (B ₄)	Environmental Quality Improvement (B ₅)
Irrigation Agriculture (A ₁)	2.763	2.081	0.943	2.211	3.120
Hydropower (A ₂)	2.776	1.362	1.997	2.667	2.419
Water Supply (A ₃)	2.733	2.146	2.991	1.529	1.822
Flood Control (A ₄)	1.690	2.549	1.606	2.146	1.515
Erosion Control (A ₅)	3.247	1.763	2.938	1.574	0.936

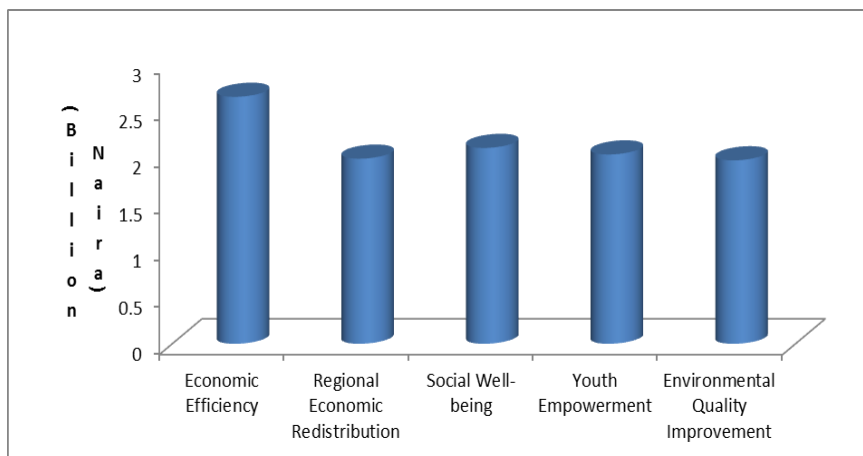


Figure 2. Cylinder Chart showing the Average Net Benefit of the various Objectives

In order to optimize the purposes, a maximization problem on the objectives of the development was formulated using the data presented in Table 1. Hence, the optimization problem was written in the form:

$$\text{Maximize, } Z = 2.6418X_1 + 1.9802X_2 + 2.095X_3 + 2.0254X_4 + 1.9624X_5 \tag{1}$$

Subject to

$$2.763X_1 + 2.081X_2 + 0.943X_3 + 2.211X_4 + 3.12X_5 \geq 11.118$$

$$2.776X_1 + 1.362X_2 + 1.997X_3 + 2.667X_4 + 2.419X_5 \geq 11.221$$

$$2.733X_1 + 2.146X_2 + 2.991X_3 + 1.529X_4 + 1.822X_5 \geq 11.221$$

$$1.69X_1 + 2.549X_2 + 1.606X_3 + 2.146X_4 + 1.515X_5 \geq 9.506$$

$$3.247X_1 + 1.763X_2 + 2.938X_3 + 1.574X_4 + 0.936X_5 \geq 10.458$$

$$X_1, X_2, X_3, X_4, X_5 \geq 0 \text{ Non-Negativity condition}$$

Where, Z = the benefit from the development, X_1 = Benefit from EE, X_2 = Benefit from RER, X_3 = Benefit from SW, X_4 = Benefit from YE, and X_5 = Benefit from EQI.

The technique was configured to choose only convergence solutions for the corresponding values of $X_1, X_2, X_3, X_4,$ and X_5 when using the multistart optimization method in R-console described in the Appendix. Hence, the optimal solution for the variables were found as: $X_1=0.762, X_2= 0.594, X_3= 0.649, X_4= 0.683,$ and $X_5= 4.768$. The optimal benefit of the development was found to be ₦15.28902 Billion ($Z= 2.6418*0.762+ 1.9802*0.594+ 2.095*0.649 + 2.0254*0.683 + 1.9624*4.768= ₦15.28902$ Billion).

4. CONCLUSION

This study looked at the optimizing of a multi-purpose/multi-objective river basin. It employed the linear programming approach using the multistart optimization method to solve the optimization problem in the multi-purpose/multi-objective development of the Anambra State river basin. The result demonstrated how funds could be apportioned to the various purposes of a dam project in Anambra State. The study revealed the huge financial reward that the basin is expected to enjoy should they allocate their planned four years ₦15.0 billion strategic development fund to the various purposes as illustrated. The findings demonstrated that the five purposes to be optimized simultaneously for a four-year strategic development fund of ₦15.0 billion should be apportioned to the various purposes as follows: ₦0.762 billion should be allocated to Economic Efficiency, ₦0.594 billion should go to Regional Economic Redistribution, ₦0.649 should go to Social Well-being, ₦0.683 billion should go to Youth Empowerment, and ₦4.768 billion should go to Environmental Quality Improvement. It was found that Environmental Quality Improvement was allocated the higher amount while Regional Economic Redistribution was allocated the least amount for the development. The study revealed that cost allocation is a highly logical and technical process can effectively be applied in determining the

optimum decision making for multi-purpose water resources planning and management as has been experimented with by the present study. According to the study's conclusions, it was advised that the basin's managers halt the current practice of distributing monies at their discretion to different uses, which has resulted in a massive oversight and the misallocation of limited resources. Therefore, all fund distributions ought to be supported by logical and mathematical reasoning. Additionally, the Anambra State River Basin Development Authorities must step up record-keeping efforts to improve the accuracy of data.

ACKNOWLEDGEMENTS

The authors acknowledged the financial support provided by Tertiary Education Trust Fund (TETFund) through the Institution Based Research (IBR) intervention [grant reference number: NAU/TETFund/IBR/2022/VOL. IV/014].

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