DEVELOPING WATER INDICES FOR DISTRIBUTING INCREASED NILE WATER YIELD AMONG THE NILE BASIN COUNTRIES

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ABSTRACT

The River Nile is one of the longest rivers in the world. It is shared by ten countries, all in varying states of development. Numerous studies indicate Nile water resources are not fully utilized. In fact, the Nile Basin's riparian countries utilize less than 50% of the river's total water resources. Cooperation amongst these countries has been recently encouraged to decrease river water losses and increase the water yield. In this study, expected water yield increase (losses saved) is divided amongst the riparian countries based upon each country's "water index". These indices are developed using several parameters that characterize/individualize each country, including its present available water resources and average water per capita as well as its population, aver-age income, future water demand and the dependence of the country's income on agri-culture and other resources. It was found that the most critical and difficult aspects of developing such indices is interlinking economic, social, institutional and environmental factors. All considered, the water index has a substantial and potentially equitable effect when estimating each country's share of the increased water yield.

INTRODUCTION

The Problem of allocating a limited water supply among a river riparian countries is not new. Reaching an agreement on the equitable allocation of an international river basin is a complex matter. For the principle of equitable use to be applied, there must exist a measure of equity. This measure should be relatively simple for each state to measure and determine its water share.

The Helsinki rules give some indications about the factors which could be taken into consideration. These factors include geography , Hydrology, climate, Past and present utilization, economic and social needs, population dependent on the water, comparative costs of alternative means to meet needs, availability of other

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resources, avoidance of unnecessary waste, practicability of compensation , and degree to which needs of one state can be met without substantial injury to another. Because of the difficulty of including all these factors in developing water indices of allocating the increased river Nile yield among the basin countries, only some of these factors have been used.

LITERATURE REVIEW

Different studies have been done to approach the equitable utilization of international river basins. Jong, 1995, recommended some steps to be taken in order to achieve optimum utilization of the Nile river water resources. These steps include:

a) A negotiating body for the basin needs to be established with a mandate to develop a strategy aimed at optimizing the water resources for the benefit of all.
b) The ground rules, including the choice of parameters to form the basis for an allocation formula, need to be agreed to by all relevant governments at an early moment.
c) A strategy should be formulated, with hydrological by significant and reliable allocations.
d) An institutional framework needs to be defined to ensure the smooth implementation of the strategy, including a mechanism to incorporate up to date hydrological socio-economic data into the allocation mechanism.

Fahmy et al, 1995, investigated the potential in using Multi-criteria Analysis (MCA) for ranking the riparian countries according to their water needs from any future water resources development projects. The investigation included the comparison between the different MCA techniques, the sensitivity of the rank reached to weight uncertainty and effect uncertainty. Socio economic issues and political aspects of the integrated river basin development are explicitly addressed through MCA.

Zarour et al, 1994, presented a formula for sharing international water resources. The formula is based on the concept of natural capacities and is compatible with the principles of international law.

Colombi, 1995, gives the principle of equitable utilization of the waters of the Nile which might actually be applied and the tools needed to determine the abstractions to which each country might be entitled and the monitoring needed to ensure compliance.

Thiessen et al, 1992, addressed the negotiation process required when there are multiple decision makers with conflicting objectives. He described a computer Program designed to assist such negotiation processes. This interactive computer assisted negotiation support system is designed for dynamic, muti-issue, multi-party negotiation problems.

HOW CAN WE DEVELOP A COUNTRY WATER INDEX?

A Country Water Index (CWI) can be developed by reducing measurements of two or more water factor variables to a single number or a set of numbers, words, or symbols that retain the meaning through a sequence of mathematical manipulations. Conceptually, a CWI is viewed as consisting of two fundamental steps:

a) Calculation of the sub-indices for the factor variables used in the index.
b) Aggregation of the calculated sub-indices into the overall index.

Suppose we are considering a set of numbers for Z factor variables, in which x_1 denotes the value for the first factor variable, x_2 denotes the value for the second factor variable, x_z denotes the value for the z^{th} factor variable. Then the set of numbers is denoted as $(x_1,x_2,x_3,\ldots\ldots\ldots,x_z)$. For each single water factor parameter variable x_z, a sub-index I_z is computed using sub-index function $f_z(x_z)$:

$$I_z = f_z(x_z) \quad (1)$$

Each sub-index function may consist of a simple multiplier, or the water factor variable raised to a power, or some other functional relationship.

Once the sub-indices are calculated, they should be aggregated together in a second mathematical step to form the final index:

$$I = g(I_1, I_2, I_3, \ldots\ldots\ldots, I_z) \quad (2)$$

The aggregation function usually consists either of a summation operation in which individual sub-indices are added together or a multiplication operation, in which a product is formed of some or all of the sub-indices, or a maximum operator, in which just the maximum sub-index is reported.

SELECTION OF WATER FACTOR PARAMETERS ON WHICH THE INDEX IS BASED

According to Helsinki rules, there are many water factor parameters which might be used in developing the country water Index. Some of these parameters have much more effect than the others. Therefore, it appears practical to use only those characteristics that are of greatest significance.

In the present study, six factors have been considered in developing CWI. These factors include:
1- Water availability in each Nile basin country.
2- Country population.
3- Population growth in each country.
4- Agriculture percentage in each country GNP.
5- Percentage of water withdrawal of total available water resources.
6- Country basin area.

Table (1) shows the values of the water factors which is used in developing CWI. Because of the shortage of data available about Eritria, only data of 9 Nile Basin Countries are used.

Table (1) Values of Water Factors Used in Developing CWI

Country	(1) $(10^9\ m^3)$	(2) (1992) (10^6)	(3) (%)	(4) (%)	(5) (%)	(6) $(10^3 * Km^2)$
1-Burundi	3.6	5.8	3.6%	63%	2.8%	28
2-Egypt	58.9	59	2.6%	16%	98%	1002
3-Ethiopia	110	50.3	3.1%	45%	2%	1131
4-Kenya	15	25.4	4.2%	26%	7.4%	583
5-Rwanda	6.3	7.4	3.8%	40%	2.4%	26
6-Sudan	120.8	25.9	2.7%	32%	14.3%	2506
7-Tanzania	76	27.2	3.3%	55%	0.6%	945
8-Uganda	66	19.3	3.4%	72%	0.3%	236
9-Zaire	1019	39.9	2.9%	32%	0.1%	2345

Sources : INBA. Bulletin, Vol. I (2), 1995
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DEVELOPMENT OF FUNCTIONS FOR SUB-INDICES

To develop a CWI, it was rational to start by defining the mathematical function to be used to calculate the sub-indices.

It is fundamental to find valid mathematical functions relating water factor variables to their effects on Nile Basin country water share. The Nile Basin can be considered as a one unit divided into subunits (countries). Each country has its water share according to the water factor part it has relative to what the whole

Basin has. Accordingly, Both population and area sub-indices can be calculated using these functions:

$$I_{i,j} = x_{i,j} / \sum_{i=1}^{i=n} x_{i,j} \qquad (3)$$

Where

i = 1, ……n, j = 1,…….m
n = No. of countries
m = No. of factors
$I_{i,j}$ = Country i sub-index due to factor j
$X_{i,j}$= Water factor number related to country i and factor j

To calculate the population growth sub-index, the population growth in the next 25 years was first estimated for each country $x_{i,3}$ then the sub-index is estimated using equation (3).

% Agriculture sub-indices ($I_{i,4}$) are calculated by first estimating the value of the agriculture production ($X_{i,4}$) and then using equation (3) to find the sub-indices. To Calculate % withdrawal sub-indices ($I_{i,5}$), the water volume withdrawal of each country is first estimated ($X_{i,5}$) and then equation (3) is used to find each country sub-index.

The calculation of water availability sub-indices ($I_{i,1}$) is slightly different. It is clear that as the water availability increase, the sub-index should decrease. Two steps have been followed to estimate these sub-indices:

$$a_{i,1} = X_{9,1}/X_{i,1} \qquad (4)$$

$$I_{i,1} = a_{i,1} / \sum_{i=1}^{i=n} a_{i,1} \qquad (5)$$

Where:

n = No. of countries
$X_{i,1}$ = Water availability factor number related to country i
$I_{i,1}$ = Water availability country sub-index

Table (2) shows the sub-indices of the different water factors.

Table (2) Subindices of Different Water Factors.

Country	(1)	(2)	(3)	(4)	(5)	(6)
Burundi	0.49	0.022	0.027	0.038	0.002	0.003
Egypt	0.03	0.227	0.176	0.234	0.719	0.114
Ethiopia	0.016	0.193	0.191	0.124	0.027	0.128
Kenya	0.118	0.098	0.151	0.105	0.014	0.066
Rwanda	0.28	0.028	0.038	0.033	0.002	0.003
Sudan	0.015	0.10	0.081	0.128	0.215	0.285
Tanzania	0.023	0.105	0.113	0.102	0.006	0.107
Uganda	0.027	0.074	0.084	0.148	0.002	0.027
Zaire	0.002	0.153	0.138	0.089	0.013	0.266

SELECTION OF AN AGGREGATION FUNCTION

Once the sub-indices are calculated, the aggregation process starts to reduce the information. This process is the most important step in developing a CWI. Aggregation of sub-indices reduced the number of sub-indices and adds analytical and interpretive value to the process.

There are many different aggregation functions which can be used. Weighted linear sum form is the function which is used to calculate CWI and can be presented mathematically as:

$$(CWI)_i = \sum_{j=1}^{m} I_{i,j}\, W_j \qquad (6)$$

$$\sum_{j=1}^{m} W_j = 1 \qquad (7)$$

where:

$I = 1, 2, \ldots\ldots\ldots, 9$

$m = 6$

W_j = Weight given to a water factor

Six different cases have been studied where a priority was given to one or more of the water factors with a higher weight (W_j) than the others. These six cases are:

Case (1) : $W_5 = 2/7$, $W_1=W_2=W_3=W_4=W_6=1/7$

Case (2) : $W_3=W_5=1/4$, $W_1=W_2=W_4=W_6=1/8$

Case (3) : $W_3=W_4=W_5=2/9$, $W_1=W_2=W_6=1/9$

Case (4): $W_1=W_3=W_4=W_5=1/5$, $W_2=W_6=1/10$
Case (5): $W_1=W_2=W_3=W_4=W_5=2/11$, $W_6=1/11$
Case (6): $W_1=W_2=W_3=W_4=W_5=W_6=1/6$

In these different cases a priority was given first to the percentage water withdrawal and then to the population growth, percentage agriculture in GNP, water availability, population, and country area.

Figures (1) to (6) show the Nile Basin countries indices for the six different cases. It is noticed from these figures that Egypt has the highest index and consequently the highest water share, which ranges between 0.25 and 0.317. Sudan has the second highest CWI and ranges between 0.124 and 0.148. Uganda has the lowest water share which ranges between 0.052 and 0.066 followed by Rwanda which has a share ranges between 0.051 and 0.074. These water indices can be easily used in distributing the expected increased Nile Water yield among the Nile Basin countries. Figure (7) shows the average CWI of each country

CONCLUSION

Simple country water indices (CWI) applicable for dividing the increased Nile Water yield among the different riparian countries have been developed. These indices take into consideration different factors which represent the country and have a considerable effect when estimating the country's share of the increased water yield. These factors included the water availability, population, growth population, % Agriculture in GNP, % country's water withdrawal of its water Resources, and country's area. The results show that Egypt has the highest water Index which ranges between 0.250 and 0.317 while Uganda has the lowest water Index which ranges between 0.052 and 0.066.

RECOMMENDATIONS

The procedure used in developing the Indices by suggesting different weights for each factor is a trial to put different priorities for the different factors. It is recommended that the different parties involved in the problem of determining the water share should decide together the different weights of the different water factors before using the previous procedure to develop the water indices.

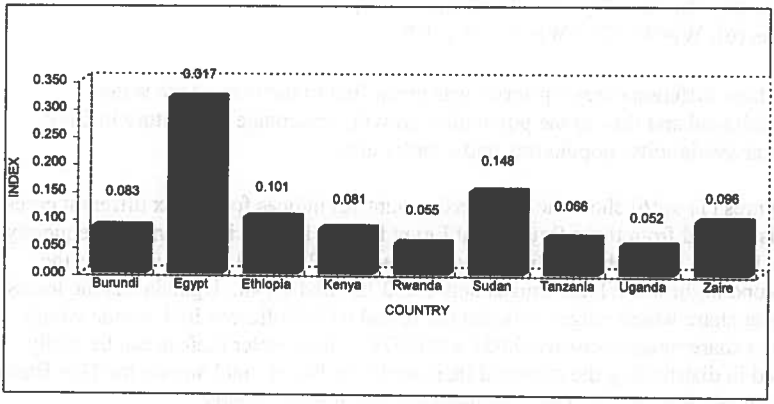

Fig. 1. Nile Basin Countries Indices (Case 1)

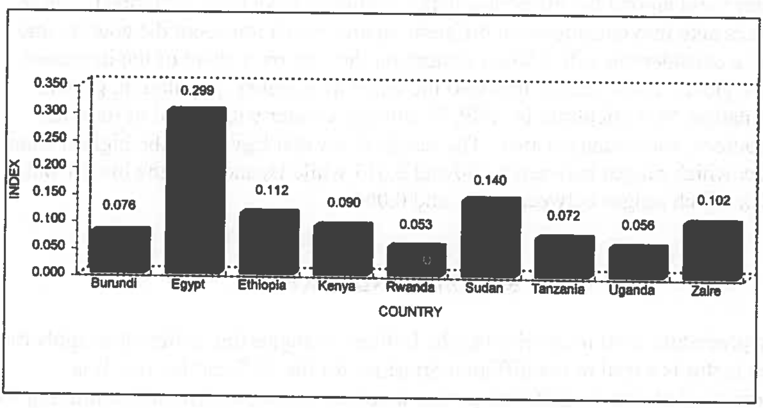

Fig. 2. Nile Basin Countries Indices (Case 2)

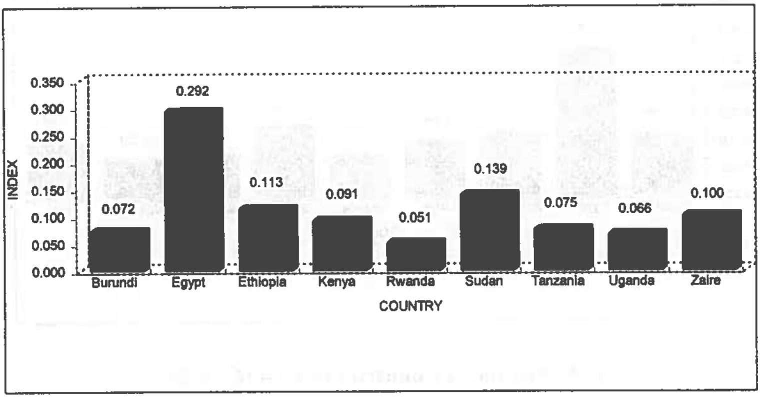

Fig. 3. Nile Basin Countries Indices (Case 3)

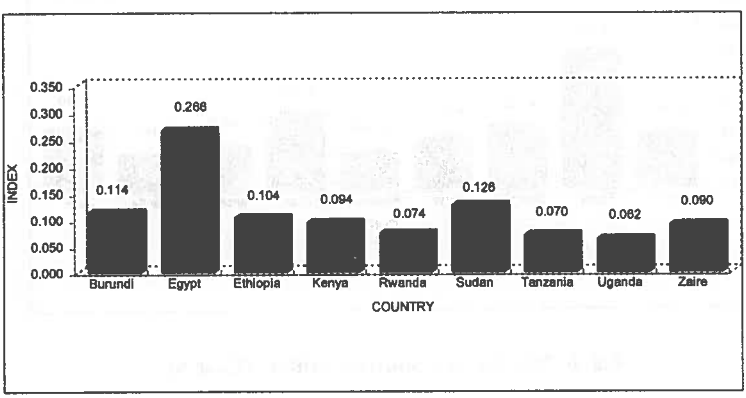

Fig 4: Nile Basin Countries Indices (Case 4)

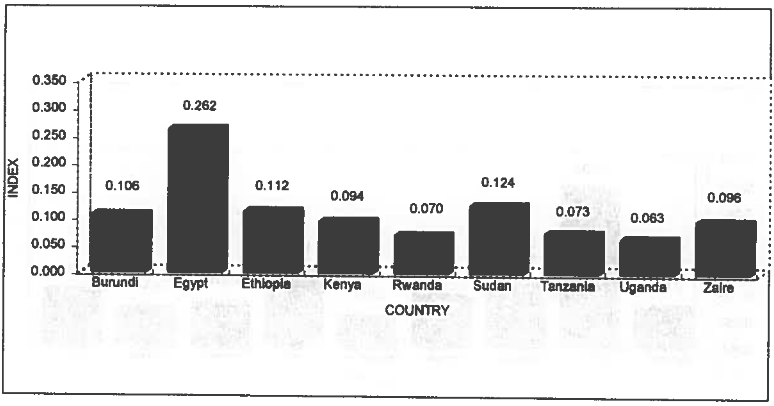

Fig 5: Nile Basin Countries Indices (Case 5)

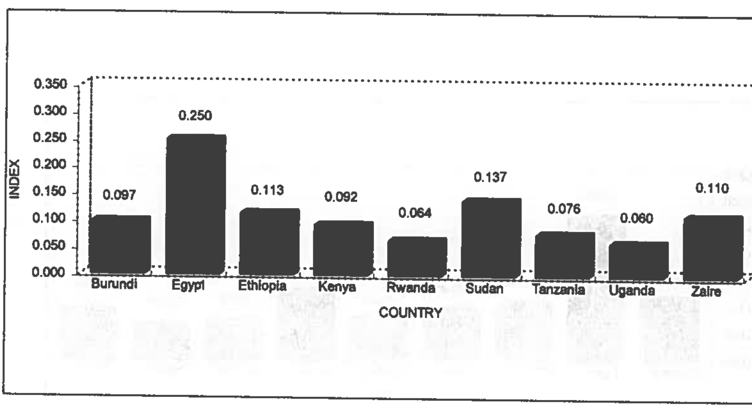

Fig. 6. Nile Basin Countries Indices (Case 6)

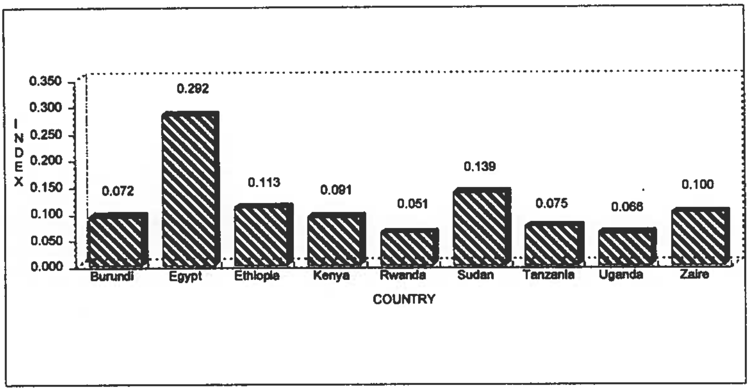

Fig. 7. Nile Basin Countries Average Indices

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