The ranking of districts in Ouagadougou by the risk of flood and runoff using the PROMETHEE

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Abstract. PROMETHEE methods are used for analyzing the risk of flood runoff in urban areas of Ouagadougou in Burkina Faso. 12 criteria are considered to calculate preference indices of the districts. We generated, on one hand, weights associated to these criteria taking into account hypotheses relatively to the importance or to the impact of each criterion evaluating the risk of flood runoff and on the other hand, we used the PROMETHEE methods to analyze this decision's problem with its diverse criteria. The PROMETHEE I and PROMETHEE II are used ranking the districts in relation with the degree of risk of flood runoff. This ranking is permitted by the calculated preference indices. Our aim is, on one hand showing to the potential decision-maker the importance of such a multi-criteria analysis and on the other hand, of verifying the coherence of the hypotheses with the obtained weights

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1. Introduction

In the current context of global warming and of issues of sustainable flood risk management in urban areas also occurs as a major concern. It appears therefore appropriate to consider issues relating to flood risk in particular by runoff in cities [18]. So, it is important that the town and country planning takes into account questions of streaming. For example, September 1st, 2009, municipality of Ouagadougou in Burkina Faso knew one of his most devastating floods with various victims. This flood was largely connected by the streaming of rainwater.

Some studies have clearly highlighted the relationship between changes in land use and changes in volumes of water run-off. The concept of decision-making is widely used. There are many definitions of decision-making process. In any case, there are different levels in

the process of decision-making: identification and definition of problems, determining collection of alternatives, determining collection of criteria for alternative evaluation, alternative evaluation and, finally, alternative sorting, description, choice or ranking. Over the last few decades, new methods have been found and the methodology of decision-making process has been improving. In order for aiding the decision-making process, many mathematical methods have been suggested. The Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) represents one of the most frequently used methods of multi-criteria decisions. Besides this method, other ones are also available[11] such as ELECTRE, AHP, ORESTE, etc.

Yougbaré and Datoloumbeye (2017) [18] used the ORESTE method analyzing the risk of flood runoff in urban areas in Ouagadougou. The ORESTE method is a method of ordinal ranking (based on ranks) which permits to avoid assigning weighs to criteria. Consequently, it comes from a non-compensatory logic.

In this paper, the methods PROMETHEE I and II are used for runoff risk comparison of the districts of Ouagadougou, which represent alternative solutions. The urban space management problem is multicriteria analysis problem with diverse conflicting criteria, protect on one side, the low districts of the cities against floods and on the other side the environment against the discharge amounts of pollutants exceeding the absorptive capacity of the natural environment. One solution to this problem is to make a ranking of districts that have a susceptibility to runoff to determine what are vulnerable will be the priority studies to prevent and manage the risk associated with runoff. Our goal in this paper is using PROMETHEE methods calculating preference indices, analyzing and ranking the districts, by comparing the risk of flooding by runoff from different districts of Ouagadougou which represent alternative solutions. According to 12 criteria their mutual risk is evaluated. This paper is organized as follow: firstly, we present Related Literature, next the mathematical model used, then we present the methodology by highlighting the alternatives, criteria and Data used applying the multicriteria method used here finally before concluding we present and analyze the results obtained.

2. Related Literature

Yougbaré and Datoloumbeye (2017) [18] used the ORESTE method analyzing the risk of flood runoff in urban areas in Ouagadougou. The ORESTE method is a method of ordinal ranking (based on ranks) which permits to avoid assigning weighs to criteria. Consequently, it comes from a non-compensatory logic. PROMETHEE methods and their applications have attracted much attention from academics and practitioners. Several authors have been interested in the development and application of the methods of Multicriteria Analysis in general and the PROMETHEE method in particular. As such, we can note certain works such as:

- Morkunaite et al. (2019) [10], used PROMETHEE technique for applying the selection of the most efficient cultural heritage contractor's alternative;

- Yan et al. (2019)[17], used PROMETHEE for ranking four alternative energy systems for heating;

- Dirutigliano et al. (2018) [5] presented an application of the PROMETHEE method for ranking different alternatives of building retrofitting at the building and district level;

- In the work of Zindani and Kumar (2018) [19] , material selection for seal strips used in turbines has been done applying PROMETHEE;

- He and Xu (2018) [7] applied the PROMETHEE II method to obtain the decision results as the standard of the group preferences;

- Coban et al (2018) [3] used PROMETHEE I and II for 8 solid waste disposal scenarios evaluation;

- Lopes et al. (2018) [9], applied the PROMETHEE and GAIA methods within a competitiveness study of eight tourist destinations located in the Northern Region of Portugal;

- In the paper of Inamdar et al. (2018) [8], PROMETHEE II method is used for evaluating and ranking of framework selects potential stormwater harvesting sites;

- In Andreopoulou et al. (2018) [2], PROMETHEE II is used for ranking websites to support market opportunities. They ranked websites and proposed to use the best website to "form a conceptual content model while designing an enhanced website for a Renewable Energy Sources (RES) enterprise" ;

- Vulevič and Dragovič (2017) [16], used the PROMETHEE II method ranking of nine sub-watersheds delineated in the Topciderska river watershed, Serbia;

- Silas and Rajsingh (2016) [12] applied different multi-criteria approaches ELECTRE, PROMETHEE and AHP for health care service applications. They concluded that the PROMETHEE method is best suited for solving multi-criteria decision making problem in the selection of desired health care services;

- In (2015) [14], PROMETHEE method is used by Veza et al. for ranking industrial enterprises based on enterprise's competences;

- Babaee et al. (2015) study allowed ranking 55 drivers, aged 70 and older by using PROMETHEE II;

- Vetschera and Teixeira de Almeida (2012) [13] studied the use of PROMETHEE outranking methods for portfolio selection problems;

- Vinodh and Girubha(2012) [15] PROMETHEE is used in the study to select the best sustainable concept considering the criteria from social, economic and natural perspectives;

- Ghafghazi et al. (2010) [6] used PROMETHEE ranking energy sources available for a case of district heating system in Vancouver, Canada.

This list cannot be exhaustive. All these studies clearly show the importance of the PROMETHEE approach in everyday applications.

3. Mathematical model

PROMETHEE methods are developed by Brans and Vinck in 1982 [1, 4].

The principle of PROMETHEE method is based on mutual comparison of each alternative pair with respect to each of the selected criteria. In order to perform alternative ranking by the PROMETHEE method, it is necessary to define preference function $p_h(x, y)$ for alternatives x and y after defining the criteria g_h. Alternatives x and y are evaluated according to the criteria functions. It is considered that alternative x is better than alternative y according to criterion g_h, if $g_h(x) > g_h(y)$ for the criterion g_h to be maximized. The decision maker has possibility to assign the preference to one of the alternatives on the basis of such comparison.

The preference can take values on the scale from 0 to 1, and relation combinations are possible to represent using following relations:

- If $p_h(x, y) = 0$ then there is indifference between x and y or no preference of x on y according to the criterion g_h;

- If $p_h(x, y) \approx 0$ then there is weak preference of x on y according to the criterion g_h;

- If $p_h(x, y) \approx 1$ then there is strong preference of x on y according to the criterion g_h;

- If $p_h(x, y) = 1$ then there is strict preference of x on y according to the criterion g_h.

In any case we have $0 \leq p_h(x, y) \leq 1$.

For each criterion g_h, the decision maker considers certain preference function. The generalized criteria are defined by the preference functions which are in number of six. If we consider that g_h is to be maximized, we summarize the six preference functions such as:

- **Type I: regular criterion:** for this preference function, we have

$$p_h(x, y) = \begin{cases} 0 & \text{if } g(x) - g(y) \leq 0 \\ 1 & \text{if } g(x) - g(y) > 0 \end{cases} \qquad (1)$$

- **Type II: U-sharpe criterion:** for this preference function, we have

$$p_h(x, y) = \begin{cases} 0 & \text{if } g(x) - g(y) \leq Q \\ 1 & \text{if } g(x) - g(y) > Q \end{cases} \qquad (2)$$

with Q parameter representing the Indifference level;

- **Type III: V-sharpe criterion:** for this preference function, we have

$$p_h(x, y) = \begin{cases} 0 & \text{if } g(x) - g(y) \leq 0 \\ \frac{g(x)-g(y)}{P} & \text{if } 0 < g(x) - g(y) \leq P \\ 1 & \text{if } g(x) - g(y) > P \end{cases} \tag{3}$$

  with P parameter representing the strict Preference level;

- **Type IV: Level criterion:** for this preference function, we have

$$p_h(x, y) = \begin{cases} 0 & \text{if } g(x) - g(y) \leq Q \\ 0.5 & \text{if } Q < g(x) - g(y) \leq P \\ 1 & \text{if } g(x) - g(y) > P \end{cases} \tag{4}$$

  with P, Q parameter representing respectively the strict Preference level and Indifference level;

- **Type V: linear criterion:** for this preference function, we have

$$p_h(x, y) = \begin{cases} 0 & \text{if } g(x) - g(y) \leq Q \\ \frac{g(x)-g(y)-Q}{P-Q} & \text{if } Q < g(x) - g(y) \leq P \\ 1 & \text{if } g(x) - g(y) > P \end{cases} \tag{5}$$

  with P, Q parameter representing respectively the strict Preference level and Indifference level;

- **Type VI: Gauss criterion:** for this preference function, we have

$$p_h(x, y) = 1 - e^{\frac{-(g(x)-g(y))^2}{2\sigma^2}} \tag{6}$$

  with σ parameter of the function.

After defining the type of preference function, it is necessary to determine the value of preference function of alternative x in relation to alternative y for each criterion, and calculate the index of preferences $\Pi(x, y)$ of alternative x in relation to alternative y. The index preference is calculated in the following way:

$$\Pi(x, y) = \sum_{h=1}^{k} w_h p_h(x, y) \tag{7}$$

where w_h is the weight of criterion g_h with

$$0 < w_h < 1 \text{ and } \sum_{h=1}^{k} w_h = 1. \tag{8}$$

After determining index preference $\Pi(x, y)$, it is finally possible to calculate alternative flow index, the flow of outclassing which makes it possible to appreciate how each alternative behaves in other faces. If n represents the number of alternatives of A, we calculate:

- The flow of outgoing outclassing

$$\Phi^+(x) = \frac{1}{n-1} \sum_{y \in A} \Pi(x,y) \tag{9}$$

that provides the index indicating the force of alternative x compared to others alternatives;

- The flow of incoming outclassing

$$\Phi^-(x) = \frac{1}{n-1} \sum_{y \in A} \Pi(y,x) \tag{10}$$

that provides the index indicating the weakness of alternative x compared to others alternatives;

- The net flow of outclassing

$$\Phi(x) = \Phi^+(x) - \Phi^-(x). \tag{11}$$

It is the difference between $\Phi^+(x)$ and $\Phi^-(x)$. When the alternative x is generally preferred to others it is positive if not it is negative.

If the different flow are obtained, it is possible defining the relation of preference according PROMETHEE I or PROMETHEE II.

PROMETHEE I

The PROMETHEE I method is to classify the actions by decreasing incoming flow and increasing outgoing flow. Consider P^I, I^I and R^I respectively the relations of preference, indifference and incomparability.

$$xP^I y \Longleftrightarrow \begin{cases} & \Phi^+(x) > \Phi^+(y) \text{ and } \Phi^-(x) < \Phi^-(y) \\ or & \Phi^+(x) = \Phi^+(y) \text{ and } \Phi^-(x) < \Phi^-(y) \\ or & \Phi^+(x) > \Phi^+(y) \text{ and } \Phi^-(x) = \Phi^-(y) \end{cases} \tag{12}$$

$$xI^I y \Longleftrightarrow \Phi^+(x) = \Phi^+(y) \text{ and } \Phi^-(x) = \Phi^-(y) \tag{13}$$

$$xR^I y \text{ othewise.} \tag{14}$$

The PROMETHEE I method provides a partial classification of actions.

PROMETHEE II

The PROMETHEE II method allows us to classify all the actions and leaves no incomparable action with others. It provides a total pre-order of actions. Consider P^{II}, I^{II} and R^{II} respectively the relations of preference, indifference and incomparability.

$$xP^{II} y \Longleftrightarrow \Phi(x) > \Phi(y) \tag{15}$$

$$xI^{II} y \Longleftrightarrow \Phi(x) = \Phi(y) \tag{16}$$

With PROMETHEE II, there is no incomparability.

4. Methodology, Alternatives, criteria and Data

In order to make a multicriteria analysis of this issue, the PROMETHEE I and II are been chosen. These methods have the ability to take into account the relative importance between different criteria depending on the decision maker. The PROMETHEE I and II methods deal with the issue of ranking or classification. These methods are advantageous because they can compare complex situations, naturally incomparable situations in including criteria of different natures (objective and subjective). We considered as alternatives the districts: BAS: Baskuy, BOG: Bogodogo, BOU: Boulmiougou, NON: Nongre-maasom and SIG: Sig-Nonghin. The districts will constitute our set of alternatives. The criteria make it possible to assess the alternatives with regard to the respect for the principles of the town and country planning, and the principles of ecology. The combination of these factors (sub-criteria) was achieved by taking into account the planning principles and the principles of ecology [18].

The criteria built to meet, these planning principles and ecology, are:

- z_1, whose ecological objective is to limit soil sealing. The sub-criteria considered are: g_1, modern proportion of habitat (high buildings, medium, low or mixed); g_2, areas of economic activities (industrial and commercial areas, the formal market, stations, airport, landfill and mining materials); g_3, proportion of traditional housing (rural housing and low buildings); g_4, agricultural areas (rainfed crops, horticulture and agriculture);

- z_2, whose objective is to use management techniques with less impact (negative). The sub-criteria considered are: g_5, area green space and planting (plantations and green spaces); g_6, recreational areas (sports and recreation grounds);

- z_3, whose objective is to minimize the development (urbanization) in sensitive areas. The sub-criteria considered are: g_7, the natural vegetation surfaces (gallery forest, shrubland, grassland and orchards); g_8, surfaces of marshy meadows;

- z_4, with the goal of sustainability is to preserve as much as possible the natural areas in an undisturbed state. The sub-criteria considered are: g_9, urbanized area in flood areas (temporary water bodies and wetlands); g_{10}, free water surface (courses and waterways, natural and artificial lake); g_{11}, soil type (hydromorphic soils);

- z_5, which aims to improve prevention. The sub-criterion considered is: g_{12}, capacity of hospitals.

By doing operations in order to make a ranking of alternatives by the PROMETHEE method we used, the data in the table 2 and the sub-criteria ($g_h, h = 1, \ldots, 12$).

Using the criteria ranking provided by the expert [18], we have the results with are summarized in the table 1

Table 1: Criteria average rank.

Min/max	z_1	z_2	z_3	z_4	z_5
Criterion	min	max	min	max	max
rank	1	3.5	2	5	3.5

This ranking gives a relationship linking the weights $(\Lambda_j, j = 1, \ldots, 5)$ of these different criteria $(z_j, j = 1, \ldots, 5)$,

$$\sum_{j=1}^{5} \Lambda_j = 1, \quad \Lambda_1 > \Lambda_3 > \Lambda_2 = \Lambda_5 > \Lambda_4. \tag{17}$$

Using the sub-criteria (of the five criteria) ranking (provided by the expert [18]) we have the results with are summarized as follows table 2.

This ranking gives a relationship linking the weights $(\lambda_h, h = 1, \ldots, 12)$ of these different sub-criteria $(g_h, h = 1, \ldots, 12)$,

$$\Lambda_1 = \sum_{h=1}^{4} \lambda_h, \quad \Lambda_2 = \sum_{h=5}^{6} \lambda_h, \quad \Lambda_3 = \sum_{h=7}^{9} \lambda_h, \quad \Lambda_4 = \sum_{h=10}^{11} \lambda_h, \quad \Lambda_5 = \lambda_{12}. \tag{18}$$

$$\lambda_2 > \lambda_1 > \lambda_3 > \lambda_4. \tag{19}$$

$$\lambda_6 > \lambda_5. \tag{20}$$

$$\lambda_7 > \lambda_8 > \lambda_9. \tag{21}$$

$$\lambda_{11} > \lambda_{10}. \tag{22}$$

The relations (17), (18), (19), (20), (21)and (22) linking the weights between them allowed us to generate weights associated with the different criteria. It must be emphasized that in our case, the determination of weights could not be explicit. We obtained the weights of criteria summarized in the table 3.

Table 2: Performance matrix.

Criteria	Sub-criteria	Rang	Min/max	BAS	BOG	BOU	NON	SIG
z_1	g_1	2	min	52.15	72.72	42.089	30.22	53.98
	g_2	1	min	29.77	3.2	2.383	3.58	4.53
	g_3	3	min	0	0.12	14.953	6.23	2.83
	g_4	4	min	1.59	15.07	25.721	23.88	23.75
z_2	g_5	2	max	0.86	0.47	1.168	9.03	1.81
	g_6	1	max	3.78	0.93	0.546	0.24	1.63
z_3	g_7	1	min	2.75	0.55	0.93	0.40	0.31
	g_8	2	min	4.6	0.74	4.706	5.17	3.56
	g_9	3	min	98.76	87.47	97.29	38.60	77.97
z_4	g_{10}	2	max	0	4.57	6.488	18.22	5.74
	g_{11}	1	max	1.04	0.07	0.247	1.19	0.78
z_5	g_{12}	1	max	985.98	1771.54	801.51	1795.14	53.98

Table 3: Weights of criteria.

λ_1	λ_2	λ_3	λ_4	λ_5	λ_6	λ_7	λ_8	λ_9	λ_{10}	λ_{11}	λ_{12}
0.0029	0.0040	0.0022	0.0019	0.0345	0.1542	0.3203	0.0788	0.0596	0.0850	0.0679	0.1887

5. Results

The essence of the problem is, using mathematical support, to find indices $\Phi^+(x), \Phi^-(x), \Phi(x)$ of the five districts of Ouagadougou. These indices evaluate performances, strengths and weaknesses in terms of risk of flooding by runoff. According to these indices, it is possible to determine the level of risk of flooding by runoff of the districts. To calculate these indices, we considered the preference function on the table 4 .

Table 4: Preference functions of criteria.

Sub-criteria	Type	Parameter
g_1	Type III	P= 14.07
g_2	Type III	P= 10.56
g_3	Type III	P= 5.55
g_4	Type III	P= 9
g_5	Type III	P= 3.21
g_6	Type III	P= 1.27
g_7	Type III	P= 0.91
g_8	Type III	P= 1.6
g_9	Type III	P= 22.02
g_{10}	Type III	P= 6.04
g_{11}	Type III	P= 0.44
g_{12}	Type V	Q= 108.16; P= 652.5

The different preference functions considered applying are summarized by the table 4 and indices $\Phi^+(x), \Phi^-(x), \Phi(x)$ calculated are summarized in the table 5 .

Table 5: Flow of districts.

	BAS	BOG	BOU	NON	SIG
$\Phi^+(x)$	0.2722	0.4007	0.1867	0.5223	0.4054
$\Phi^-(x)$	0.5866	0.2256	0.4816	0.1699	0.3235
$\Phi(x)$	-0.3144	0.1751	-0.2950	0.3524	0.0819

With PROMETHEE I method the indices obtained provide the following relations (P= Preference, R= Incomparability, I= Indifference) summarized by the table 6.

Table 6: Relation with PROMETHEE I.

	BAS	BOG	BOU	NON	SIG
BAS			R		
BOG	P		P		R
BOU	R				
NON	P	P	P		P
SIG	P	R	P		

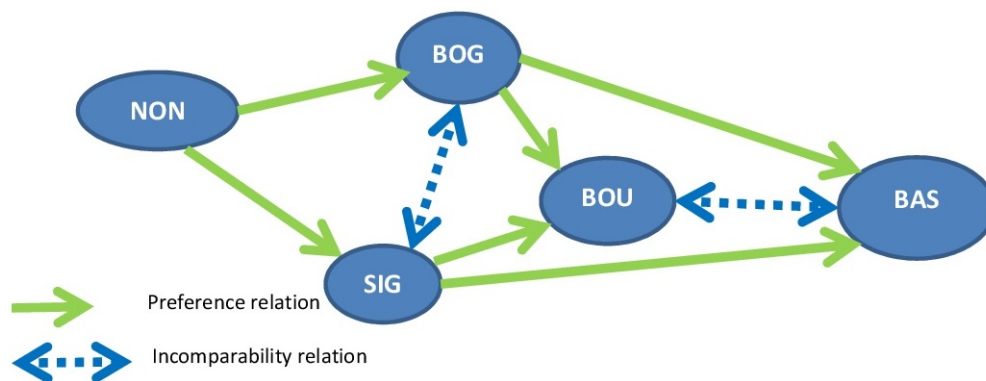This table provides the graph of outranking given by the following figure 1.

Figure 1: Graph of outranking of the districts by PROMETHEE I.

With PROMETHEE I we obtained that the district of Nongr-maasom is best ranked as the others and there are two incomparability relations: Baskuy and Boulmiougou are considered incomparable. The first has a better force measured by the flow $\Phi^+(x)$ than the second and the latter has a low weakness so desirable than the first. We cannot base

on these two indices to distinguish them; Sig-Nonghin and Bogodogo are also considered incomparable. The first has a better force measured by the flow $\Phi^+(x)$ than the second and the latter has a low weakness so desirable than the first. We cannot base on these two indices to distinguish them; As for the district of Nongr-maasom, the application of PROMETHEE I showed that it is better ranked than all others. It appears from this study that Sig- Nonghin is the district less vulnerable in terms of flood runoff and the two incomparable districts, Baskuy and Boulmiougou, the most vulnerable districts. With PROMETHEE II we obtained the following relations summarized by the figure 2.
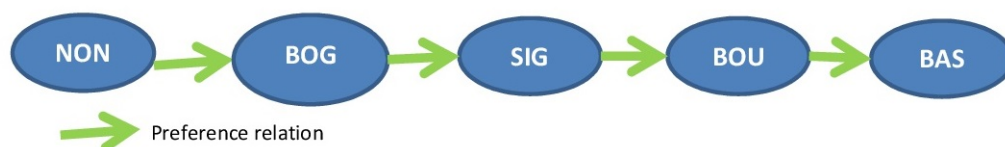

Figure 2: Graph of outranking of the districts by PROMETHEE II.

It shows the following result

$$NON \succ BOG \succ SIG \succ BOU \succ BAS$$

It appears from this study that Nongre-maasom is the district less vulnerable in terms of flood runoff and Baskuy the most vulnerable district.

Comments

In the paper of Yougbaré and Datoloumbeye (2017) [18], with the same data the results show that Boulmiougou is more vulnerable than the others districts. Here, with PROMETHEE I the results show that Boulmiougou and Baskuy are incomparable and they are the most vulnerable districts than the others. With PROMETHEE II the results show that Baskuy is the most vulnerable district.

In the paper of Yougbaré and Datoloumbeye (2017) [18], results show that Bogodogo, Nongre-Massom and Sig-Nonghin are incomparable and by compensatory Sig- Nonghin is the district which is less vulnerable in terms of flood runoff. Here, with PROMETHEE I and PROMETHEE II, the results show that Nongre-Massom is the district which is less vulnerable in terms of flood runoff.

These two studies show that the Boulmiougou and Baskuy areas need to be monitored more because they have a higher risk of runoff flooding than the others.

6. Conclusion

The purpose of this study is to compare and classify the districts by risk of flooding and to guide the decision-maker by proposing values representing solutions verifying the crite-

ria and constraints set by the experts. The aim of the research in this paper is to obtain preference indices of risk of runoff of the districts of Ouagadougou by using multi-criteria analysis. In this paper, the PROMETHEE method is used, as well as a mathematical tool in order to obtain preference indices. The PROMETHEE method is ranked as one of the most famous and most frequently used methods of multi-criteria decisions. We generated the weights of criteria according the hierarchic relation between these criteria.

By using the PROMETHEE method, preference indices are obtained for the districts of Ouagadougou on the basis of twelve criteria. According to these results, Nongre-Massom emerged as the district less vulnerable in terms of flood runoff. It emerges from this study that flood risks by streaming are especially high for the district of Boulmiougou and Baskuy.

The results about the method are meanwhile promising. Indeed, to take into account all the factors characterizing a risk stays a challenge. The application of the PROMETHEE method allows having an order of priority with regard to the districts where will proposals for actions to prevent and manage the risk associated with runoff.

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