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Bayesian Decision Modeling in Watershed Management - Cross River Basin, Nigeria

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Abstract

This paper aimed at examining simulation modeling in Bayesian Decision theory and its application in day to day decision making as well as planning in water resources and Environmental engineering. It also gives more insight in the validation of prior probability. The research objectives deals with the multi-objective value of water for its wide range of purposes such as Power generation, water supply, Navigation, Irrigation, and Flood control, in the Cross River basin using Bayesian Modeling. In line with foregoing objectives, the research aim to achieve the following: (i) to lay bare the usefulness of the Bayesian theory that gives more than point estimation. It measures the magnitude of the difference between alternative actions and provides a variety of estimates for consideration, (ii) to present selected empirical results of a study employing decision-making theory as a framework for considering decision making under uncertainty. (iii) to evaluate the optimal policy or strategy or action that maximizes the expected benefit in the River Basin within the available limited resources and funds over the planning period of a course of action or alternatives. The multi-objectives arising from the development that were optimized include: Economic Efficiency, Regional Economic Distribution, State and Local Economic Redistribution, Youth Employment and Environmental Quality Improvement, which are primarily essential in Cross Rivers State and Nigeria. Methodology applied involving methods, experiments and data were collected for the River Basin Engineering Development, from Parastatals and Ministries. The conceptual framework on Bayesian Decision Model (BDM) as presented captured the iterative updates of prior probability toward achieving an optimum solution of a set problem. The analysis and presentation of results were based on simulation of Bayesian Models Iterations. Chi-square, Contingency and association and Pearson Product Moment Correlation were carried out as Interaction, reliability and Validity tests respectively. The study applied Bayesian Decision Model, where the following parameters were obtained:: (a)Posterior Probabilities of the States of Nature (b) Marginal Probability of the Courses of action, (c) Maximum Expected Monetary Value[EMV*] (d) Expected Profit in a Perfect Information[EPPI], (e) Expected Value of Perfect Information[EVPI], and (f) Expected Value of System Information[EVSI]. In the process of Iteration, and at some point the Prior becomes equal to the Posterior Probability, when this occurs an optimum solution is said to be achieved. However, the correlation of prior and posterior probability is equal to one (1) at the optimum solution. In conclusion, the efficiency of system information is 50%. Table 25 indicates monetary allocation to the multi-objectives which gave a clear indication that the life wire of the watershed/dam lies on it; and therefore should be comparatively considered; because without it, it will be difficult to maintain the watershed. The Basin Authority is expected to pay the researcher the Expected Value of System Information (EVSI) value of = ₦0.1billion for information generated using the Bayesian Decision theory model spreadsheet. The value of Economic efficiency optimized from 1st iteration to 2ndIteration with the EMV values of ₦2.54billion to ₦2.74billion respectively as in [Table 4 & 15]

Keywords: Optimum Solution, Prior-posterior, Probability, River Basin.
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1.0 Introduction

In This Paper, The Integrated Water Resources Management of cross river watershed will be demonstrated by using Bayesian decision Model. (BDM), this will look at simulation in the optimization of multi-purpose projects from the perspective of multi-objectivity. However, simulation modeling in Bayesian decision model as explicated can be applied in decision making in planning toward resolving conflict which may arise in the resources management of Watershed operations. Similar models like Game and Markovian theory have been used in the past in River basin allocation management.

Against the foregoing background this paper present Bayesian decision theory in the allocation of resources to Multi-Objective of the River basin. The research objectives deals with the multi-objective value of water for its wide range of purposes such as Power generation, water supply, Navigation, Irrigation, and Flood control, in the Cross River basin using Bayesian Modeling. In line with foregoing objectives, the research aim to achieve the following: (i) to lay bare the usefulness of the Bayesian theory that gives more than point estimation. It measures the magnitude of the difference between alternative actions and provides a variety of estimates for consideration, (ii) to present selected empirical results of a study employing decision-making theory as a framework for considering decision making under uncertainty. (iii) to evaluate the optimal policy or strategy or action that maximizes the expected benefit in the River Basin within the available limited resources and funds over the planning period of a course of action or alternatives. The multi-objectives arising from the development that were optimized include: Economic Efficiency, Regional Economic Distribution, State and Local Economic Redistribution, Youth Employment and Environmental Quality Improvement, which are primarily essential in Cross Rivers State and Nigeria. Methodology applied involving methods, experiments and data were collected for the River Basin Engineering Development, from Parastatals and Ministries.

Statement of the Problem: Inefficient Allocation of Resources to the River basin Multi-Purpose and Multi-Objective**Study Area:** The study area is cross river watershed which extends between latituides 48000N and 68500N and Longitudes 78400E and 98400E.

Figure1: Obudu Dam

2.0 Methodology and Basic Concept

Method of computing posterior probabilities from prior probabilities using a mathematical formula called Bayes' theorem. A further analysis of problems using these probabilities with respect to new expected payoffs with additional information is called **prior-posterior analysis**. The Bayes' theorem in general terms can be stated as follows:

Let $A_1, A_2, \ldots\ldots\ldots\ldots\ldots\ldots A_n$ be mutually exclusive and collective exhaustive outcomes.

The probabilities $P(A_i)$, $P(A_2), \ldots P(A_n)$ are known.

There is an experimental outcome B for which the conditional probabilities $P(B/A_1)$, $P(B/A_2)$, ……..$P(B/A_n)$ are also known. Given the information that the outcome B has occurred, the revised conditional probabilities of outcomes A_j, i.e. $P(A_1/B)$, i = 1, 2…n are determined by using following conditional probability relationship:

Thus,

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A Bayesian Decision Theory Model will be used to simulate the Cross River Watershed for an optimum result. The mathematical model is of the form:

P (A/DATA) = [P (DATA/A) X P (A)]/P (DATA) Equation 1

Model Objective Optimization can be handled as follows:
Where:
P (A/DATA) = K [P (A/DATA) P (A)] Equation 2
And the constraints are as follows:
Constraints:
P (A/DATA) = 0 Equation 3
P (DATA/A) = 0 Equation 4
P (A) = 0 Equation 5
P (B) = 0 Equation 6

A –River Basin Purpose [Hydropower, Water –Supply, Navigation, Irrigation and Flood Control]. See Table-2, for details.
DATA- Values of the various Objective [Economic Efficiency, Regional Distribution, State distribution, Youth Employment and Environmental Control] Yields expressed as courses of action and likelihoods corresponding to the River Basin Purposes. See Table-2, for details
P (A/DATA)-Probability of A occurring given the DATA [Objective-Likelihood].
P (DATA/A)-Probability of the Data occurring given the A [Posterior]
P (A) - Prior Probability of A
P (DATA) - Probability of DATA occurring [Marginal Probability or Evidence of Objectives].
The Bayesian theory stated above is transformed to a Bayesian Decision simulation model and iteration method as displayed below in a flow chart:

BAYESIAN DECISION THEORY MODEL-FLOW CHART

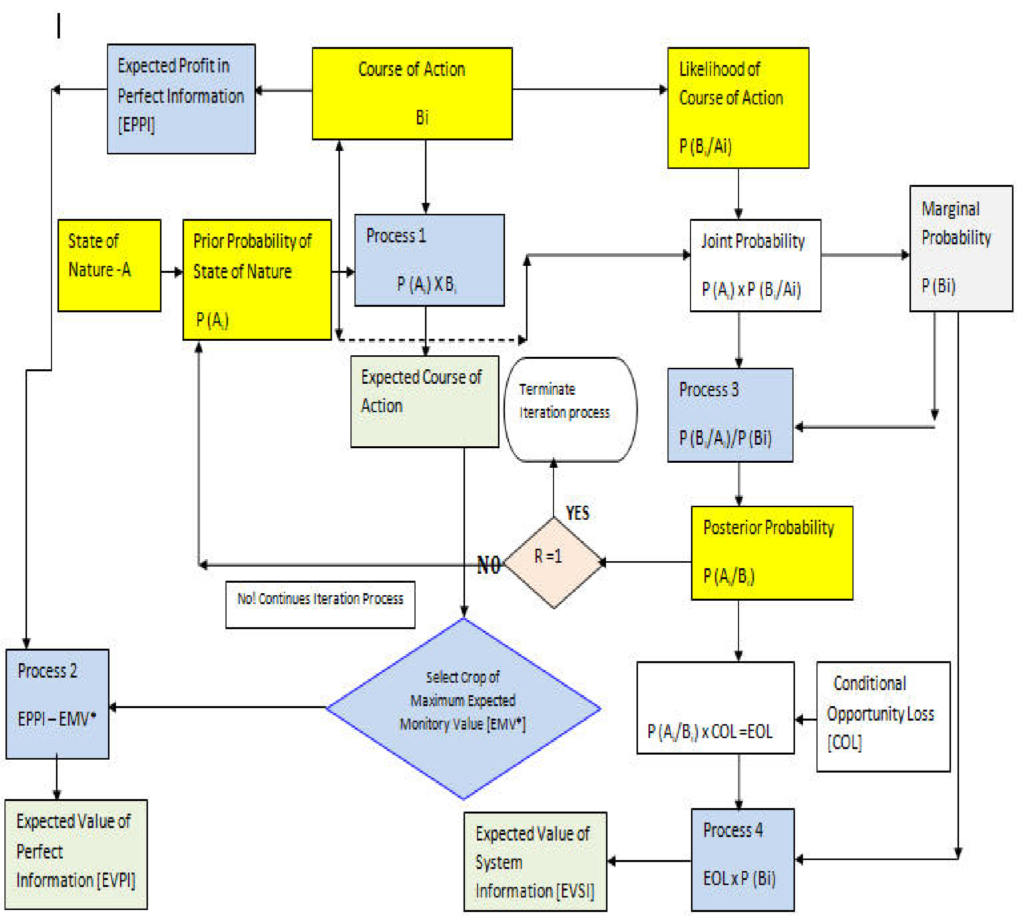

Figure 2: Bayesian Decision Theory Model Flow Chart

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3.0 Analysis and Discussion of Results

Prior Probability was estimated using the Hydropower capacity of the only functional Obudu dam in the watershed. The installed capacity of the dam is less than 100MW. However, the Breakdown of economic benefits by installed capacity is depicted in column 2 of table 1; from which the prior probability of the Watershed "State of Nature" i.e. "Purposes" were estimated as can be seen in column 4 of table 1.However, ratios of each of the Dam Purposes were deduced from the **Breakdown of economic benefits by installed capacity**. Against the foregoing, the prior probability estimated can be said to be objective priors; contrast to Subjective prior which largely depends on experts' decisions or questionnaires.

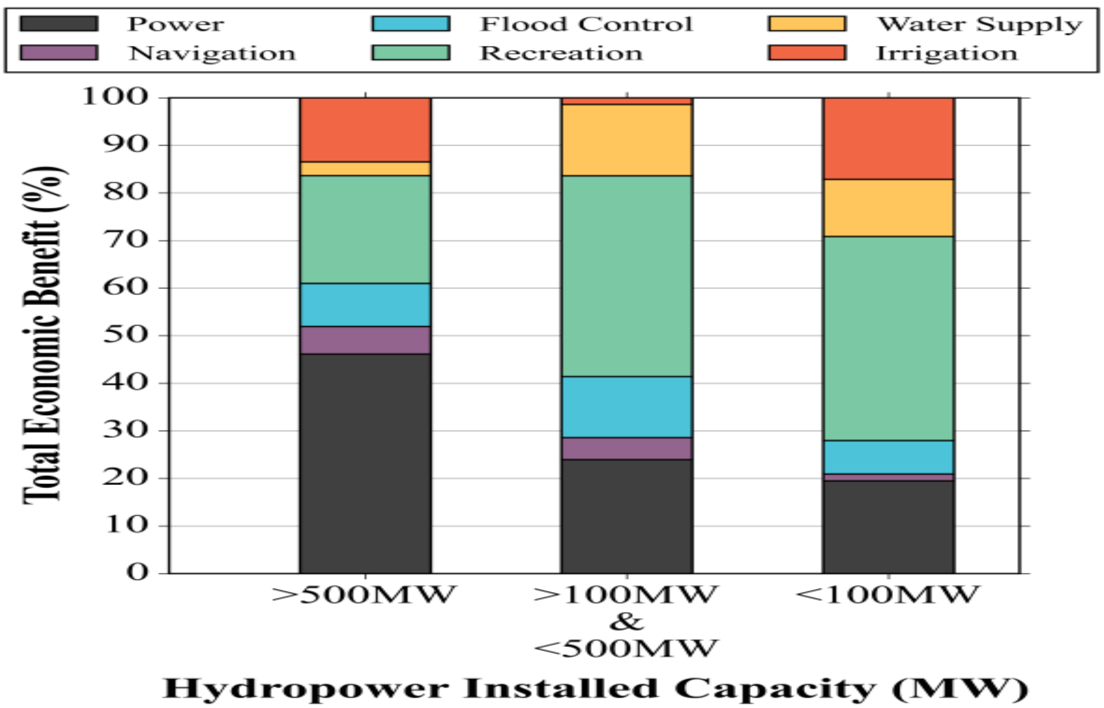

Figure 3: Breakdown of economic benefits by installed capacity

Table 1: Estimation of prior probability

State of Nature(N)	**Ratio**	**%age of ratio**	**P(N)**
Hydropower	**20**	35.71428571	0.357143
Water supply	**12**	21.42857143	0.214286
Navigation	**1**	1.785714286	0.017857
Irrigation	**17**	30.35714286	0.303571
Flood control	**6**	10.71428571	0.107143
Total	**56**	100	1.0

Table 2: Watershed Benefits versus Purpose

River Basin Purposes	**Prior Probability**	**Courses of action of River basin Benefits or Benefits**				
State of nature		Economic efficiency	Regional economy[B]	State economic distribution[C]	Environment[D]	Youth employment[E]
Hydropower	0.357143	1.42	1.3	0.192	0.1	0.8
Water supply	0.214286	4.05	0.8	0.8	0.151	0.7
Navigation	0.017857	2	0.3	1.6	0.2	0.1
Irrigation	0.303571	3	0.475	0.255	1.8	0.195
Flood control	0.107143	2	0.134	0.176	0.112	1.9

The outcome of Table 1 is enlisted in column 2 of table 2 which serves as the prior probability of the state of natures. Hence table 2 can be called Pay Matrix. The likelihood of the observed data is calculated as shown in table 3.

Table 3: Likelihood Forecast of Observed river basin benefits

River Basin Purposes		**Likelihood Forecast**				
State of nature		P(A1/N1)	P(A2/N2)	P(A3/N3)	P(A4/N4)	P(A5/N5)
Hydropower	N 1	0.37	0.34	0.05	0.03	0.21
Water supply	N 2	0.62	0.12	0.12	0.02	0.11
Navigation	N 3	0.48	0.07	0.38	0.05	0.02
Irrigation	N 4	0.52	0.08	0.04	0.31	0.03
Flood control	N 5	0.46	0.03	0.04	0.03	0.44

4.0 Bayesian Decision Modeling and Simulation processes

1st Iteration In line with the Bayesian Decision Flow Chart (Fig.3), the Products of Prior Probability generated from table 1 & Course of Action of table 2 [1stIteration] resulted to the following output: table 4[EMV], table 5[EPPI & EVPI], table 6[Marginal Probability], table 7[Posterior Probability], table 8[EOL of Economic Efficiency], table 9[EOL of Regional Economy], table 10[EOL of State Economic Distribution], table 11[EOL of Environmental Control], table 12[EOL of Youth Employment], table 13[EVSI] from which expected Monetary values of the benefits were obtained as follows. This process will be said to have be performed without data because it was computed with the first prior.

2nd Iteration

Similarly, in line with the Bayesian Decision Flow Chart (Fig.3), the Products of Posterior Probability(2nd Iteration Prior) generated in table 7& Course of Action of table 2 [Table 14] resulted to the following outputs: Table 15[EMV], table 16[EPPI & EVPI], table 17[Marginal Probability], table 18[Posterior Probability], table 19[EOL of Economic Efficiency], table 20[EOL of Regional Economy], table 21[EOL of State Economic Distribution], table 22[EOL of Environmental Control], table 23[EOL of Youth Employment], table 24[EVSI].

Table 4: Expected Monetary Value at the 1thIteration [without "Data"]

River Basin Purposes	Expected Benefit				
State of nature	Economic efficiency	Regional economy[B]	State economic distribution[C]	Environment[D]	Youth employment[E]
Hydropower	0.50714306	0.4642859	0.068571456	0.0357143	0.2857144
Water supply	0.8678583	0.1714288	0.1714288	0.032357186	0.1500002
Navigation	0.035714	0.0053571	0.0285712	0.0035714	0.0017857
Irrigation	0.910713	0.144196225	0.077410605	0.5464278	0.059196345
Flood control	0.214286	0.014357162	0.018857168	0.012000016	0.2035717
EMV	**2.53571436**	**0.799625187**	**0.364839229**	**0.630070702**	**0.700268345**

EMV (Course of action, $S_J = \sum_{j=1}^{m} Pij\ Pj$ Equation 7

EMV* $= \sum_{j=1}^{m} Pij\ Pj = 2.5$

The Maximum Expected Monetary Value from Table 4 = 2.5

Table 5:EPPI and EVP1

EPPI	0.357143x1.42 + 0.214286x 4.05+0.017857x2+0.202571x3+0.107143x2 = 2.53571436
EVPI	**EPPI-EMV** = 2.53571436 -2.53571436 =0

Table 6: Marginal Probability

State of Nature	Prior Probability	Likelihood	Joint Probability				
	P(N_i)	P(Ai/Ni)	P(Ai ∩ Ni) = P(Ni) P(Ai/Ni)				
N 1	0.36	0.37	0.133039				
		0.34		0.121795881			
		0.05			0.017988		
		0.03				0.009369	
		0.21					0.074951
N 2	0.21	0.62	0.133496				
		0.12		0.026369605			
		0.12			0.02637		
		0.02				0.004977	
		0.11					0.023073
N 3	0.017857	0.48	0.008503				
		0.07		0.0012755			
		0.38			0.006803		
		0.05				0.00085	
		0.02					0.000425

N 4	0.303571	0.52	0.159077				
		0.08		0.025187114			
		0.04			0.013522		
		0.31				0.095446	
		0.03					0.01034
N 5	0.107143	0.45	0.048569				
		0.03		0.003254117			
		0.04			0.004274		
		0.03				0.00272	
		0.45					0.048326
Marginal Probability			0.482683	0.177882216	0.068956	0.113362	0.157116

Table 7:Posterior Probability of the Watershed 1st Iteration [No Data]

Outcome	Marginal Probability	Joint Probability	Posterior Probability
(Ai)	P(Ai)	P(Ai п Ni) = P(Ni) P(Ai/Ni)	P(Ni/Ai) = P(Ai п Ni)/P(Ai)
A1	0.483694829	0.133038578	0.275046518
		0.133496124	0.275992456
		0.008503333	0.017579955
		0.159076507	0.328877832
		0.049580287	0.10250324
A2	0.177949979	0.121795881	0.684438864
		0.026369605	0.148185489
		0.0012755	0.007167745
		0.025187114	0.141540413
		0.003321879	0.018667489
A3	0.069045154	0.017988315	0.260529721
		0.026369605	0.381918252
		0.006802667	0.098524896
		0.013521503	0.195835655
		0.004363065	0.063191476
A4	0.11341891	0.009368914	0.082604514
		0.004977263	0.043883889
		0.000850333	0.00749728
		0.095445904	0.841534307
		0.002776496	0.02448001
A5	0.155891128	0.074951312	0.48079267
		0.023073404	0.148009732
		0.000425167	0.002727331
		0.010339973	0.066328168
		0.047101273	0.302142099

Table 8: Expected Opportunity Loss[EOL] of Economic Efficiency

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.275622832	0	0
N 2	0.276570753	0.12	0.03318849
N 3	0.017616791	1.228	0.021633419
N 4	0.329566941	1.32	0.435028363
N 5	0.100622682	0.62	0.062386063
Posterior EOL			**0.552236335**

Table 9: Expected Opportunity Loss[EOL] of Regional Economic Distribuition

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.684699595	0	0
N 2	0.148241939	3.25	0.481786303
N 3	0.007170475	3.25	0.023304044
N 4	0.141594332	3.899	0.5520763
N 5	0.018293658	3.35	0.061283756
Posterior EOL			**1.118450402**

Table 10: Expected Opportunity Loss[EOL] of State Economic Distribution

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.260865987	0	0
N 2	0.382411194	1.7	0.65009903
N 3	0.098652062	0.4	0.039460825
N 4	0.19608842	1.8	0.352959157
N 5	0.061982337	1.9	0.11776644
Posterior EOL			**1.160285451**

Table 11: Expected Opportunity Loss[EOL] of Youth Empolyme

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.082645784	0	0
N 2	0.043905814	2.525	0.110862
N 3	0.007501026	2.745	0.02059
N 4	0.84195475	1.2	1.010346
N 5	0.023992626	2.805	0.067299
Posterior EOL			**1.209098**

Table 12: Expected Opportunity Loss[EOL] of nt Environmental Control

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.477044685	0	0
N 2	0.146855933	1.866	0.274033171
N 3	0.00270607	1.824	0.004935872
N 4	0.065811112	1.888	0.124251379
N 5	0.3075822	0.01	0.003075822
Posterior EOL			**0.406296243**

Table 13:Expected Value of System Information [EVSI] at Prior Probability

Outcome	Marginal Probability	Posterior Opportunity Loss (EOL)	Expected Value of Sample Information (EVSI)
(Ai)	**P(Ai)**	**(EOL)**	**(EVSI)**
A1	0.482683445	0.552236335	0.266555337
A2	0.177882216	1.118450402	0.198952436
A3	0.068956153	1.160285451	0.080008821
A4	0.113362273	1.209097511	0.137066042
A5	0.157115914	0.406296243	0.063835606
		Total	**0.746418241**

* ₦ 0.75 billionis the EVSIthe River Basin Authority has to pay for hiring the services of the forecaster

Table 14: Prior Probability & Courses of action at the 2nd Iteration

River Basin Purposes	**Prior Probability**	**Courses of action or River basin Benefits**				
State of nature		**Economic efficiency**	**Regional economy [B]**	**State economic distribution [C]**	**Environment[D]**	**Youth employment[E]**
Hydropower	0.275622832	1.42	1.3	0.192	0.1	0.8
Water supply	0.276570753	4.05	0.8	0.8	0.151	0.7
Navigation	0.017616792	2	0.3	1.6	0.2	0.1
Irrigation	0.329566941	3	0.475	0.255	1.8	0.195
Flood control	0.100622682	2	0.134	0.176	0.112	1.9

Table 15: Expected Monetary Value with "Data"

River Basin Purposes	**Expected Benefit**				
State of nature	Economic efficiency	Regional economy[B]	State economic distribution[C]	Environment[D]	Youth employment[E]
Hydropower	0.391384421	0.358309682	0.052919584	0.027562283	0.220498266
Water supply	1.12011155	0.221256602	0.221256602	0.041762184	0.193599527
Navigation	0.035233584	0.005285038	0.028186867	0.003523358	0.001761679
Irrigation	0.988700823	0.156544297	0.08403957	0.593220494	0.064265553
Flood control	0.201245364	0.013483439	0.017709592	0.01126974	0.191183096
EMV	**2.736675742**	**0.754879058**	**0.404112215**	**0.677338059**	**0.671308121**

EMV (Course of action, $S_J = \sum_{j=1}^{m} Pij\ Pj$ Equation 8

EMV* $= \sum_{j=1}^{m} Pij\ Pj = 2.74$

The Maximum Expected Monetary Value from Table 15 = 2.74

Table16: EPPI and EVPI

EPPI	0.275622832x1.42 + 0.276570753x 4.05+0.017616792x2+ 0.329566941x 3 + 0.100622682x 2 = 2.74
EVPI	**EPPI-EMV =** 2.74 - 2.74 =0

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Table 17: Product of Likelihood & Prior Probability of 2nd Iteration

State of Nature	Prior Probability	Likelihood	Joint Probability				
	$P(N_i)$	P(Ai/Ni)	P(Ai ⊓ Ni) = P(Ni) P(Ai/Ni)				
N 1	0.28	0.37	0.102672				
		0.34		0.093995195			
		0.05			0.013882		
		0.03				0.00723	
		0.21					0.057843
N 2	0.28	0.62	0.172298				
		0.12		0.034034241			
		0.12			0.034034		
		0.02				0.006424	
		0.11					0.02978
N 3	0.017616792	0.48	0.008389				
		0.07		0.001258342			
		0.38			0.006711		
		0.05				0.000839	
		0.02					0.000419
N 4	0.329566941	0.52	0.172699				
		0.08		0.027343982			
		0.04			0.014679		
		0.31				0.103619	
		0.03					0.011225
N 5	0.100622682	0.46	0.046563				
		0.03		0.003119722			
		0.04			0.004098		
		0.03				0.002608	
		0.44					0.044235
Marginal Probability			0.502621	0.159751482	0.073405	0.12072	0.143503

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Table 18: Posterior Probability of the Watershed at 2nd Iteration [with Data]

Outcome (Ai)	Marginal Probability P(Ai)	Joint Probability P(Ai п Ni) = P(Ni) P(Ai/Ni)	Posterior Probability P(Ni/Ai) = P(Ai п Ni)/P(Ai)
A1	**0.502620821**	**0.102671674**	***0.204272624***
		0.172298346	***0.342799859***
		0.008388949	***0.016690412***
		0.172698834	***0.343596657***
		0.046563018	***0.092640448***
A2	**0.159751482**	**0.093995195**	**0.588383865**
		0.034034241	**0.213044917**
		0.001258342	**0.007876874**
		0.027343982	**0.171165748**
		0.003119722	**0.019528596**
A3	**0.073404714**	**0.013882367**	**0.189120923**
		0.034034241	**0.463651985**
		0.006711159	**0.091426811**
		0.014679401	**0.199978995**
		0.004097546	**0.055821287**
A4	**0.120720087**	**0.0072304**	**0.059893923**
		0.006423963	**0.053213705**
		0.000838895	**0.006949091**
		0.1036193	**0.858343487**
		0.002607529	**0.021599794**
A5	**0.143502897**	**0.057843197**	**0.403080342**
		0.029779961	**0.207521673**
		0.000419447	**0.00292292**
		0.011225424	**0.078224374**
		0.044234867	**0.308250692**

Table 19: Posterior Opportunity Loss[EOL] of Economic Efficiency

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.204272624	0	0
N 2	0.342799859	0.12	0.041135983
N 3	0.016690412	1.228	0.020495826
N 4	0.343596657	1.32	0.453547587
N 5	0.092640448	0.62	0.057437078
Posterior EOL			**0.572616474**

Table 20:Posterior Opportunity Loss[EOL] of Regional Economic Distribuition

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.588383865	0	0
N 2	0.213044917	3.25	0.69239598
N 3	0.007876874	3.25	0.02559984
N 4	0.171165748	3.899	0.667375252
N 5	0.019528596	3.35	0.065420798
Posterior **EOL**			**1.45079187**

Table 21:Posterior Opportunity Loss[EOL] of State Economic Distribution

State of Nature	Posterior Probability	COL	EOL
N 1	0.189120923	0	0
N 2	0.463651985	1.7	0.788208375
N 3	0.091426811	0.4	0.036570724
N 4	0.199978995	1.8	0.35996219
N 5	0.055821287	1.9	0.106060445
Posterior EOL			**1.290801735**

Table 22:Posterior Opportunity Loss[EOL] of Youth Empolymet

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.059893923	0	0
N 2	0.053213705	2.525	0.134365
N 3	0.006949091	2.745	0.019075
N 4	0.858343487	1.2	1.030012
N 5	0.021599794	2.805	0.060587
Posterior EOL			**1.244039**

Table 23:Posterior Opportunity Loss[EOL] of nt Environmental Control

State of Nature	Posterior Probability	Conditional Opportunity Loss (COL)	Expected Opportunity Loss(EOL)
N 1	0.403080342	0	0
N 2	0.207521673	1.866	0.387235441
N 3	0.00292292	1.824	0.005331405
N 4	0.078224374	1.888	0.147687617
N 5	0.308250692	0.1	0.030825069
Posterior EOL			**0.571079533**

Table 24:Expected Value of System Information [EVSI] at Posterior Probability

Outcome	Marginal Probability	Posterior Opportunity Loss (EOL)	Expected Value of Sample Information (EVSI)
(Ai)	P(Ai)	(EOL)	(EVSI)
A1	0.502620821	0.572616474	0.287808962
A2	0.159751482	1.45079187	0.231766152
A3	0.073404714	1.290801735	0.094750932
A4	0.120720087	1.244039466	0.150180552
A5	0.143502897	0.571079533	0.081951567
		TOTAL	**0.846458165**

* **₦ 0.85 billion Naira** is the EVSI the River Basin Authority has to pay for hiring the services of the forecaster.

Deductions from the outputs

From table 4 and 15 it is clear that optimization of the process actually took place from EMV* value of ₦2.54billion to ₦2.74billion, in Process 1 without Data and Process 2 with Data respectively, .and having a differential increment of ₦0.2billion. However, the River basin Authority will be willing to pay for the *additional information* that made the optimization possible within the foregoing monetary range of ₦0.2billion.

Efficiency of System Information[EFSI]

Difference between Expected Value of Perfect Information [EVPI] in 1st and 2nd Iteration

Therefore: EVPI = 2.74 -2.54 = 0.2

Expected Value of System Information[EVSI] and Efficiency of System Information[EFSI]

Therefore, EVSI = 0.845– 0.75 = 0.1

Efficiency of System Information[EFSI]

EVPI is always greater than EVSI, therefore, EFSI Ratio = EVSI/EVPI = 0.5

$$EVSI = \frac{0.1}{0.2} \text{ X } 100 = 50\% \qquad \text{Equation 9}$$

Therefore the efficiency of system information is equal to 50% That shows that the system is operating at 50% efficiency

Financing and Management

Ultimately, in a casewhere Federal government allocated a sum of 100 Billion Naira for ***Cross River Basin*** the following allocation decision on the River Basin Benefits [Objectives] will be made base on the Marginal Probability of the 2nd iteration table 17

Table 25: Allocation of resources to the Benefits in Percentage

S/N	Description of Objective/Benefit	Percentage Allocation	Monetary Allocation
1	Economic efficiency	0.502620821	**50.26208207**
2	Regional Economic Distribution	0.159751482	**15.97514823**
3	State Economic Distribution	0.073404714	**7.340471376**
4	Youth employment	0.120720087	**12.07200867**
5	Environmental Quality	0.143502897	**14.35028965**
	Total	1	**₦100billion Naira**

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Table 26: Prior and Posterior Pearson Product Moment Correlation Coefficient 1st Iteration

Prior	Posterior	X	y	Xy	x^2	y^2
0.357143	0.275622832	0.107143	0.025623	0.002745307	0.01148	0.000657
0.214286	0.276570753	-0.035714	0.026571	-0.000948948	0.001275	0.000706
0.017857	0.017616791	-0.232143	-0.232383	0.053946135	0.05389	0.054002
0.303571	0.329566941	0.053571	0.079567	0.004262481	0.00287	0.006331
0.11	0.100622682	0	0	0.060004975	0.069515	0.061695
1	1					
		R	**0.9163**			

Table 27: Prior and Posterior Pearson Product Moment Correlation Coefficient 2nd Iteration

Prior	Posterior	X	y	Xy	x^2	y^2
0.275622832	0.204272624	0.025622832	-0.045727	-0.001171665	0.000657	0.002091
0.276570753	0.342799859	0.026570753	0.0928	0.002465762	0.000706	0.008612
0.017616792	0.016690412	-0.23238321	-0.23331	0.054217231	0.054002	0.054433
0.329566941	0.343596657	0.079566941	0.093597	0.0074472	0.006331	0.00876
0.10	0.092640448	0	0	0.062958527	0.061695	0.073897
1	1					
		R	**0.9324**			

5.0 Conclusion & Contribution To Knowledge

This research however, demonstrated the Cross River basin capacity to provide significant economic benefits to the region, state, environment, job creation and environmental control and as such is worthy of priority investments by elected officials and decision-makers to protect and restore these natural resources

Summary of Findings

-The efficiency of system information is 50%

-Table 25 indicates monetary allocation to the multi-Objectives which gave a clear indication that the life wire of the watershed/dam lies on it; and therefore should be comparatively considered; because without it, it will be difficult to maintain the watershed.

-The Basin Authority is expected to pay the researcher the Expected Value of System Information (EVSI) value of = ₦0.1billion for information generated using the Bayesian Decision theory model spreadsheet.

Model Optimization

The Expected Monetary Values of the watershed objectives were optimized. The value of Economic efficiency was optimized from 1st iteration to 2ndIteration with the EMV values of ₦2.54billion to ₦2.74billion respectively.[See Table 4 & 15]

Model Validation

-The Pearson correlation coefficient of Prior & Posterior of the 1stand 2nditeration gave a value of r=0.9163 and r=0.9324 respectively.

-Conclusively, the Pearson reliability test on the research work came up perfectly well; this is an indication of a well distributed data. Hence Null hypotheses was accepted which implies that there are relationships between the watershed purposes and objectives at Chi-square value of 12.45304 which is less than the critical value of 23.54 at 0.10 significant.

Integrated Water Resources management in Cross River basin

The various purposes under consideration at the 2nd iteration with expected profit for perfect information has the following demand values(Table 18):

Hydropower = 20.43; Water Supply = 34.28; Navigation = 2; Irrigation =34.4; Environmental = 1

The result above gave the indication that there is relatively high demand for water supply for domestic use and irrigation for agricultural crops. However, the researcher is recommending inter dam water transfer within the watershed to take care of water demand imbalance in the system. If this management decision is imbibed on, it will increase the production of cereal in the eastern part of Nigeria comparative with that of Northern Nigeria. These decisions also support FGN Initiatives in establishing more Dams in Cross River watershed to checkmate on food security, most especially Rice production which has been confirmed to be doing extremely well based on research and information received.

Contribution to Knowledge

The author developedBDT Excel Algorithms and Flow Chart aimed for learning in Higher Institution. I hope it will give a good idea about the exciting nature of Bayes' Decision Model.

The study can provide an organized baseline for future work, mainly in obtaining superior estimates for institutional water use and planning conjunctive uses of water resources. However, the findings of the study can be vital input into the demand management process for long term sustainable water supply within the region and beyond.

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