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"Gheorghe Asachi" Technical University of Iasi, Romania

CHOICE OF SITE AND RANKING ELEMENTARY WATERSHED FOR HYDRAULIC EQUIPMENT USED FOR IRRIGATION APPLICATIONS TO THE TERRITORY OF WILAYA OF MOSTAGANEM ALGERIA

Mohamed Zaoui[1]*, Slimane Himouri[2] Bernard Etlicher[1]

[1]*Laboratory ISTHM University Jean Monnet, Saint Etienne France, 6 rue «Basse des rives», 42023 Saint Etienne, France*
[2]*Laboratory Construction, Transportation and Environmental Protection, University of Mostaganem, Algeria Bp 227, Les Castors University of Mostaganem, Algeria*

Abstract

The selection of the favourite elementary watershed for a hill reservoir needs the association of all the essential criteria and all the interested decision makers. A geographical information system (GIS) is a strong tool for studying spatial data but it does not offer an appropriate decision making methodology. Due to their spatial aggregation functions, Multicriteria Analysis (MCA) methods can simplify decision making in situations where various solutions are available, and when several criteria have to be considered and decision-makers are not in accord. Nevertheless, they often do not consider the spatial reference of the data. Therefore, the use of GIS and multicriteria methods generate a forceful spatial decision making system. The approach is tested on the selection of hill reservoirs established in the territory of the Wilaya of Mostaganem in Northen Algeria. The approach covers the following points: determination of the criteria by the use of open source GIS tool SAGAGIS and evaluation of the hierarchy of alternatives through a tool specialized in AMC (D-Sight software, developed by laboratories coded SMG, ULB) by applying algorithms PROMETHEE-GAIA thereafter the AHP method was applied. The consistency of results confirms the effectiveness of the followed approach. This research contributes to help decision makers to rank elementary watersheds drained by the main hydrographic streams of the study area for the establishment of hydraulic equipment in our case «hill reservoirs».

Key words: decision maker, elementary sub-watershed, hill reservoir, multicriteria, PROMETHEE-GAIA, AHP, ranking technology

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1. Introduction

For a long time, Algeria provided significant efforts to find solutions to fight the degradation of natural resources, by the conservation and storage of run off by the construction of dams and hill reservoirs. The first hill reservoirs were built during the seventies. A program was started by the State for the construction of hill reservoirs taking into consideration the economic criteria and the optimal exploitation of the reserves. Series of measures were taken to allow fast construction according to standardized rules. Hundreds of hill reservoirs were built. Abacuses were standardized taking into account the average contributions of watersheds according to the model of Moran, by the use of chronic hydrometric observations of the hydrometric stations of the various geographical units (Zerrouk and Zsuffa, 1988).

However, analysis of hill reservoirs conducted in Northen Algeria revealed that programs have not benefited from the necessary rigor for their implementation. Many deficiencies were noted

* Author to whom all correspondence should be addressed: e-mail: med_zaoui_dagc@yahoo.fr; Phone: 0021345203933; Fax: 0021345203933

including the choice of the sites of these hill reservoirs (Boutkhil et al., 2007). Several failures recorded in the construction of hill reservoirs in Algeria, due to negligence of preliminary study. Public administration has supported the design of these structures on the basis of a program of studies that met standards and established techniques (Benlaoukli and Touaïbia, 2004).

A methodological approach based on two methods PROMETHEE and ELECTRE TRI on a test area of Oran (Algeria) was applied by (Mendas et al., 2010) based on the integration criteria of nine sites extracted from a study conducted by SOGREAH. The results are not the same compared to observations derived from the study by SOGREAH in the same context using conventional methods based on field of observations.

With this objective, the preliminary studies of such hydraulic equipment are those related to the research and the choice of the best site, with the good knowledge of topographical, geological, geotechnical and hydrological site (Rolley, 1977; Tricoli, 2003). In this article, a new vision is proposed to focuse on reasoning not at the level of the site but at that the elementary catchment because in our opinion it constitutes the basic receptacle for the accumulation of water runoff at its outlet.

A study was conducted by experts of National Office for Studies in Rural Development, BENDER, Mostaganem using necessary information for basic watershed drained by the main hydrographic stream in the same context using conventional methods based on ground observations. BENDER experts founded for the choice of site installations of hill reservoirs on their experiences and on the most important criteria.

Choosing the best position of hill reservoir is a complex interfere where various parameters (quantitative and / or qualitative variable influence and adversarial behavior). Hence the necessity of means, techniques and powerful methods that should help to manage and analyze spatially referenced data that can be of different nature and origin. GIS is a strength tool to manipulate, manage and analyze spatial and referenced data. It helps in data collection, production of information and handling a large amount of data to contribute to study the problem in all its complexity (Pornon, 2011). It allows representing different components of the problem. However, it does not take into consideration the preferences of decision makers since the choice may be faced with conflicting objectives and criteria.

Multi-criteria analysis methods are appropriate for the decision-making process that is consistent with choices where different assessments are made. They contribute to aggregate information in order to make the interpretation more convenient for decision making (Roy, 1985). In addition, they facilitate selecting the best system using spatial aggregation functions. That is why the combined use of GIS and multi-criteria analysis methods is a way to exploit the powerful features of GIS with useful tools of multicriteria analysis decision to support the process of decision making (Laaribi, 2000).

The elementary watersheds (EW), defined object and classification are located respectively in the sub-watershed “wadi Cheliff” the maritime part of the basin and low “Cheliff Mina” sub-watershed and coastal watershed Gueltta belonging to Dahra (according to the National Agency of the Water Resources) in the territory of the wilaya of Mostaganem. Determining criteria was performed by the use of open source GIS tool, (SAGAGIS2.0.8), the evaluation and the ranking of different potential actions through a specialized tool in AMC (D-Sight, developed by laboratories CODE-SMG, ULB), applying the reasoning PROMETHEE-GAIA.

The problem consists of organizing the necessary data on the territory of Mostaganem to provide the needed information for elementary watersheds drained by the main hydrographic stream. In order of priority, these entities for the establishment of hydraulic equipment were based on a number of criteria. This operation constitutes complex problems, requires a judicious choice of criteria and more interaction with decision makers. PROMETHEE method supplemented by GAIA is well suited to resolve this kind of problem. This method allows the modeling of the problem of arranging elementary watersheds for shelter hydraulic equipment (hill reservoir or small dam). Firstly, we describe the evaluation criteria, recall the basic multicriteria methods PROMETHEE and GAIA and finally we discuss the advantages of the proposed method.

2. Proposed methodology

2.1. Study area

It covers an area of approximately 2175 km^2. It is bounded on the north by the Mediterranean Sea, to the west by Oran and Mascara, to the east by the Wilaya of Chélif and to south by the Wilaya of Relizane. It is characterized by a semi-arid climate and a temperate of winter, taking into account the proximity of the sea.

The rainfall is lower than 400 mm, ranging from 350 mm at the plate and 400 mm in the foothills of Dahra. The maximum average temperature of the hottest month is 28°4. The minimum average temperature of the coldest month is 9°. The topography of the wilaya of Mostaganem is divided into 6 major morphological units: the coastal strip, an area of coastal hills, mounts of Dahra, a plateau region, the valley of low Cheliff and a zone of plain (the plain Bordjias). The diversity of the wilaya of Mostaganem enables it to possess enormous natural potentialities.

2.2. General methodology

The research began by identifying the key stakeholders who would be involved in the planning of hydraulic equipment. Their involvement is important to ensure that the approach is efficient, fair and transparent. Franco and Montibeller (2009) have identified key stakeholders, individuals who have the power to influence the decision to study, or groups that are affected, or perceived to be affected by decisions. The methodology presented in Fig. 3 was used for our purpose to classify elementary watersheds. This methodology is simple, transparent and effective, taking into account all effective alternatives to solve the problem. The sequential process makes it simple and easy to follow each step and recursive steps which aim to improve the quality of decision-making.

In our case, PROMETHEE, an outranking method is adopted in recognition of evaluation criteria, the priority between them, then the classification of elementary catchments. There are at least four arguments to adopt PROMETHEE for this research. Firstly, it is flexible in accepting data from various fields such as topography, hydrology, geology and economics in elementary watersheds. Secondly, qualitative and quantitative data can be processed together, each in its own units. Thirdly, it can provide two types of classification with and without incomparability elementary watersheds, which helps to identify the strengths and weaknesses of each alternative.

The study area in the northwest of Algeria is shown in Fig. 1. The map of land use of the study area is shown in Fig. 2.

Finally, using the GAIA tool that admits a visual representation of the problem of support decision and to interpret associations, inter-dimensional conflict and inter-actors, and to ensure discussion and agreement between the stakeholders. Therefore, the method AHP (analytic hierarchy process) is applied for the comparison of results.

A version of the AMC D-Sight tool (Quantin et al., 2011), based on PROMETHEE-GAIA methodology was used in this article.

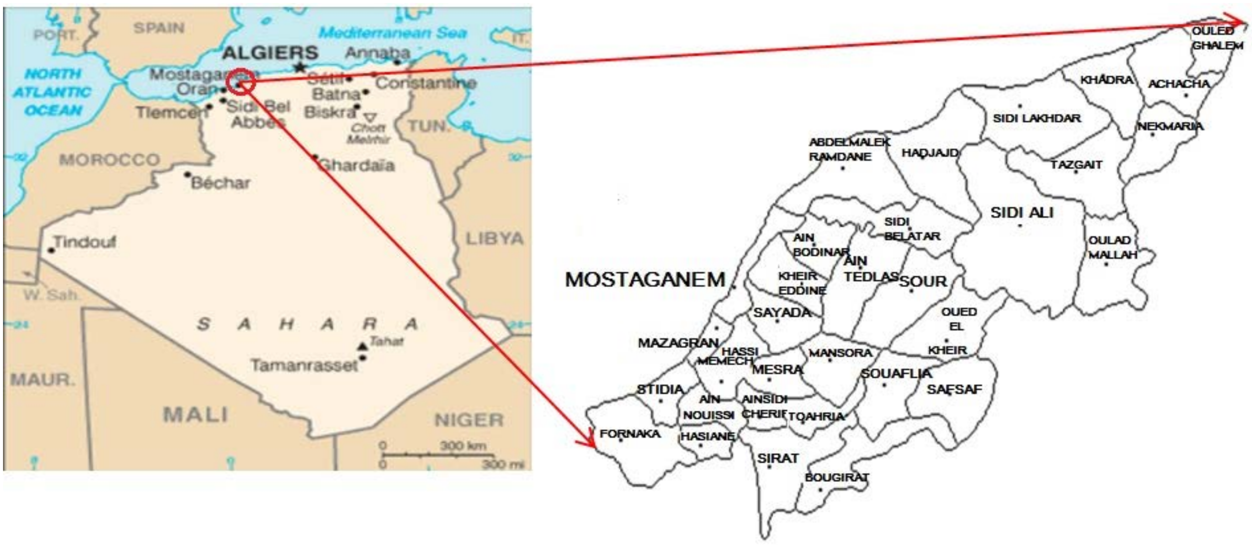

Fig. 1. Location of the study area

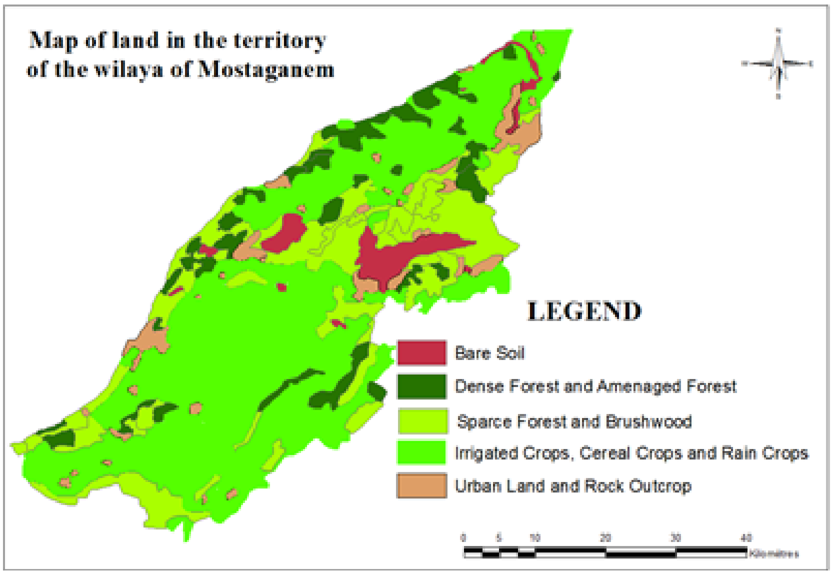

Fig. 2. Map of land of the study area

Alternatives can be marked on numerical scales or defined by qualitative scales. D-Sight enables faster decisions and visual tools that allow better interaction between stakeholders. Tools available for sensitivity analysis to examine several scenarios in a more transparent manner and increasing the confidence of stakeholders in the solutions are established. The methodology presented in Fig. 3 was used for our purpose to classify elementary watersheds.

2.3. Determination of criteria

The basic geometrical characteristics of the elementary watershed used primarily to design the hill reservoirs are the criteria for the evaluation of elementary watersheds. SRTM (Shuttle Radar Topography Mission) data of the study area were obtained from the USGS (United States Geological Survey) with original information with spatial resolution of 90 m and reference ellipsoid WGS 84. The process of automatic delineation of elementary watersheds has been developed under the free open source (SAGAGIS2.0.8) software. The methodology obtained in this process is divided into four stages shown in Fig. 4: filling depressions "fill sinks", "hydrologic analysis", "Catchment area", shape file outlet of the elementary watershed and delineation of watersheds "extended watershed basins."

The use of DTM (Digital Terrain Model) for the calculation of hydrological parameters gives results compatible with those obtained with the manual methods by saving time and means (Jenson and Domingo, 1988). The DTM makes it possible to obtain information on changes in land surface elevation being applicable to various studies reported in geomorphology analysis to the analysis of the hydrographic network to the delimitation of flooded sectors and automatic delineation of catchment areas among others. SRTM mission was conducted in 2000 and their data publicly are available globally through the USGS. Thus, various studies are being conducted with the objective to analyze, compare and update information from the Earth's surface using SRTM data. In this context, the work developed can be cited (Gerstencker et al., 2005) by evaluating several bases for generations of DTM topographic maps have concluded that the mission STRM is a considerable stage of importance.

Pinheiro (2006) concluded that the altitudes measured by SRTM DTM obtained after corrections showed better results compared with the DTM produced from topographic maps at scales 1/50000. This work has been applied to the automatic delineation of elementary watersheds objects of classification using SRTM data (90 m and 30 m), integrated and processed in a GIS environment validated in the territory of the wilaya of Mostaganem.

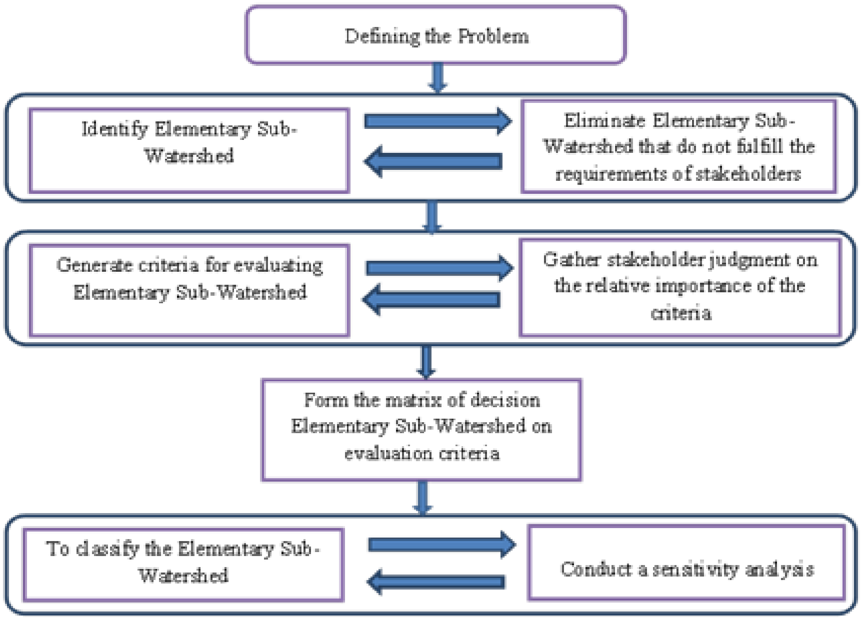

Fig. 3. Methodology of ranking

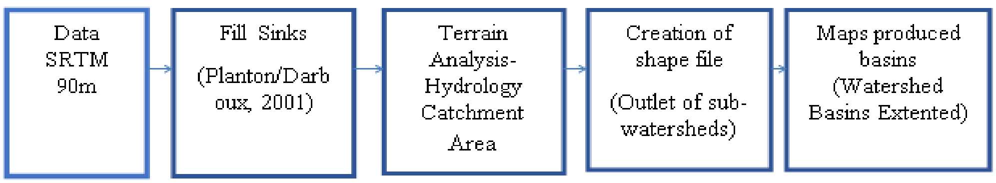

Fig. 4. Principal steps boundary basins from SRTM under SAGAGIS 2.0.8

Table 1 illustrates the criteria obtained above for the classification of elementary watersheds. The problem consists of determining the necessary characteristics for each elementary catchment area being able to shelter a hill reservoir. To conduct a multi-criteria evaluation and the choice will be to use the method PROMETHEE-GAIA based on the following criteria.

2.4. Weighting of criteria

No specific guidelines exist for PROMETHEE to determine the weights of criteria. A tool was adopted in this article based on the card package technique which is implemented in software Simos Roy Figueira (SRF) (Figuiera and Roy, 2002). This software was developed by Jean Simos of the Federal Polytechnic school of Lausanne (FPSL). It was then revised by Bernard Roy Laboratory Analysis and Modeling for Decision support (LAMSADE, Paris, France), and programmed by José Figueira of Faculty of Economics of the University of Coimbra (Portugal-FEUC). SRF software allows the determination of the weights of the criteria comparing them with cards, where each one has a number that indicates its importance relatively to other cards.

2.5. Modeling of criteria

The first step consists of structuring the relative data with the area of study in the form of a database with spatial references in GIS (SAGAGIS). The GIS tool is used for storage, analysis and choice of the best alternatives. The choice of this GIS is justified by its flexibility in handling geographical data and the strength nature of spatial analysis tools with hydrological data. In order to feed algorithm PROMETHEE-GAIA using criteria and according to the parameters introduced by the decision maker. The digital storage of data is in layers of information and in data base form. The GIS is able to handle all types of request related to these data. The GIS tool is used for storage, analysis and automatic delineation of elementary watersheds. Calculation attributes to criteria and visualisation of data. The multicriteria analysis chooses the best compromises, and then classifies the alternatives according to the parameters introduced by the decision maker. Database designed on the study area consists primarily of the following main layers of information: digital terrain model (90 m, 30 m) of resolution, slope map and orientation, geological map, rainfall map, map of land use, map of the physical units and hydrogeological map and more descriptive data on rainfall stations, temperatures, evaporation, cloudiness, etc.

2.6. Determination of matrix performance

Once the alternatives are identified, the next step is to evaluate alternatives for criteria. Most of the criteria are usually measured quantitatively with the exception of the criterion of the geology of the site structure with a qualitative scale adapted with five levels of measurement.

The selected criteria according to the methodology of studying the physical specifications are as follows: area of elementary watershed determined by automatic delineation using STRM data (90 m) after choosing the outlet of each elementary watershed (AEW), drainage density using GIS tool expending channel network layer (DD), geology of the site structure using geology layer of study area (GEOS), irrigated area and determined areas in collaboration with the departments responsible for the management of irrigation schemes (IRA), flood discharge determined in conjunction with the agricultural water service responsible for the selection and installation of hydraulic equipment (FD). The matrix performance thus built is given in (Table 2).

3. Results and discussion

In this section, two decision makers express their own preferences. Table 3, summarizes the parameters of preferences, the selected function is "linear", indifference thresholds and preferences are also expressed. Some parameters are minimized while others are to be maximized. These parameters lead to the results shown in Table 4.

Table 1. Definition of the criteria

Number of criterion	*Name of the criterion*	*Notation*	*Scale*	*Observations*
1	Area	AEW	numerical	Area Elementary Watershed Criterion related to the choice of classification EW: topographical conditions
2	Drainage density	DD	numerical	Criterion related to the choice of classification EW: topographical conditions
3	Geology of the site structure	GEOS	qualitative	Criterion related to the choice of classification EW: geological conditions
4	Irrigated area	IRA	numerical	Criterion related to the choice of classification EW: economic conditions
5	Flood discharge	FD	numerical	Criterion related to the choice of classification EW: Hydrological Conditions

It may be noted that the elementary reservoirs B2 and B6 are ranked first by both AHP and PROMETHEE methods, and are therefore a recommended choice. They are followed by B11 and B14. These parameters lead to the results shown in Table 4 and Fig. 4.

However, other elementary basins are then ranked approximately at the same positions. Fig. 4 sets the ranked alternatives with respect to the net flow, while Fig. 5 expresses the contribution of each criteria for each alternative, which validates the consistency of the two methods.

GAIA scheme, IRA and DD criteria are strongly in conflict with GEOS as their projections have a large angle as illustrated in Fig. 6. DD Criteria and IRA on the one hand and AEW and IRA on the other hand distinguish alternatives in the same way (their projections are almost united). Given this set of parameters, alternatives B1, B8 and B15 are significantly different from all other EW alternatives while alternatives B2, B5, B11, B6 and B14 are relatively close.

Moreover, alternatives B3, B9, B10 and B13 are the opposite of other alternatives, which explains why they have different characteristics and are clearly surpassed by all other actions that they are located in the opposite direction of the stick D decision (Decision stick) in red in Fig. 6.

Table 2. Evaluation Matrix of elementary sub-watershed

ALTERNATIVE	***AEW***	***DD***	***GEOS***	***IRA***	***FD***
B1	21.71	3.29	Not resistant	191	57.77
B2	87.82	3.59	Resistant	460	161.88
B3	19.47	3.07	Weak resistant	180	52.87
B4	18.8	3.31	Not resistant	449	53.32
B5	61.82	3.51	Medium resistant	124	148.06
B6	32.65	3.48	Medium resistant	600	73.82
B7	48.88	3.46	not resistant	267	107.88
B8	24.41	3.49	Not resistant	180	64.43
B9	20.63	3.18	Very resistant	192	56.66
B10	32.26	3.46	Not resistant	299	89.93
B11	81.36	2.29	Not resistant	725	167.30
B12	61.28	4.09	Not resistant	439	135.89
B13	28.23	3.66	Resistant	239	69.42
B14	53.09	2.25	Medium resistant	469	111.16
B15	28.61	2.02	Not resistant	267	59.80

Table 3. Parameters of the criteria

Criteria	***Type***	***Min/Max***	***Function***	***Weights***	***Indif.***	***Pref.***	***Unit***	***Scale***
AEW	Pair Wise	Max	linear	17.95 %	0.1	1	km^2	Num
DD	Pair Wise	Min	linear	5.12 %	0.5	2	km/km^2	Num
GEOS	Pair Wise	Max	linear	33.24 %	0.25	0.5	-	Num
IRA	Pair Wise	Max	linear	40.35 %	10	100	ha	Num
FD	Pair Wise	Min	linear	3.34 %	5	20	m^3/s	Num

Table 4. Positive, negative and net flow

Alternatives	***Rang***	$\Phi^+(.)$	$\Phi(.)$	$\Phi (.)$
B1	15	0.076	0.579	-0.502
B2	1	0.628	0.115	0.513
B3	8	0.378	0.441	-0.063
B4	6	0.327	0.325	0.002
B5	10	0.318	0.460	-0.142
B6	2	0.482	0.170	0.482
B7	12	0.251	0.443	-0.192
B8	14	0.082	0.581	-.0499
B9	9	-0.113	0.327	0.440
B10	11	0.278	0.451	-0.173
B11	4	0.592	0.214	0.378
B12	5	0.407	0.312	0.095
B13	7	0.348	0.347	0.001
B14	3	0.595	0.176	0.419
B15	13	0.252	0.325	0.457

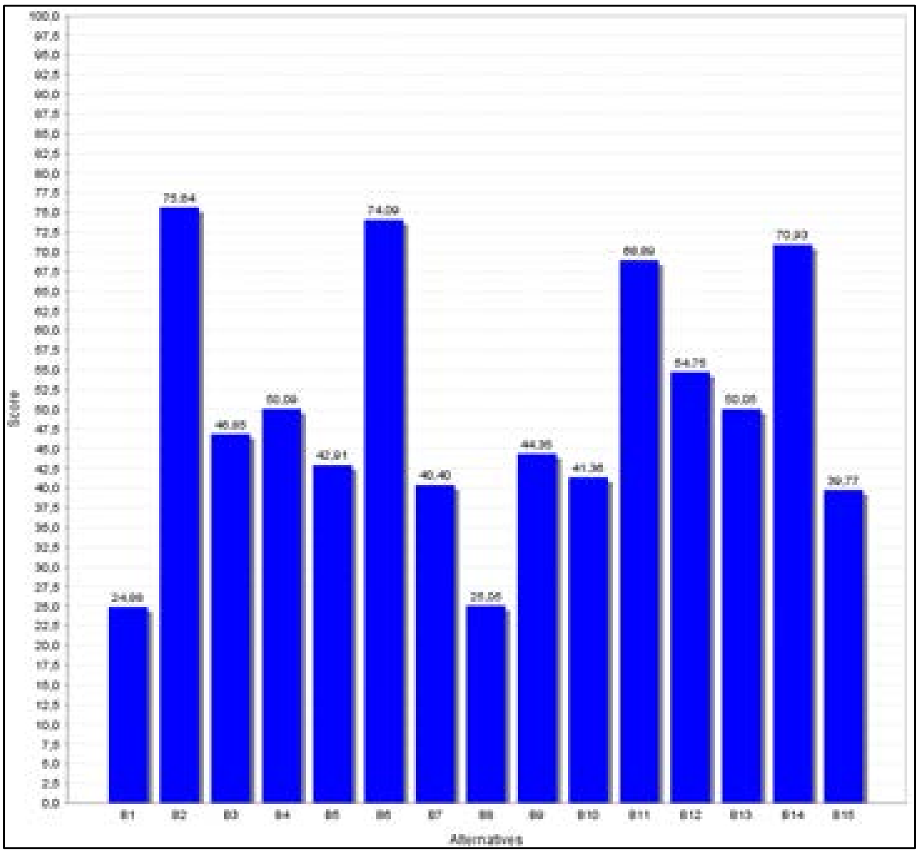

Fig. 4. Net flow

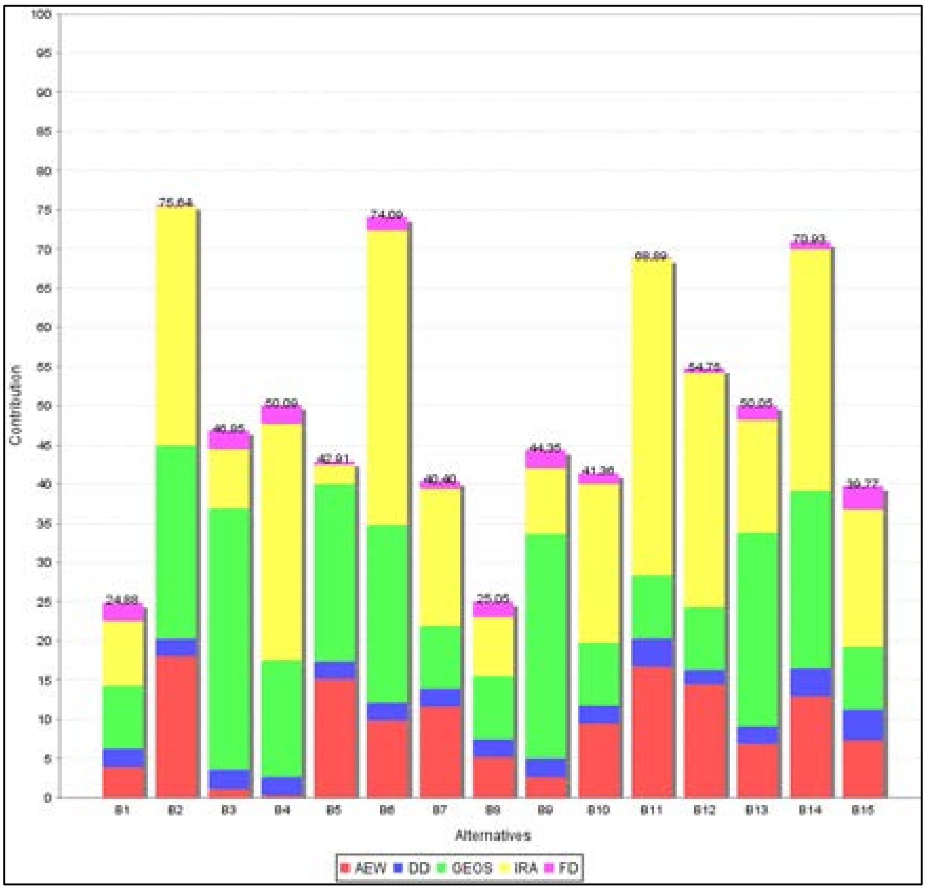

Fig. 5. Contribution of criteria for each alternative

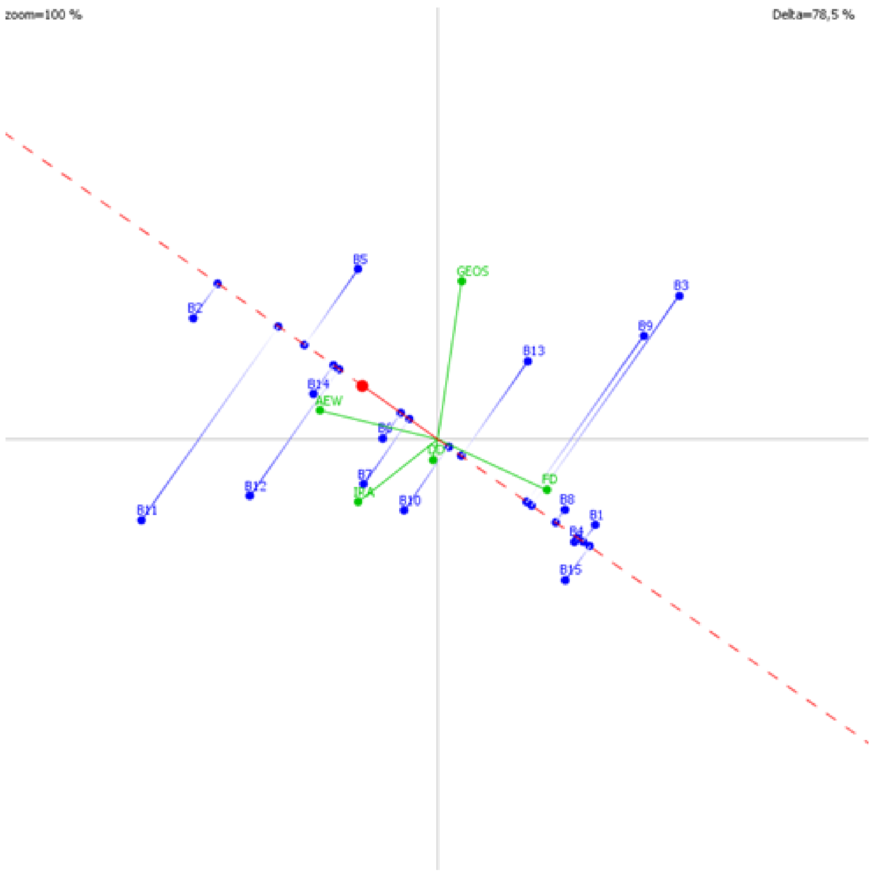

Fig. 6. GAIA plan

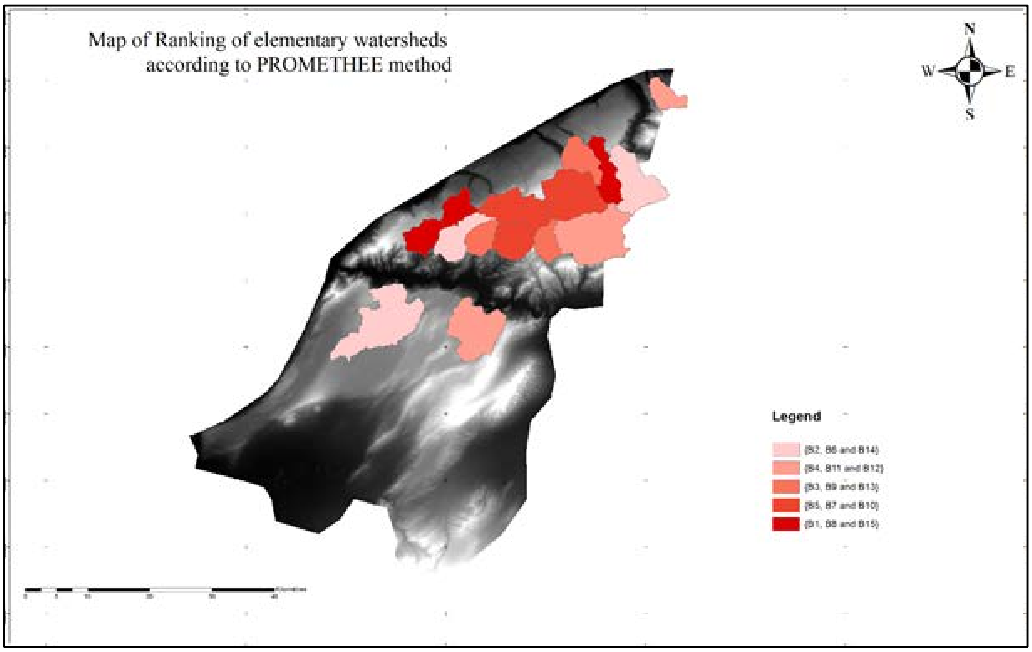

Fig. 7. Classification Map EW according to PROMETHEE Method

Alternatives B2, B10, B11, B12 and B14 are powerful for DD, AEW and IRA as they are projected in the same orientation. In addition, GAIA has a descriptive power to detect actions with different behavior on criteria that cannot be exhibited by the net final flow. The results of this study can be regarded as acceptable, because, the solutions obtained by both «PROMETHEE» and «AHP» methods show generally that the same elementary watersheds B2, B6, B11 and B14 are ranked first. In addition, these results are globally close to the observation deduced from the study carried out in the context of a classical method based on the observation ground by BNEDER (2006). The results obtained in this study are closer to reality because all criteria are taken into account at the same time and overall performance is aggregated.

The BNEDER experts presented their conclusions, based on their experiments and most important criteria. Indeed, according to this study, B11, is interesting but requires the construction of a hill reservoir at a significant height (h = 16 m). B2 is extremely interesting because the city of Mostaganem is located in the outlet of the watershed. An event occurred around the year 2000 that caused extensive damage. To prevent such kind of event, the construction of a hill reservoir would allow better flood control.

In addition, this site is interesting despite the need to sacrifice a fertile ground in use. B14 is interesting and must be studied as it may contribute to maintaining the rural population surrounding the future structure.

Therefore, the process of decision must take into account all the data necessary to establish a classification of elementary watershed (EW) from best to worst for the implementation of water projects in the study area. The thematic map shown in Fig. 7 illustrates the classification in five groups of elementary catchments compared to the PROMETHEE method, while Fig. 8 shows the ranking given by the AHP method.

4. Conclusions

The use of GIS and multicriteria analysis in a unique framework provides a database in the context of spatial decision-making. This study can guide and assist the decision maker in the process of decision-making to facilitate the allocation and / or control alternative (to implement hill reservoirs in our case). It helps to overcome the difficulties on the number of possible solutions, a variety of built in criteria decision making, and the possibility of the existence of several makers. The two different methods, PROMETHEE outranking and AHP available in this research offer the possibility to compare the results. The various EW were arranged from the best to the worst case. The B2, B6, B11 and B14 sites were ranked best obtained by the PROMETHEE method. The consistency of the results reproduced by both methods increases the confidence and affirms the effectiveness of the method. In this context, we also find that the results obtained in this study are generally close to the conclusions made by BNEDER, which ranked sites B2, B14 and B6 as interesting. Once the best EW for the realization of hill reservoirs are given, the decision makers can select the best option. The application of this method was very useful to structure and organize the totality of the data dedicated to this kind of problem. The exploitation of the potentialities of this study provides to the decision maker a great amount of information. Compared to other methods, AHP is an attractive method as it allows a comparison of different alternatives.

As for PROMETHEE, it allows different ranks or global (group) while taking into account possible weight alternatives and an individual ranking while taking account possible weight alternatives.

We will integrate the map of the hydrous potentialities and the map of sensitivity to erosion to enrich the database already developed and reveal important criteria for the choice of elementary watershed able to receive from such hydraulic equipment.

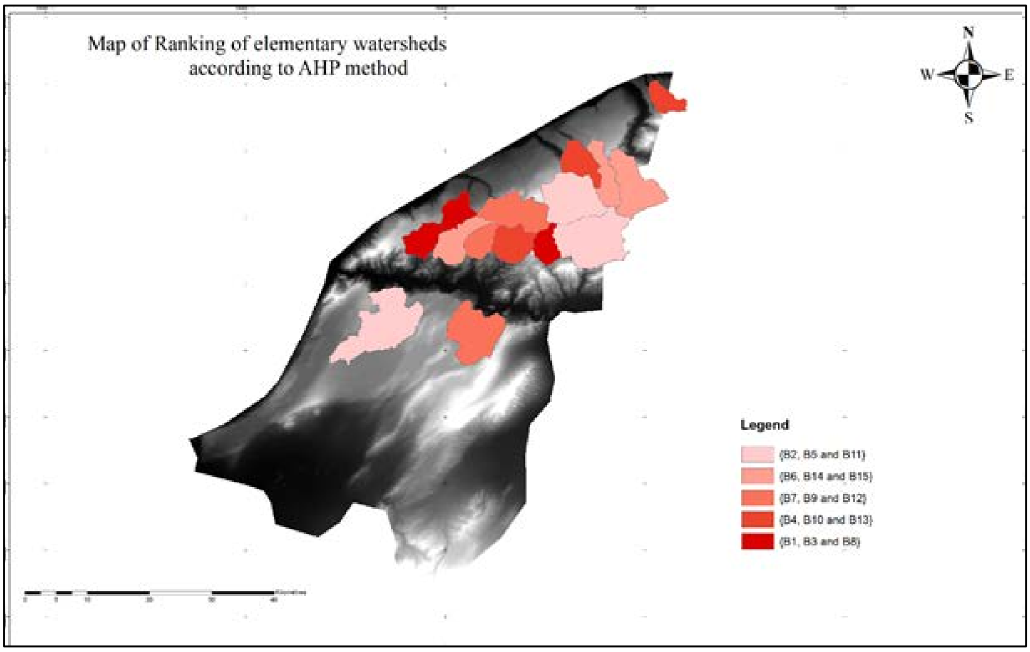

Fig. 8. Classification Map EW according to AHP Method

Our work is currently focused on extending this study to use for other problems of water resources. The work currently in hand aims to integrate the methods applied in a fuzzy environment such as fuzzy PROMETHEE and fuzzy AHP as well as the programming of computing attributes by using the Python language.

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