Weighting of water resources vulnerability factors in the context of global environmental change in the Sebou basin: case of Fez, Ifrane and Meknes perimeters (Morocco)

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***Abstract*— *Water resources are at the center of all developments, whether it is a society or a living organism. It is rightly noted that the state of water resources around the world is no longer, what it once was because of the strong pressures resulting from global environmental change and human activities. Undertaking vulnerability assessments of water resources is a necessary and rapid need to spatially delineate the areas likely to be impacted. The main purpose of this study is to identify with water resource management experts a set of factors considered relevant, and to know the relative contribution of each factor in terms of vulnerability. To this end, the opinions of 32 water resource management experts were collected in order to define and weigh the factors of water resource vulnerability in the Sebou basin. The result of this survey shows that 25 factors divided into 5 components (hydrology, pollution, socioeconomics, environment, and eco-environment) of vulnerabilities are likely to affect the state of water resources in the area. The application of multiple factor analysis under R software for data processing to reduce dimensions has shown that 15 out of the 25 factors are the most important in terms of water resource vulnerabilities according to experts' opinion. The weights of these 15 factors and the 5 components of water resources vulnerability are different from each other, which highlights the relative nature of water resources vulnerability. This can help water managers to be more effective and relevant in water resource vulnerability analysis tools.*

Keywords*— *water resource vulnerability, Vulnerabilities, vulnerability factors, water resources, factor weighting, water resource management.

I. INTRODUCTION

Water resources are at the center of all developments, whether it is a society or a living organism. It is accurately noted that the state of water resources around the world is no longer, what it was once. Rapid population growth, significant industrialization of societies, and global climate change are potential causes of water resource vulnerability [1](Pandey et al., 2010). Indeed, as the population and economy increase, as human-induced climate change accelerates, so does the pressure on regional water resources [2]. In a natural way, the distribution of water resources throughout the world is unevenly distributed [3], due to the physical and environmental characteristics of each locality, however the human dimension such as urbanization, and poor water management arevery important in the scarcity and vulnerability of water resources[1]. The notion of vulnerability in water resource management has a long history[1, 4]. However, Gleick [2]argues that there are many challenges to any effort to develop a water resources vulnerability assessment tool: the definition of vulnerability, the vulnerability indicators section, data availability and quality. Studies conducted around the world and in recent decades on water resource vulnerability assessments have presented several definitions of the term "vulnerability" and the definitions are still based on the environmental problems encountered, the objective of the study and the availability of data [4]. Several methods for assessing pressure on water resources

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have been developed to estimate this pressure quantitatively in the form of indices [2]. Padowski et al[3]estimate that many indices and indicators have been developed to improve understanding of water scarcity and identify areas at risk of vulnerability. Kanga et al[4]report that the methodological approaches to water resources vulnerability assessment developed in recent decades aim at a holistic conceptualization of the water resources system taking into account all components of vulnerability: these are the physical, environmental, socio-economic, institutional and governmental dimensions. It is imperative, nowadays, to recognize the links between socio-economic, cultural and institutional factors in a water resource system [5]. The assessment of water resource vulnerability depends on the context and specificities to each case study [5]. As a result, the factors used in the vulnerability assessment framework are so many and relative [4]. Winograd et al[6]argue that there is no single set of factors that is applicable in all contexts and that the selected vulnerability factors should be closely linked to the context of the study. Sonhs et al[7]have inventoried, through a qualitative study of the existing literature, the factors contributing to the vulnerability of household water in the Arctic. Kanga et al[4]also inventoried, with a systematic review of the international scientific literature, the tools (including factors) for the vulnerability of water resources at the local level. Several researchers [8, 9]have previously expressed the need to provide indicators for water resource vulnerability assessments. In Morocco, the problem of water stress is increasingly felt. Studies on the vulnerability of water resources have already been carried out [10, 11, 12, 13], but these are partial studies that focus only on the vulnerability of groundwater to pollution. The identification of water resources vulnerability factors in a participatory manner with water sector stakeholders can be a major asset in assessing the impact of different pressures on the entire water system in the area. To our current knowledge, there are no studies to assess the vulnerability of water resources in a multidimensional way of the water system in Morocco. The main purpose of this study is to identify with water resource management experts a set of factors considered relevant, and to know the relative contribution of each factor in terms of vulnerability.

II. MATERIALS AND METHODS

1. The study area

The study area is located in the large Sebou catchment area and extends over two aquifers: the Fès-Meknès aquifer and the aquifer of the Barren limestone plateau. It covers 7 provinces, including 64 municipalities, and covers an area of 5,849 Km^2. The economy is mainly based on agriculture and industry. Water resources are used for crop irrigation but also for drinking water supply to nearby cities. The use of agroinputs was already very high in the study area in 1996 and averaged 66.5% of farms. 51 potential sources of pollution are identified in the study area. Much of the study area has clayey textured soil, especially in the northwest, north and northeast. The eastern and central parts are mainly made up of sandy-clay textures. The western part of the study area consists of sandy-clay textured soils.The western part of the study area consists of sandy-silty textured soils and raw minerals. The deep aquifer of Fés-Meknès includes the highly fractureddolomitic limestone formations of the Lias. The thickness of this aquifer varies from a few metersatthe center to 760 m north of the study area. However, the water level is on average 50 m deep in the captive part of the water table and 250 m deep in the non-captive part. The nappe the Barren limestone plateau is juxtaposed with the Fès-Meknès water table and the basaltic aquifer of the Quaternary. The groundwater recharge is mainly provided by infiltration of rainfalls. Wells and boreholes are the means of exploiting groundwater in this area. Annual precipitation is highly variable. Average rainfall between 1988 and 2017 is 479 mm in the north and northeast and 800 mm in the south. The inventory of waterbodies in the study area shows some natural rivers and lakes: Fés river, Guigou river(flow rate: 0 to 54 m3/s), Boufekrane river, Tizguit river, Agay river, and Dayet (lake)Aoua. Figure 1 shows the location of the study area and its land use.

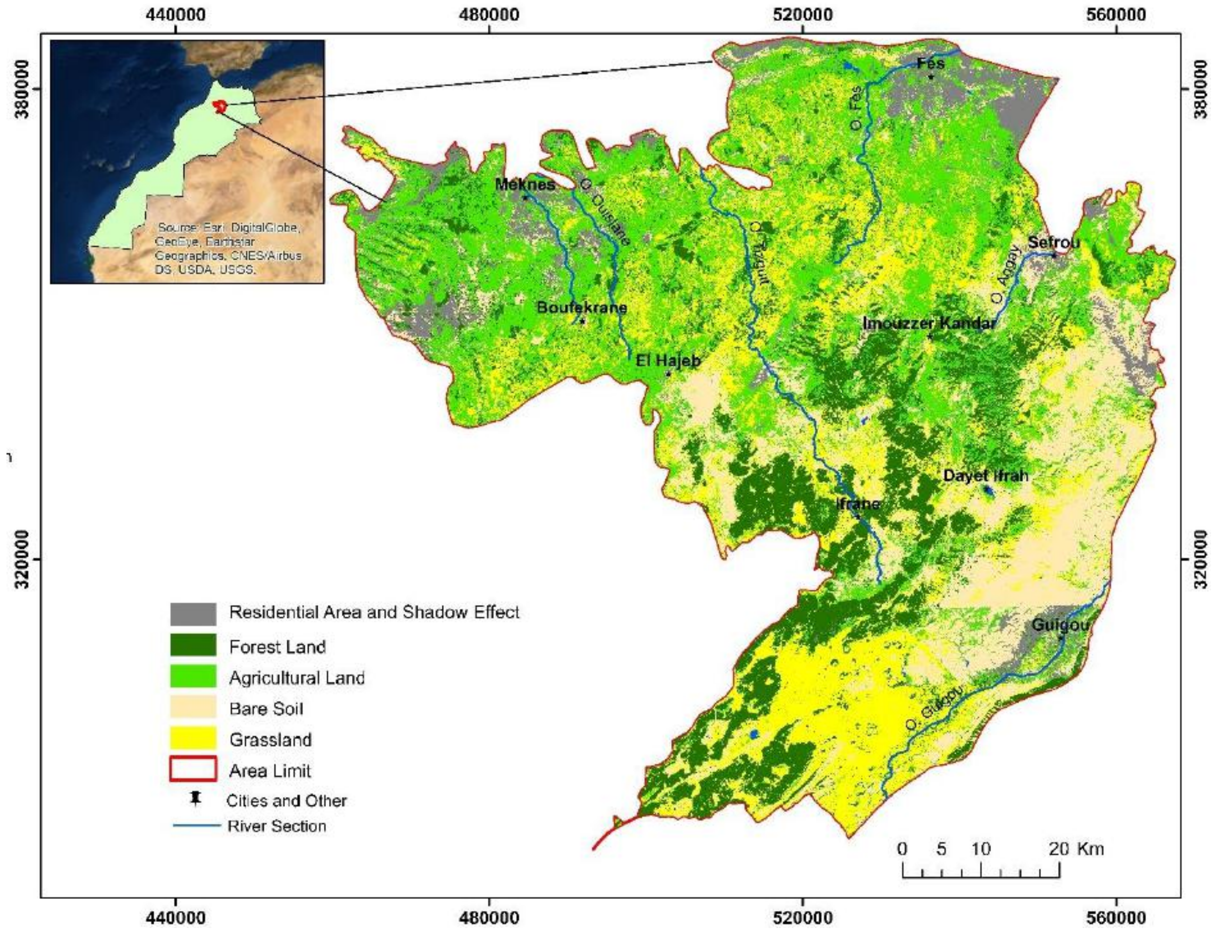

Fig.1:Study area and land use

III. METHODS

The vulnerability factors of water resources do not have the same impacts in terms of vulnerabilities. It is therefore necessary to prioritize them and assign them weights according to their relative contributions. A survey was conductedto identify vulnerability factors and to determine the relative importance of each factor. Several methods of investigating weight attributions through the survey exist in the scientific literature. Kanga et al [4] list several methods of assigning the following weights: the Delphi technique, participatory methods, the budget allocation process, public opinion, etc. The survey method used is very similar to the budget allocation process method reported by OECD[14]. It consists ofdefining the subject of the survey, then based on the definition, inventory a number of factors on a survey sheet, on which water management experts, are asked to assign weights to the various factors in terms of vulnerabilities based on the expert's personal experience. Experts are also asked to suggest other factors they consider important and to reallocate weights. A problem of the study area is summarized on the survey sheet in order to briefly present the study area for experts who are not familiar with the study area. To frame the study in relation to its objective, the notion of "water resources vulnerability" was defined.

1.1. The Survey Process

Four main steps were followed to carry out the survey: definition of the subject of the study, selection of experts, preliminary selection of factors, and assignment of weights by experts.

1.1.1. Define the subject of the study

The purpose of the survey is to assign weights to the importance of a factor in terms of the vulnerability of the water resources system. For the purpose of this survey, the vulnerability of water resources has been defined as follows: "the vulnerability of the water resources system, the degree of fragility or susceptibility with which human activities and natural factors affect water quality and quantity while taking into account society's ability to address these threats to the system in a sustainable manner".

1.1.2. Selection of experts

All water resources management institutions, universities and private firms working in the water sector were identified for the purpose of the survey. In each institution, the sheets are distributed while taking into account the

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expert's potential knowledge on the subject. The range of experts includes officials of the State Secretariat for Water, officials working in the private water sector, university professors, water engineers, and officials of the National Water and Electricity Office. A number of 58 experts were asked to express their opinions on the importance of vulnerability factors. Table 1 presents the category of experts who responded to the questionnaires and their numbers.

Table 1: Category of experts who participated in the survey

Categories of experts participating in the survey	Number
University Professors in the fields of water resources management	3
Engineers in water resource management working in private and publiccompanies	14
PhD students in hydrology, environmental and water management	13
Directors or heads of division of publicwater management agencies	2

1.1.3. Selection of factors

In the field of water resources vulnerability assessment, access to and availability of data is considered a challenge to which the actors involved in water management must respond. Gleick [2], Padowki et al [3] and Simha et al [5] reported that data availability is one of the major challenges in assessing water resource vulnerability. Therefore, the choice of factors was made according to whether the data of a factor can be collected or calculated over several years. Thus, 25 factors were defined in advance taking into account the objective of the study, the characteristics of the study area and how the notion of "water resource vulnerability" was defined. Appendix 1 presents the different factors, their descriptions and impacts on water. Five components of water resource vulnerability are defined in which several factors have been chosen for each component.

1.1.4. Assignment of weights by experts

To each expert addressed, it is to ask to distribute 200 points out of the 25 factors in an instinctive way and according to his personal experience in the management of water resources. Moreover, if there are other factors that the expert considers important but are not on the list, the expert is asked to incorporate them and reallocate the weights to the different factors of water resources vulnerability.

1.2. Determination of the average weights of the components of water resource vulnerability

Experts are not asked to directly weight the components of vulnerability. However, the factors were classified according to vulnerability components. To determine the weight assigned to a component, the weights of each factor constituting the vulnerability component are counted. Moreover, since the components do not have the same number of factors, the number of factors that makes up the vulnerability component divides the total weight for each component. Mathematically,

Let X_{ij} be the sum of the weights of the jth component of water resources vulnerabilities affected by the i^{th} expert, and x_{ij} the weight of each factor j affected by the i^{th} expert.

$X_{ij} = \sum_{i=1,j=1}^{n} x_{ij}$(1)

Let n_j be the number of factors containing the jth component of vulnerability,

$\overline{X_{ij}} = \frac{\sum_{i=1,j=1}^{n} x_{ij}}{n_j}$(2)

With $\overline{X_{ij}}$, the average weight of the jth component assigned by the i^{th} expert.

Let Y_{ij}be the sum of the average weights of each water resource vulnerability component, then:

$Y_{ij} = \sum_{i=1,j=1}^{n} \overline{X_{ij}}$(3)

Let Z_{ij} be the normalized weight for each component of water resources vulnerability, with values between 0 and 1. The relative importance of each vulnerability component is calculated in percentage terms as follows:

$Z_{ij} = \left(\frac{\overline{X_{ij}}}{Y_{ij}}\right)$, with $Z_{ij} \in [0, 1]$ (4)

1.3. Determination of the average weights of the factors of vulnerability of water resources

For each factor, the number of experts who participated in the experiment divided the sum of the weights. The values are then transformed between 0 and 1 by dividing the average for each factor by the total sum of the weights (200).

1.4. Multiple factor analysis and ascendant hierarchical clustering

The data collected were subjected to two types of multidimensional analyses. First, a multiple factor analysis (MFA) was performed, as the table of responses to the questionnaire is presented as Individuals X Groups of quantitative variables. The five groups of variables that have been constituted are as follows: Hydrology (6 variables), environmental physics (2 variables), socio-economics (10 variables), potential sources of pollution (4 variables) and eco-environment (3 variables). In addition, the variables have been reduced, in order to give them the same importance in the calculation of the MFAdimensions. At the end of the MFA, a hierarchical bottom-up classification of its results was carried out in order to see the profiles of the respondents. Finally, it should be noted that all these analyses were performed with the FactoMineR (version 1.34) and R (version 3.5.0) packages.

IV. RESULT AND DISCUSSION

Out of the 58 experts requested, 32 responded to the questionnaire, or 55%. This is because most experts find the survey difficult and time-consuming. The results of this study are presented in two parts: descriptive statistics of the data and the results of the multiple factor analysis.

1. Average weights of the components of water resource vulnerability

The average of each vulnerability component or factor group has been calculated to determine the relative importance of each group in terms of water resource vulnerability. Furthermore, they were transformed into values between (0 and 1). Table 2 presents the relative weight of each component of water resource vulnerability according to experts.

Table 2: Vulnerability components of water resources and their weights from the survey

Component	Hydrologic	Environment	Socioeconomic	Pollution	Eco environment
Mean Weight	8,76	7,25	7,07	8,79	8,98
Transformed Weight	0,21	0,18	0,17	0,22	0,22

The groups of factors "potential sources of pollution", the group "eco-environment" and hydrological factors have the highest values with 0.22;0.22; and 0.21 respectively. While the "physical factors of the environment" and the "socio-economic" factors presented the smallest values with 0.18 and 0.17 respectively. The values are transformed between 0 and 1 since several researchers who assessed the vulnerability of water resources in a multidimensional way transformed all the variables on this scale.In general, factor data are standardized between 0 and 1 also or between 0 and 100 by multiplying by 100. For example, Sullivan [15]ranked the final water resources vulnerability index between 0 and 100 after standardizing data on the same scale, with 0 means no vulnerability and 100 very high vulnerability, while for Plummer et al [16], the value 0 means high vulnerability and 1 no vulnerability. Pandey et al[1]and Alessa et al [17] ranked the final index of the outcome of the water resources vulnerability assessment on a scale of 0 and 1.Still in this same classification quantity for the final vulnerability of water resources, Wang and Li [18]classified the final index between 0 and 1.80 (extreme vulnerability).

2. Average weights of water resource vulnerability factors

Table 3 presents the mean, median, observed standard deviation, minimum and maximum of each variable from the survey. The largest averages are observed in the factors "Irrigated Areas (IA)", "Relative Annual Variability of Precipitation (RAVP)", "Number of Industries Discharging Wastewater (NIDW), "Population Density (PD)" and "Water Withdrawal for Industrial, Agricultural and Domestic Activities (WWA)". While the smallest averages are observed for the following factors : "Multidimensional Poverty Rate (MPR)", "Percentage of People Working in the Water Sector (PWWS)", "Illiteracy Rate (IR)", "Livestock Density (LD)", "Percentage of the Population with Access to the Toilet (PAT)" and "Net Activity Rate (NAR)". The means of the remaining variables are comparable and range from 7 to 9.

Table 3: Relative weights for each factor and its elementary statistics

Number	Factors	Mean	Median	Standard deviation	Minimum	Maximum
1	E	9,09	8,50	4,74	2,00	20,00
2	R	8,77	8,00	3,88	2,50	20,00
3	IC	8,44	8,00	4,54	3,00	20,00
4	GR	8,95	8,00	4,72	2,50	20,00
5	DC	8,59	8,00	4,61	2,00	20,00
6	RAVP	9,84	9,50	5,24	2,00	20,00
7	SWRC	7,09	7,50	2,79	1,00	15,00
8	FCR	7,38	7,50	2,70	1,00	15,00
9	PD	9,88	10,00	3,67	2,00	20,00

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10	MPR	5,69	5,00	4,85	0,00	20,00
11	PWWS	4,16	5,00	2,14	0,00	10,00
12	WWA	11,88	10,00	5,01	5,00	25,00
13	LD	6,88	7,00	3,09	1,00	16,00
14	IR	5,94	5,00	4,30	0,00	20,00
15	ATW	7,31	8,00	3,87	1,00	20,00
16	AWS	7,22	8,00	3,61	1,00	17,00
17	UR	4,59	4,00	2,87	0,00	12,00
18	NAR	6,41	6,00	3,05	0,00	12,00
19	PAT	6,81	6,00	3,60	1,00	20,00
20	WEST	7,81	8,00	3,83	1,00	20,00
21	NIDW	10,38	10,00	2,98	5,00	16,00
22	NPS	8,97	10,00	2,82	3,00	15,00
23	AAL	9,53	10,00	4,28	1,00	20,00
24	IA	10,22	10,00	3,82	1,00	20,00
25	NTP	8,19	8,00	3,16	3,00	15,00

1. Evapotranspiration (E) 2. Runoff (R) 3.Infiltration Capacity (IC) 4. Groundwater Recharge (GR) 5. Dam Capacity (DC) 6. Relative Annual Variability of Precipitation (RAVP) 7. Soil Water Retention Capacity (SWRC) 8. Forest Coverage Rate (FCR) 9. Population Density (PD) 10. Multidimensional Poverty Rate (MPR) 11. Percentage of People Working in the Water Sector (PWWS) 12. Water Withdrawal for Industrial, Agricultural and Domestic Activities (WWA) 13. Livestock Density (LD) 14. Illiteracy Rate (IR) 15. Percentage of Access to Tap Water (ATW) 16. Access to Water and Sanitation (AWS) 17. Unemployment Rate (UR) 18. Net Activity Rate (NAR) 19. Percentage of the Population with Access to the Toilet (PAT) 20. Wastewater Evacuation by Septic Tank (WEST) 21. Number of Industries Discharging Wastewater (NIDW) 22. Number of Pollution Sources (NPS) 23. Areas of Agricultural Land (AAL) 24. Irrigated Areas (IA) 25. Number of Treatment Plants (NTP)

The medians are close to the averages for all factors. The standard deviations show a very large dispersion of dataforsome factors. The highest values of standard deviations are observed for"Relative Annual Variability of Precipitation (RAVP)", "Water Withdrawal for Industrial, Agricultural and Domestic Activities (WWA)", "Multidimensional Poverty Rate (MPR)", "Groundwater Recharge (GR)", "Evapotranspiration". Minimum and maximum values range from 0 to 25 for the entire dataset. Five factors have minimum values of 0 and 9 other factors have minimum values of 1; the factors having maximum values greater than or equal to 20 are 15 and are generally those with the highest standard deviation values.

3. Multiple Factor Analysis (MFA) and Cluster Analysis

3.1. Determination and analysis of retained components

The scree plot [19] was used in the investigation of the number of main components or dimensions to be used in interpreting the results of this survey. It is a graphical representation of the eigenvalues of the main components. When the curve undergoes a sudden variation at the level of a main component, and follows a continuity without significant variation, the test scree consists ofretaining the main components before the slope of the variation. Figure 2 shows the change in eigenvalues according to the main components. The red line in Figure 2 consists of applying the Kaiser criterion [20], which retains only Eigenvalues whose values are greater than 1, without losing any significant information on the source variables. The Kaiser criterion is also used to solve the problem of the number of main components to be retained [21]. The number of main components included in the multiple factor analysis is also a choice that depends on the number of variables in the survey. Bouroche and Saporta [22]assume that a first main axis that explains 45% of inertia with 11 variables is much more interesting than if the variables were 5; only the analysis of the significance of the main components and experience can define the number of main components retained. In Figure 2, the variation in the pace of the curve is observed on the fifth main component, and the application of the Kaiser criterion shows that the first 8 main components should be retained. However, the analysis of Table 4, which presents the correlations of variables with the main components, shows that only the first 4 main components show an interest for this study since beyond the fourth component, the variables no longer have a significant correlation. Therefore, only the first four main components are selected for this study and will be interpreted.

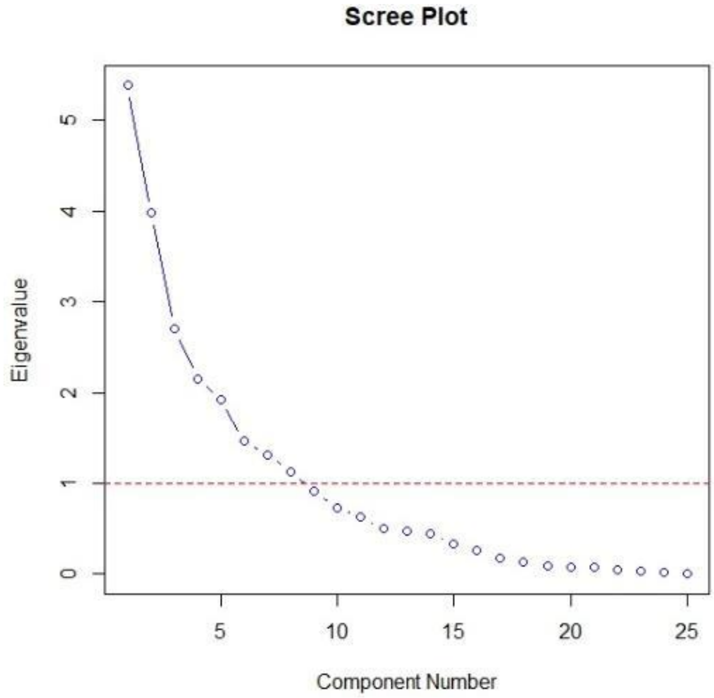

Fig.2: Scree plot for the 25 main components to be interpreted.

Table 4 shows the variation in inertia of the main components for the first 8 dimensions. The first 4 main components selected for this study explain 58.5% of the cumulative variability over the 25 main components. The other 21 main components explain only 41.85%, which means that the main components selected contain the essential information of the survey. The first 8 main components explain more than 81% of the information contained in the survey. The main plan (Dimensions 1 and 2) recovers one-third (36.5%) of the data set information.

Table 4:Eigen values of variables groups

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8
Variance	2.4	1.9	1.567	1.124	0.874	0.758	0.592	0.549
% of var.	20.2	16.2	12.813	9.188	7.149	6.201	4.841	4.489
Cumulative % of var.	20.2	36.5	49.313	58.501	65.650	71.851	76.692	81.181

Table 5 presents the correlation coefficients with the main components. To facilitate the interpretation of correlations, Liu et al[23]applied the following classification: >0.75, 0.75-0.50 and 0.50-0.30 for “high”, “moderate”, “low” respectively. The factor groups of "potential sources of pollution" are strongly correlated to the first dimension, the factor groups "socio-economic" and "hydrological" are moderately correlated to the first main component. This first dimension can be interpreted as the axis of potential water pollution sources and socio-economic factors or the axis of anthropogenic vulnerability factors. On the second main component, the socio-economic factors group is highly correlated; the hydrological factors group is moderately correlated. This axis can be considered as the sensitivity factors of water resources. The group of hydrological factors is both moderately correlated with dimension 1 and 2, but does not contribute sufficiently to both axes compared to the group of factors "potential sources of pollution" and "socio-economic". The group of "environmental physics" and "eco-environment" factors are moderately correlated with the fourth main component, which can be considered as the axis of water resource vulnerability related to the physical component of the environment. The pollution factor is the one that contributes most to the formation of the first axis of the MFA, while dimensions 2 and 3 depicta high contribution from socio-economic and environmental factors.

Table 5: Dimensions used to interpret the results.

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8
Hydro	**0.560**	**0.544**	0.127	0.053	0.303	0.063	0.030	0.147
Environment	0.414	0.386	**0.640**	0.159	0.028	0.162	0.005	0.067
Socioeconomic	**0.612**	**0.759**	0.123	**0.522**	0.281	0.240	0.362	0.210
Pollution	**0.802**	0.060	0.055	0.311	0.110	0.043	0.154	0.066
Eco-environment	0.090	0.238	**0.622**	0.078	0.152	0.250	0.040	0.058

Out of the 25 factors of vulnerability of water resources, 14 are positively and negatively correlated in a moderate way to the first two dimensions. On dimension 1, the "dam cover (DC)", "Relative Annual Variability of Precipitation (RAVP)", "Forest Coverage Rate (FCR)" factors are moderately and negatively correlated on the main level. In contrast to factors such as "Percentage of Access to Tap Water (ATW)" which are strongly and positively correlated to dimension 1, and factors such as "Percentage of the Population with Access to the Toilet (PAT)", "Wastewater Evacuation by Septic Tank (WEST)", Number of Industries Discharging Wastewater (NIDW), Number of Pollution Sources (NPS) which are moderately correlated to dimension 1. Figures 2, 3 and 4 present the graphical representations of dimensions 2, 3 and 4 with the main dimension providing the most information.

Table.6: Loadings of variables on the first eight components of data set

	Dim.1	Dim.2	Dim.3	Dim.4	Dim.5	Dim.6	Dim.7	Dim.8
E	-0.449	-0.110	0.322	-0.291	-0.399	-0.246	0.112	-0.191
R	-0.349	**-0.693**	-0.143	0.168	-0.125	-0.069	-0.179	-0.135
IC	-0.490	**-0.581**	0.093	-0.086	-0.415	-0.011	-0.160	0.105
GR	-0.335	**-0.731**	0.078	-0.050	-0.211	-0.012	-0.007	0.478
DC	**-0.606**	0.086	0.339	-0.045	0.411	0.111	-0.058	-0.279
RAVP	**-0.614**	-0.087	0.259	-0.098	0.457	-0.287	-0.035	0.045
SWRC	0.168	-0.296	**0.762**	0.269	0.080	0.406	0.022	-0.132
FCR	**-0.625**	**0.551**	0.262	0.297	0.147	0.003	0.071	0.226
PD	-0.135	0.323	0.031	-0.330	0.026	0.003	0.071	0.226
MPR	0.011	**0.746**	-0.105	0.301	-0.259	0.339	-0.246	0.003
PWWS	0.408	0.280	-0.239	0.225	0.355	-0.067	-0.366	0.299
WWA	0.324	0.211	-0.037	**-0.671**	0.010	0.409	0.139	0.126
LD	0.377	0.218	0.225	0.146	0.463	0.030	0.218	0.463
IR	-0.225	**0.796**	0.084	-0.232	-0.234	0.012	-0.115	-0.106
ATW	**0.800**	-0.064	0.045	0.116	-0.253	-0.132	-0.166	-0.012
AWS	0.463	0.166	0.057	**0.565**	-0.174	-0.023	0.233	-0.337
UR	-0.017	**0.575**	-0.338	0.407	-0.345	-0.050	-0.238	0.102
NAR	0.396	0.146	-0.251	0.031	0.095	-0.280	-0.363	-0.486
PAT	**0.704**	-0.223	0.293	-0.323	0.007	-0.280	-0.363	-0.486
WEST	**0.647**	0.173	0.149	-0.500	0.321	-0.170	-0.049	0.107
NIDW	**0.564**	0.564	-0.030	0.383	-0.304	-0.223	0.359	0.043
NPS	**0.609**	-0.105	0.046	0.348	0.157	-0.054	0.330	0.287
AAL	-0.037	-0.244	**-0.643**	-0.012	0.344	0.381	0.131	-0.281
IA	-0.292	-0.149	**-0.737**	-0.046	-0.145	0.412	0.177	0.132
NTP	-0.252	**-0.562**	-0.290	0.358	0.340	-0.321	-0.138	0.015

On dimension 2, "Runoff (R)", Infiltration Capacity (IC), Groundwater Recharge (GR), Number of Treatment Plants (NTP) factors are moderately and negatively correlated while the "Illiteracy Rate (IR)" factor is strongly correlated with this dimension. In contrast, factors such as "Multidimensional Poverty Rate (MPR)", "Unemployment Rate (UR)" which are positively and moderately correlated on dimension 2 (Table 6 and Figure 2). Dimension 3 is

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mainly explained by the Soil Water Retention Capacity (SWRC) factor with a strong and positive correlation coefficient on the one hand, and the Areas of Agricultural Land (AAL) and Irrigated Areas (IA) factors with moderate correlations on the other hand. Dimension 4 is mainly explained by the factor "Water Withdrawal for Industrial, Agricultural and Domestic Activities (WWA)" which has a negative and moderate correlation coefficient, and the factor "Access to Water and Sanitation (AWS)" which is moderately and positively correlated to this main component.

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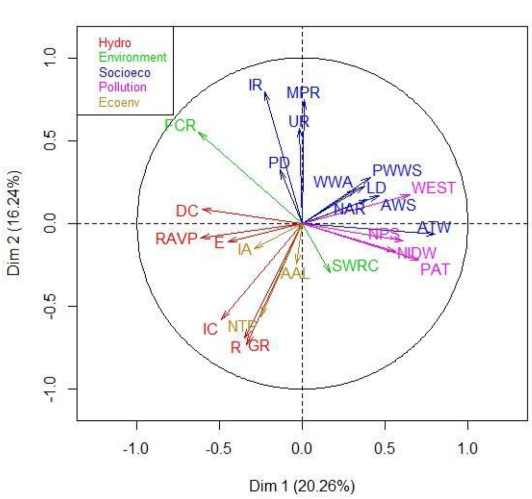

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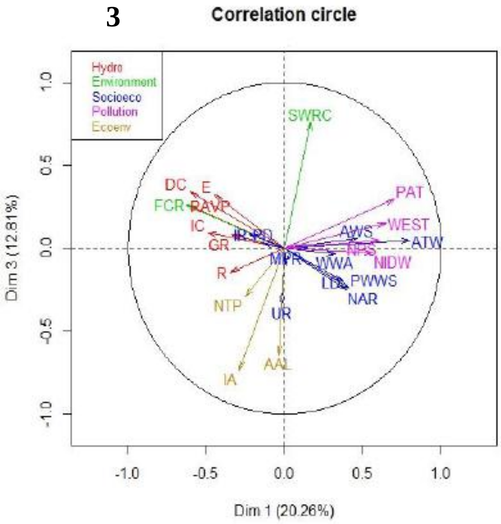

Fig.2 and 3: Representation of variables on dimensions 1, 2 and 3

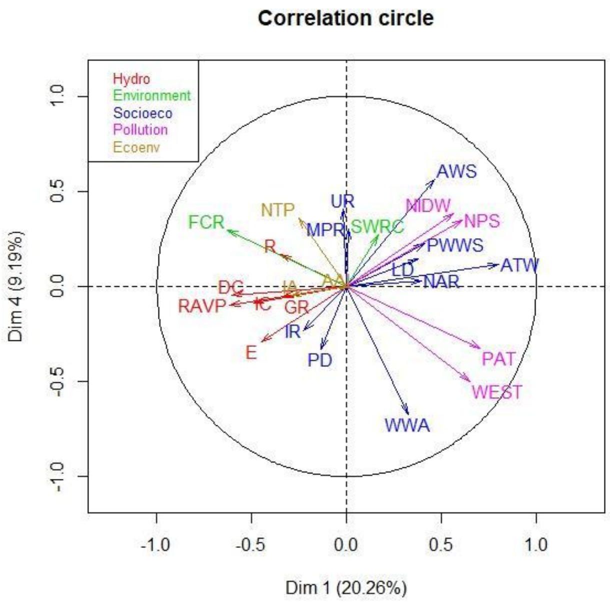

Fig.4: Representation of variables on dimension 1 and 4.

The projection of data in Table 6 on correlation circles (Figures 2, 3 and 4) shows opposite directions and senses for some factors along the dimensions. This opposition can be explained by the allocation of weights by experts. Indeed, multiple factor analysis makes it possible to establish linear relationships between variables. When an expert considers a factor very important, it would result in a depreciation of the weight of one or more factors. In any case, to assess the quality of representation on the correlation circle, the absolute value of its correlation coefficient is considered. Thus, out of the 25 vulnerability factors of water resources analyzed, 20 participate strongly to moderately in the formation of the different dimensions of the multiple factor analysis of this study (Table 6).

Based on the classification criteria of Liu et al[23], it can be seen that there has been no effective reduction in factors. To reduce factors whose contributions are not as important, only factors with a correlation coefficient greater than or equal to 0.60 are considered. Table 7 presents the different groups of factors and the factors considered important with their transformed weights. Only 15 of the 25 source factors show some relative importance for experts in a holistic assessment of water resource vulnerability in this study. Kanga et al [4] found that on average 16 factors are used in integrated water resource assessments.

Table 7: Selected factors with their transformed weights after the application of MFA

Factor	Group	Correlation Coefficient	Factor weight	Group weight
DC	Hydrologic	-0.606	0,043	0,21
RAVP	Hydrologic	-0.614	0,049	0,21
FCR	Environment	-0.625	0,037	0,18
ATW	Socioeconomic	0.800	0,037	0,17
PAT	Pollution	0.704	0,034	0,22
WEST	Pollution	0.647	0,039	0,22
NPS	Pollution	0.609	0,045	0,22
IR	Socioeconomic	0.796	0,030	0,17
MPR	Socioeconomic	0.746	0,028	0,17
GR	Hydrologic	-0.731	0,059	0,21
R	Hydrologic	-0.693	0,044	0,21
SWRC	Environment	0.762	0,035	0,18
WWA	Socioeconomic	-0.671	0,059	0,17
AAL	Eco environment	-0.643	0,048	0,22
IA	Eco environment	-0.737	0,051	0,22

Each of the 5 factor groups presented at least one factor at the end of the correlation analysis. For the "hydrologic" group, these are Dam Capacity (DC), Relative Annual Variability of Precipitation (RAVP), Runoff (R), and Groundwater Recharge (GR). For the environmental physics group, the following factors are considered: Forest Coverage Rate (FCR), Soil Water Retention Capacity (SWRC). For the group of potential pollution sources, 3 factors are retained: Percentage of the Population with Access to the Toilet (PAT), Wastewater Evacuation by Septic Tank (WEST), Number of Pollution Sources (NPS). The socio-economic factor group is represented by Percentage of Access to Tap Water (ATW), Multidimensional Poverty Rate (MPR), Water Withdrawal for Industrial, Agricultural and Domestic Activities (WWA), and Illiteracy Rate (IR). Finally, the group of eco-environmental factors is presented by the following factors: Areas of Agricultural Land (AAL), Irrigated Areas (IA). The assessment of water resource vulnerability using several groups of factors is increasingly being used around the world. The former concept of water resource vulnerability assessment was based on the vulnerability of groundwater to pollution [24]. It should be noted that since the 2000s, the conceptualization of water resource vulnerability has taken on a new connotation by focusing on all natural and anthropogenic factors that are likely to directly or indirectly induce negative impacts on water. Kanga et al[4]reviewed the scientific literature on locally used water resource vulnerability tools, and found that 62.7% of the tools assess vulnerability in an integrated manner using physical factors, socio-economic factors, environmental and eco-environmental factors, institutional and government factors. Plummer et al [16] used 5dimensions of vulnerability for the integrated assessment of water resources vulnerability at the community level: the "water resources" (with all hydrological and qualitative factors), the "other physical environmental" (climate change, pressures on the environment, etc.), the "economic" dimension (factors related to the economy), the "institutions" (governance, conflicts, politics), and the "social" (culture, knowledge, etc.). The classification of factors into one or another vulnerability component (with the exception of the most obvious factors) is also relative and related to the researcher's understanding of the factors. Several researchers [3, 7, 8, 15, 16, 17, 25, 26, 27] have conceptualized water resource vulnerability with physical components (hydrology, hydrogeology, etc.).), socio-economic, environmental or eco-environmental, infrastructure, institutional and governance, etc., but the factors that describe these components are not necessarily the same. Water resource vulnerability assessment is seen by several researchers [15, 16,17,18,24, 28]as a relative

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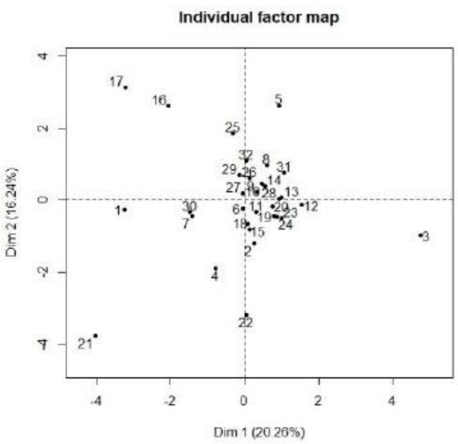
and often subjective notion in which each study seeks to deal with the environmental problem in its own study area. The number of factors to be taken into account is very often limited due to the availability and access of data. Many researchers [2, 3, 29]have previously pointed to data availability and quality as one of the challenges in assessing water resource vulnerability.

3.2. Studies of experts' opinions on factors and factor groups

To analyze the experts' opinions, the study of links and similarities or proximities between the experts was carried out. In order to better define the inter-expert opinion typology, an ascendant hierarchical clustering on the results of the MFAwas produced as well as its graphical representation in 3-dimensions. Figures 5, 6 and 7 show the dendrogram, the map of representation of individuals (2-dimensions), and the 3-dimensional distribution of groups of individuals on the main plane, according to their opinion classes. The analysis in Figure 5 shows that the majority of individuals are condensed towards the origin of the main plan. This means that the opinions of the majority of experts are close. However, some individuals are dispersed in the plan, and show that there is a heterogeneity in the opinions of experts. Figure 6 shows the dendrogram of the relationship between expert opinions. Five classes are distinguished and can be interpreted as 5 groups of opinions within experts on the factors of vulnerability of water resources. The 3-dimensional representation shows that classes 3 and 4 are more or less the closest groups of individuals among the 5 classes, and are the groups that contain most individuals. The diversity of expert opinions is not surprising. Indeed, each of the experts gives his point of view ona given factor according to his personal experience and in an instinctive way. In addition, in conceptualizing the vulnerability of water resources, the factors for assessing this vulnerability cannot be considered with the same importance. The choice of factors and their relative importance is always subjective even if they are related to the objective of the study, since from a perspective outside the study area; the environmental problem encountered may not be the same. In any case, there is no universal set of indicators that is suitable for all contexts; thus, the selection and weighting of indicators must be closely linked to the objectives [6]. IPCC[30]reports that many specialists in several fields have developed conceptual frameworks for vulnerability according to their areas of intervention based on the objectives to be achieved.

5



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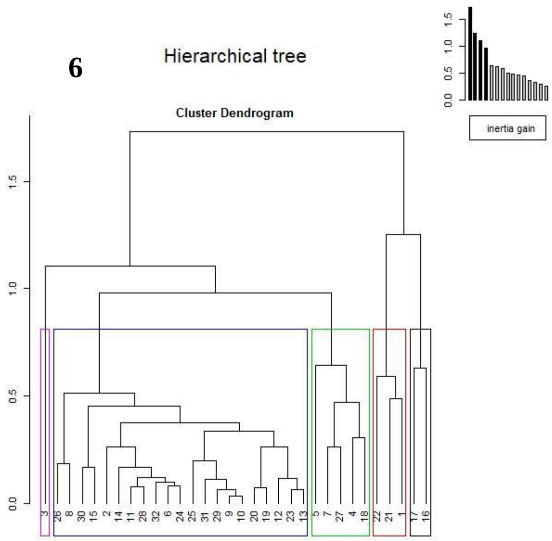

Fig.5 and 6: Representations of individuals on the main plane and dendrogram of the 5 classes of individuals.

Figure 7 shows the distribution of individuals in a 3-dimensional space in order to better visualize the proximities between individuals and between different classes. Class 3 and 4 are the closest in terms of opinions and contain more than 81% of individuals. Class 5 is the one whose opinion does not correspond to any of the classes and contains only one individual.

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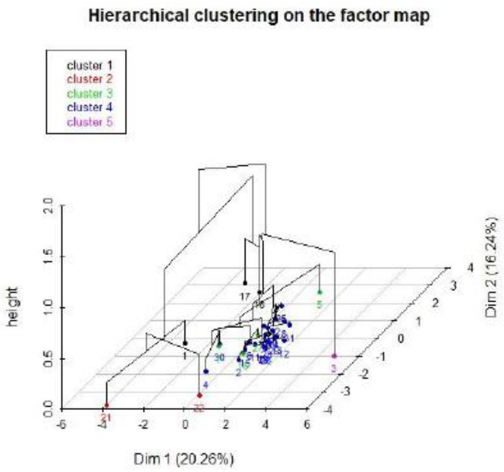

Fig.7: Representation of clusters in 3-D on the main plane

Table 8 presents the link between the 5 classes and the vulnerability factors, and examines the different opinions on the factors and their influences in terms of water resource vulnerabilities according to experts. With reference to the dendrogram (Hierarchical clustering), five classes of expert opinions are observed. Table 8 summarizes the characteristics of the classes of individuals with respect to factors and factor groups. Thus, the classes are summarized as follows:

Class 1: represents 9% of experts. It is the class whose individuals have the most diversified opinion in the sense that all five groups of factors studied are present, and is the class with the most factors. These experts strongly believe that environmental and hydrological factors affect vulnerability where eco-environmental and pollution factors play only a minor role. However, these same individuals have a mixed view of socio-economic factors. Thus, there are socio-economic variables NAR and ATW that do not affect vulnerability in the opinion of these expert groups, while the PD factor significantly affects vulnerability.

Class 2: represents 6% of expert individuals. They believe that hydrological and environmental factors lead to a high vulnerability of water resources, while socio-economic factors play a minimal role.

Class 3: represents 13% of expert individuals. For the later, only three factors significantly contribute to the vulnerability of water resources. These are the variables IC (Eco-environment), WWA (Socioeconomic) and SWRC (Environment). Thus, for them, the variables IC and WWA significantly affect the vulnerability of water resources while SWRC plays a minimal role.

Class 4: represents 69% of individuals. They believe that socio-economic and polluting factors induce a high vulnerability of water resources while hydrological factors play a minimal role, and these two groups of factors have already explained the majority of the contribution of the first two dimensions.

Class 5: 3% of the interviewees, or one individual. The later has the most diversified opinion (i.e., the type of factors) after those of class 1. Thus, for this expert, socio-economic and pollution factors significantly affect the vulnerability of water resources, while environmental and eco-environmental factors hardly affect it.

Table 8: Link between the cluster variable and the quantitative variables

Class	Variables	Groups	Influence	Class	Variables	Groups	Influe nce
1	FCR	Environment	+++	3	IA	Eco-environment	+++
	DC	Hydrology	+++		WWA	Eco-environment	+++
	IR	Hydrology	+++		SWRC	Environment	---
	RAVP	Hydrology	+++	4	NPS	Pollution	+++
	PD	Socioeconomic	+++		NAR	Socioeconomic	+++
	E	Hydrology	+++		LD	Socioeconomic	+++
	NAR	Socioeconomic	---		AWS	Socioeconomic	+++

	NIDW	Pollution	---		NIDW	Pollution	+++
	AAL	Eco-environment	---		WWA	Socioeconomic	---
	NPS	Pollution	---		GR	Hydrology	---
	ATW	Socioeconomic	---		IC	Hydrology	---
2	IC	Hydrology	+++	5	E	Hydrology	---
	GR	Hydrology	+++		PAT	Pollution	+++
	RAVP	Hydrology	+++		ATW	Socioeconomic	+++
	SWRC	Environment	+++		WEST	Pollution	+++
	LD	Socioeconomic	---		FCR	Environment	---
	NAR	Socioeconomic	---		IA	Eco-environment	---
	PD	Socioeconomic	---				
	UR	Socioeconomic	---				
	PWWS	Socioeconomic	---				

+++: influence; ---: non influence

V. CONCLUSION

The assessment of the vulnerability of water resources in a multidimensional way is increasingly being used around the world. The investigation to define the different components with their factors or indicators of this vulnerability, and their hierarchies is important for water resource modelers or managers. This research on the choice of factors and especially their weightings has shown that the notion of vulnerability of water resources to a relative connotation because experts do not consider the factors with the same importance in a given area. It is always very difficult when conceptualizing the vulnerability of water resources to define the factors at stake because there are several factors that can influence this vulnerability in one way or another. Again, even if these factors are known, it is conceivable that they do not have the same importance in the impact they can have on water resources. Therefore, survey methods to collect opinions on differences and their weights can be a major asset for water sector stakeholders. It is clear that the information from opinion surveys is subjective, but is very necessary because even other methods such as statistical methods to weight factors can also be subjective because the weights from these operations are linked to sourcedata that have a well-defined time scale. These vulnerabilities, defined and weighted in this way, are of great value in this context of global change in the study area, and perhaps elsewhere. It should be noted that the availability of data on these factors might limit the assessment of water resource vulnerability. Therefore, awareness raising and the creation of accessible databases on water resources in Morocco can help water managers be more effective and relevant in water resources vulnerability analysis tools.

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