https://erjm.journals.ekb.eg
ISSN: 1110-1180

DOI: ---------

ERJ
Engineering Research Journal
Faculty of Engineering
Menoufia University

Improved Multidimensional Method for Management Water Scarcity Using Water Poverty Index at Different Scales

Mohamed Ahmed Reda Hamed

Civil Engineering Department., Canadian International College (CIC), El Sheikh Zayed, Giza, Egypt. E-mail: moha_hamed@cic-cairo.com

ABSTRACT

Regarding water resources, the Egypt governorate facing many sustainable availability challenges. Evaluating indicators can be developed to represent the various water environment aspects related to the governorate's target planning, management, and security. In this respect, the water poverty index is universally utilized, but one of the existing reactions incorporates the overall accuracy related to its involved components, criteria, and indicators weighting approaches. Thus, this research proposes an improved multidimensional method for accurate water poverty index (WPI) estimation to overcome the indices overview limitations. However, three integrated approaches based on a principal component analysis (PCA) framework are introduced to facilitate the assessment and represent the interrelationship between WPI's main linked components and their involved combined indicators. On the basis of the newly developed index, this study evaluates the current water poverty in various Egyptian governorates to determine the relative water poverty challenges between them.

In addition, the study concludes that with this approach, WPI can determine the responsible parameters that cause water poverty and their inverse reflection on water infrastructure and provide detailed information on social fragilities as well.

Keywords: *Principal Component Analysis, Water Infrastructure Investment, Water Poverty Index, Water Resources.*

1. Introduction

The Water Poverty Index can be considered one of the important multidimensional indicators for evaluating water adequacy, sustainability, and resilience to socio-economic factors of poverty [1]. Moreover, it was obvious that the main weakness in different water poverty indices methodologies they're transferring the weighting of the indicators and aggregating them into one composite index [2].

Egypt has successfully managed many consecutive plans to move forward in the water sector development that aimed to maximize the economic value of their water resources. These integrated plans are taken into their consideration including implementation of new water desalination plants, water leakage reduction, water treatment plants rehabilitation, agriculture performance [3].

The application of principal components analysis (PCA) methods have many superior advantages in optimizing water resources management, especially in various cases of complicated data sets [4].

PCA is a special statistical method involving linking the interrelated variables with the aim of limiting the number of variables and consequence developing particular dominant variables [5].

In Brasil, Maia, et al, (2019) uses PCA to develop a new WPI for Seridó river basin. This developed index facilitates the accurate determination of the distinctive geographical locations that suffer from relatively high values of water poverty [6].

This study aims to provide a conceptual framework that accurately supports determining WPI through an enhanced adaptation mechanism for improving water resource management planning in Egypt's governorate. Thus, for developing the required index, the PCA method is chosen due to its superior capability to link the multidimensional interrelationship of water poverty components and indicators.

2. Study area

The study area includes twenty-two Egyptian governorates; (Kafr EL-Sheikh, Gharbia, Dakahlia, Domiat, Sharkia, Menofia, Qalubia Behaira, Alexandria, Ismailia, Sewis, Port Said, and Cairo) governorates are located in Lower Egypt. While (Giza, Bani Sewif, Fayoum, and Minya) are located in Middle Egypt and five governorates are located in Upper Egypt: Asiut, Sohaj, Qena, Luxor, and Aswan), Figure 1.

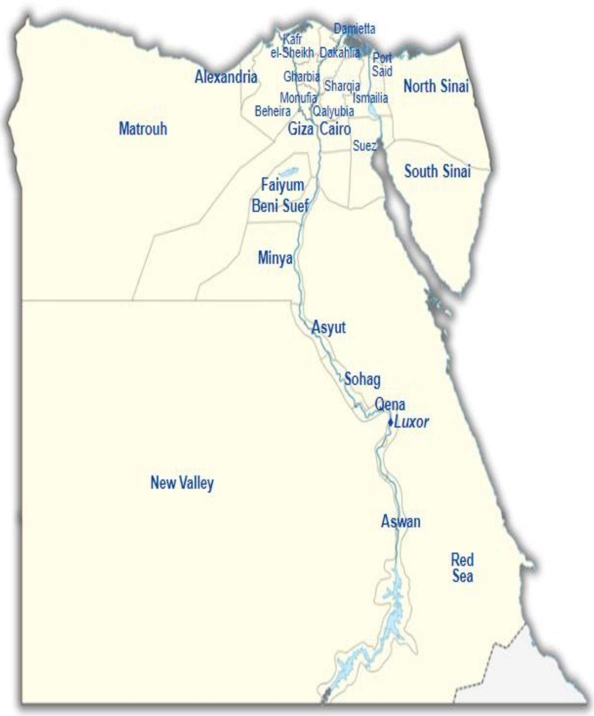

Figure 1- The Egyptian Governorates

3. Water Poverty Index Developing Methodology

In order to accomplish the study objective, the interrelated hierarchy steps were implemented to develop the improved multidimensional water poverty index as shown in Figure 2.

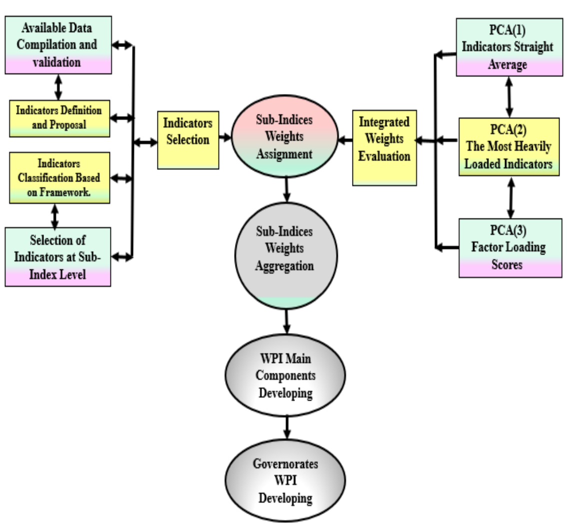

Figure 2- WPI Developing Methodology

4. Water Poverty Index Framework Structure

4.1 Selecting the WPI Components and Indicators

Five main components and twenty-five indicators are selected based on literature reviews recommendations and their Egyptian conditions relevancy to measure the proposed multidimensional water poverty index. Table 1 illustrates the main WPI components and their corresponding indicators.

Table 1- WPI Components and Indicators Outlines

Main Component	Main Component	Data Source
Resources	*R1: Water Quantity Sufficiency*	[7]
	R2: Supply Reliability	[7]
	R3: Water Resources Variability	[6]
Access	Water Safe :A1 Accessibility	[8]
	Accessibility Sanitation :A2	[8]
	A3: Distance to Water Source	[8]
	Waiting Maintenance :A4 Time	[8]
	Service Cost Water :A5	[8]
	A6: Water Source Operational Status	[8]
Capacity	C1: Education index	[9]
	Water Services :C2 ivationPr	[7]
	C3: Gross Domestic Product (GDP) Per Capita Index	[10]
	C4: Under-Five Mortality Rate	[10]
	Control Financial :C5	[9]
	Related -C6: Gender Development	[9]
USE	Consumption Water :U1 Rate	[10]
	U2: Conflict Over Water Sources	[7]
	ocal Water Treatment U3: L Use	[7]
	aterW gricultureA :U4 Sharing	[11]
	Sharing aterW U5: Industrial	[11]
Environment	E1: Water Quality Index	[12]
	Sources E2: Water Protection	[12]
	E3: Number of Pollution Sources	[12]
	Environmental Impacts :E4	[12]
	E5 Agricultural Drainage Indicator	[13]

4.2 Sub-Indices Weights Assignment

According to the indicator's classification framework, the main components of the WPI were determined based on three various approaches with regard to the conceptual weighting of indicators to each component. Meanwhile, the three developed alternatives based on these approaches' analysis are: -

Alt. (1): involved in determining a straight average of all indicators. This alternative has the merit of its simple calculation process [13].

Alt. (2): in this alternative, PCA has utilized the sub-indices weights based on that most collected data representative availability. However, in this weighting manner, the Resources component the variable "Water Resources Variability" was preferred to "Supply Reliability"; to assess the access sub-index. Likewise, "Safe Water Accessibility" appeared to be more straightforward than "Distance to Water Source". Meanwhile, in the capacity component, "GDP Per Capita Index" was chosen instead of "Gender-Related Development".

Alt. (3): PCA as a factor loading scores were introduced to determine sub-index weights. Thus, PCA was weighted based on the variance percent of the involved variables concluded from the first principal component of each specific component.

4.2 Weights Aggregation

Additive and geometric main aggregation methods were used for the five components interrelated linkage in specific indexes. The weights were firstly set according to the statistical structure of the data set. In the two cases, weights were imposed to be nonnegative and their summation value tends to one. However, six alternatives are developed for both PCA additives: PCA $_{(AD1)}$, PCA $_{(AD2)}$, and PCA $_{(AD3)}$ systems and PCA geometric: PCA $_{(GE1)}$, PCA $_{(GE2)}$, and PCA $_{(GE3)}$ systems. Moreover, the final WPI score are calculated according to eq. (1) , [15].

$$WPI=w_rR+w_aA+w_CC+w_uU+w_eE \quad (1)$$

Where, wr, wa, wc, wu, and we are the applied weights for each sub-index, R is the resource sub-index value, A is the access sub-index value, C is the capacity sub-index value, U is the use sub-index value, and E is the environment sub-index value.

After that, the cumulative average WPI for each governorate is calculated according to eq. (2): -

$$\text{Cumulative average WPI}= (WPI_{(AD1)} + WPI_{(AD2)} + WPI_{(AD3)} + WPI_{(GE1)} + WPI_{(GE2)} + WPI_{(GE3)}) /6 \quad (2)$$

Where, WPI $_{(AD1)}$, WPI $_{(AD2)}$, and WPI $_{(AD3)}$ are the additive WPI for PCA $_{(AD1)}$, PCA $_{(AD2)}$, and PCA $_{(AD3)}$ respectively. While, WPI $_{(GE1)}$, WPI $_{(GE2)}$, and WPI $_{(GE3)}$ are the geometric PCA $_{(GE1)}$, PCA $_{(GE2)}$, and PCA $_{(GE3)}$.

In addition, the final score of WPI is categorized into five main classes as shown in Table 2.

Table 2- WPI Classification

WPI	Class	Explanation
0.2 - 0	Very Poor	Governorate water sector strategy reform is mandatory required
0.4 – 0.2<	Poor	An immediate action plan for water poverty causing components are required
0.6 –0.4<	Good	Medium priority action plans for improvement governorate water sector strategy are required
0.8 –0.6<	Very Good	Relatively limited priority attention for governorate water sector strategy
1.0 –0.8<	Excellent	Having an excellent classification. However, comparing the index between governorates is preferred.

5. Results and Discussion

Table 3 illustrates the weighted indicators results of the three proposed alternatives.

Table 3- Weighted Indicators Results

Main Component	Indicator Weight			
	Indicator	Alt. (1)	Alt. (2)	Alt. (3)
Resources	R1	0.333	0.400	0.415
	R2	0.333	0.200	0.294
	R3	0.333	0.400	0.292
Access	A1	0.167	0.200	0.112
	A2	0.167	0.200	0.219
	A3	0.167	0100	0.141
	A4	0.167	0.100	0.122
	A5	0.167	0.200	0.207
	A6	0.167	0.200	0.198
Capacity	C1	0.167	0.233	0.228
	C2	0.167	0.233	0.214
	C3	0.167	0.233	0.138
	C4	0.167	0.100	0.122
	C5	0.167	0.100	0.148
	C6	0.167	0.100	0.150
USE	U1	0200	0.220	0.255
	U2	0200	0.220	0.156
	U3	0200	0.120	0.145
	U4	0200	0.220	0.224
	U5	0200	0.220	0.225
Environment	E1	0200	0.210	0.248
	E2	0200	0.210	0.235
	E3	0200	0.160	0.094
	E4	0200	0.210	0.174
	E5	0200	0.210	0.248

It is clear that high relative differences occur with Alt. (2). In addition, Figure 3 shows the overall main components weights are calculated by using both PCA additives: PCA $_{(AD1)}$, PCA $_{(AD2)}$, and PCA $_{(AD3)}$ systems and PCA geometric: PCA $_{(GE1)}$, PCA $_{(GE2)}$, and PCA $_{(GE3)}$ systems.
It is clear that high relative differences occur with Alternative (2). Furthermore, Figure 3 shows the overall main components weights are calculated by using both PCA additives: PCA $_{(AD1)}$, PCA $_{(AD2)}$, and PCA $_{(AD3)}$ systems and PCA geometric: PCA $_{(GE1)}$, PCA $_{(GE2)}$, and PCA $_{(GE3)}$ systems.

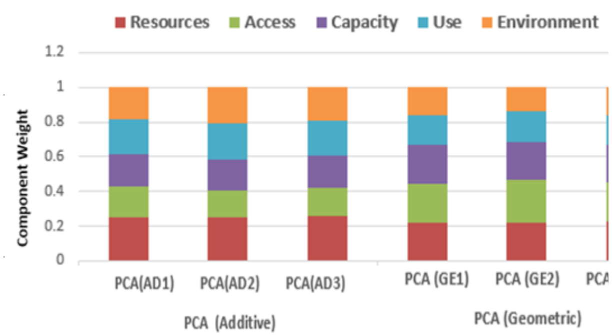

Figure 3- WPI Main Components Weights

In addition, Table 4 illustrates governorates WPI of both additive and geometric for all the three developed alternatives.

Table 4- Governorates WPI Additive and Geometric

Governorate	WPI (AD1)	WPI (AD2)	WPI (AD3)	WPI (GE1)	WPI (GE2)	WPI (GE1)
Alexandria	0.49	0.50	0.51	0.45	0.44	0.43
Behera	0.43	0.44	0.45	0.40	0.41	0.39
Menofia	0.32	0.34	0.35	0.30	0.29	0.28
-Kafr el Sheikh	0.38	0.36	0.39	0.32	0.31	0.33
Gharbia	0.42	0.43	0.45	0.40	0.37	0.36
Dakahlia	0.44	0.46	0.45	0.41	0.40	0.39
Domiat	0.53	0.54	0.56	0.49	0.46	0.44
Port Said	0.49	0.48	0.47	0.42	0.38	0.40
Ismailia	0.51	0.49	0.52	0.43	0.41	0.43
Sharkia	0.37	0.38	0.39	0.30	0.29	0.31
Qalubia	0.44	0.45	0.47	0.36	0.34	0.33
Giza	0.55	0.58	0.59	0.47	0.51	0.48
Fayoum	0.29	0.31	0.32	0.26	0.23	0.22
Cairo	0.75	0.76	0.78	0.64	0.67	0.71
Sewis	0.68	0.69	0.67	0.58	0.61	0.60
Bani Sewif	0.25	0.28	0.29	0.20	0.17	0.16
Minya	0.24	0.26	0.29	0.16	0.15	0.13
Asiut	0.31	0.33	0.34	0.21	0.22	0.20
Sohaj	0.28	0.31	0.30	0.23	0.20	0.210
Qena	0.38	0.37	0.39	0.29	0.28	0.240
Luxor	0.38	0.37	0.39	0.30	0.31	0.320
Aswan	0.49	0.48	0.47	0.39	0.38	0.370

Moreover, the WPI was calculated at a cumulative average scale of the six remaining support functions to determine the relative water stresses in Egyptian governorates and consequences go forward for preparing planning stages according to WPI the water sector important guideline, Figure 4.

.

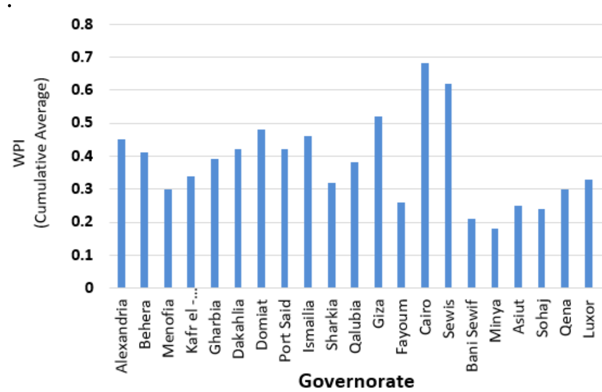

Figure 4 - WPI Egyptian Governorates

It is obvious that water poverty levels suffer from a relatively lower value in the case of geometric function use.

From figure (4), it can be noted that the calculated WPIs of the Egyptian governorates have relatively extended scores from 0.18 to 0.68. This requires a very high level of attention from policymakers, among whom the administration has a very poor WPI. In addition to that, eleven governorates: Bani Sewif, Sohaj, Asiut, Fayoum, Qena, Menofia, Behera, Sharkia, Luxor, Kafr el-Sheikh, and Qalubia have poor WPI. Thus, these mentioned governorates can be allocated as second interest level with respect to water sector country strategy. Moreover, eight governorates: Gharbia, Dakahlia, Port Said, Aswan, Alexandria, Ismailia, Domiat, and Giza have good WPI. These governorates can be ranked in the third priority level of water sector country strategy. Same as the Cairo governorate Swiss governorate has a very good WPI.

6. References

[1] El-Gafy I, El-Ganzori A, Mohamed A., (2015), the Decision support system to maximize the economic value of irrigation water at the Egyptian governorates meanwhile reducing the national food gap.

[2] Wagdy A. (2008). Progress in water resources management: Egypt, proceedings of the 1st technical meeting of Muslim water researcher's cooperation (MUWAREC) Malaysia.

[3] Shrestha, S., Kazama, F., (2007), Assessment of surface water quality using multivariate statistical techniques: A case study of the Fuji river basin, Japan Environmental Modelling & Software, 22(4): 464-475.

[4] Wulder M., (2007), A practical guide to the use of selected multivariate statistics.

[5] Larynne Dantas de Senna1, Adelena Gonçalves Maia and Joana Darc Freire de Medeiros, (2019), The use of principal component analysis for the construction of the Water Poverty Index, Brazilian Journal of Water Resources, Brasil.

[6] Water Resources Management Institute, (2017), Urban Flood Damage in Egypt.
Cairo: Water Resources Management Institute, NWRC.

[7] Holding Company for Drinking Water and Sanitation, Egypt, Annual Report, (2017).

[8] United Nations Development Program (UNDP) and The Institute of National Planning Egypt (INPE),(2017), Egypt.

[9] Information and Decision Support Center (IDSC), (2017), Description governorates of Egypt with information.

[10] Ministry of Planning, (2018), Gross Domestic Product estimation. Cairo: Ministry of Planning, Egypt.

[11] EEAA., (2018), Water Quality Status report. Cairo: EEAA.

[12] Central Agency for Public Mobilization and Statistics (CAPMAS). Statistical year book, Egypt, 2018.

[13] Sullivan, C., (2002), "Calculating a Water Poverty Index." World Dev., 30(7), 1195–1210.

[14] El-Sherbini A, El-Moattassem M., (1994), River Nile water quality index during high and low flow conditions. In: National conference of the river Nile. Assiut University Center for Environmental Studies (AUCES).