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Article

Prospective of an Inland Waterway System of Shipping Canals in Skikda (Algeria)

Amira Ghennaï [1], Said Madani [1], and Carola Hein [2,*]

[1] Laboratoire Puvit, University F A Setif 1, Algeria
[2] Faculty of Architecture and the Built Environment, Delft University of Technology, The Netherlands

* Corresponding author (c.m.hein@tudelft.nl)

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Abstract

Sustainable development projects require careful balancing of economic interests and ecological needs. The case of Skikda, a city in northeast Algeria, located on the Mediterranean coast, illustrates the challenges connected with such a development. The ancient city coexists with a young hydrocarbon port and industrial pole that serves as a transfer hub in the flow of petroleum between hinterland and sea. The installation of the port and petrochemical refining plants on the banks of the estuary of the Safsaf River presents many challenges to local citizens and the ecosystem, including pollution of the water system, groundwater, and river water, and damage to the area's ancient heritage. This study argues that we need new and less polluting forms of intermodality between hinterland and seaport to make urban mobility more sustainable. It asks whether and how the existing rivers and wadis (river channels that are dry except during rainy periods) can be transformed into artificial canals for river navigation to improve the transport fluidity and sustainability of Skikda. To answer this question, the study adopts a prospective approach using the MICMAC scenario method. This approach entails, first, presenting and evaluating the potentialities of the existing rivers of Skikda using QGIS, and second, discussing and proposing scenarios for transforming these rivers into urban waterways, that is, artificial canals for inland navigation. The prospect of inland waterway transport in Skikda may be a radical scenario, yet, despite its hydraulic capacity and advantages, this system is not receiving attention in Algeria. We suggest that water transport can breathe sustainable blue life into a vulnerable industrial port city, transforming its challenges into opportunities.

Keywords

inland waterway system; MICMAC; prospective; scenario; shipping canals; Skikda

Issue

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1. Introduction

Many contemporary port cities have grown over centuries or even millennia at places where rivers discharge into the sea, creating complex landscapes where shipping and industrial development create multiple challenges for historic sites, urban living, and ecological health. Skikda, an ancient port city located in the northeast of Algeria on the Mediterranean at the mouth of the Safsaf River, provides an example of such challenges. The second-most important port of the country, after Algiers, Skikda is considered the eastern gateway for the export of hydrocarbons to international and European markets by sea. Since the 1970s, Skikda has been a stronghold of the oil and gas industry (Ghennaï et al., 2022).

Skikda's economic advantage has led to deficiencies in terms of urban development. Apart from the pollution and vulnerability imposed by the oil industry, Skikda faces important challenges of urban mobility, due to the location of the city between two natural barriers, the sea on one side and the mountains on the other. Urban development is further constrained by a large industrial zone that is close to the heart of Skikda's urban center. Since the 1990s, security measures taken to protect this sensitive state infrastructure have led to the restriction of access to the area and the closure of Skikda's airport. Furthermore, access to the boulevard that links Skikda and the tourist area, Filfia, has been limited. Restricted access to this boulevard adjacent to the port creates urban mobility problems. The boulevard is key to maritime and touristic activities, and citizens have demanded the reopening of this route (Ghennaï & Madani, 2022).

Traffic congestion and everyday traffic jams in Skikda are a serious problem for both the city and the industry. They require rethinking the transport systems in Skikda. The authors propose investigating the potential of the hydrological assets of Skikda by creating a waterway system that relies on existing channels and rivers, such as the Safsaf River (Figure 1), which links the port to the industrial area and the hinterland, as a new means of facilitating urban transport in Skikda and, indeed, Algeria. This waterway can be both internodal and intermodal, as it would connect the seaports to new inland shipping functions.

The use of such waterways for transport functions raises many questions about water quality because the Safsaf River connects several municipalities of Skikda located in the Safsaf valley, including the industrial zone, as well as the Safsaf River, feeding agricultural activities and biodiversity in Skikda's rural area. The Safsaf River basin is a vital watercourse because of its flora and fauna and it contributes to the irrigation of agricultural areas. It is controlled by four major dams, including Zerdaza Dam, and is home to some 460,000 inhabitants (Rouidi et al., 2022). The city of Skikda receives its water from the basin of the Safsaf River, which starts in the south of Algeria. This basin has an area of 1,158 km^2 (Rouidi et al., 2022). The Safsaf River derives its name from the willow trees that line its banks. It was along this river that the Phoenicians established one of the earliest cities, Skikda Thapsus. In fact, some historians suggest that the river mentioned as "Thapsus africae, juxta Rusicadem" is none other than the present-day Safsaf River (Tissot et al., 1884). Over the years, the river has experienced significant pollution due to its location as a population center and industrial hub (Rouidi et al., 2022).

Parts of the river are in fact a dumping ground for unpurified rainwater and wastewater, and from the river they flow directly into the sea, posing major threats to humans and non-humans. The source of the Safsaf River is the Djebel Taïa mountain, but the Safsaf River is fed by the dam of Zardza. This has contributed to contaminating these waters with dangerous toxic pollutants, mainly metals such as iron, cadmium, and manganese. The contaminated Safsaf River is equipped with only four wastewater treatment plants, with a treatment capacity of 42,000 m^3/day, holding a large volume of untreated wastewater, which extends to 16,153.2 m^3/day (Boubelli et al., 2018).

To develop more sustainable ways of living and working we need new approaches to industrial and urban mobility. This article explores the potential of new approaches to intermodal transportation through the development of artificial shipping canals in Skikda, while also considering the ecological implications of such transportation. Following a short introduction to the role of inland waterway transport (IWT), this article explores the potential of converting the Safsaf River into a new mobility system to improve urban flows, solve urban connectivity problems, and connect ports with the industrial zone and hinterland. Our plan for converting the Safsaf River to a canal involves integrating a sustainable river transport system in Skikda as an asset for promoting tourism and meeting urban and industrial challenges.

The objective of this study is to develop a prospective scenario for the recovery of the river and the development of a canal as an urban waterway. It aims to both absorb the negative effects of the oil industry and promote the role of water in improving the quality of life. To achieve this objective, the study suggests creating a hydraulic map of the Safsaf River using geographic information system. Subsequently, the researchers employ MICMAC, a tool that facilitates idea sharing by utilizing a matrix to analyze the interrelationships among variables assumed to influence the studied strategy's implementation.

1.1. Brief Introduction to Inland Waterway Transport

Canal shipping has long been the backbone of trade in many countries. IWT is one of the oldest inexpensive and reliable navigation systems (Bu & Nachtmann, 2021). The largest IWT systems are located in China, Russia, and Brazil (Wiegmans & Konings, 2016). IWTs have been constructed through the transformation or connection of rivers, as well as through excavation. Herodotus, for example, mentioned the restoration of the Great Canal of Babylon around 1700 B.C. The construction of the Suez Canal began around 600 B.C., connecting the Nile in Egypt and the Mediterranean to the Red Sea. The Great Canal of China was built in the 7th century to link the sea to the capital via Canton (Hepburn, 1909).

In the 12th century, European leaders started to develop a great canal system of Europe, including Charlemagne's connection of the Rhine and the Danube. One of the historic artificial navigable canals is the Canal du Midi in Toulouse, France. Built in the 17th century, it is an impressive piece of engineering, with flows provided by water collection in the test channel, water flow at Naurouze, and the Montagne Noire (Mukerji, 2021). The canal has been a success, even though it has been closed some summers for lack of water (De Wolff et al., 2021). IWT has been key to the development of the Netherlands, connecting the port facilities of Amsterdam

(a) (b)

Figure 1. (a) Zeramna River Branch of the Safsaf valley and (b) the estuary of the Safsaf River on the Mediterranean Sea.

to the hinterland in 1826 and again in 1876. Similarly, the port of Rotterdam was connected to the lower Rhine in remarkable feats of engineering (Hepburn, 1909). The Seine River canal, the Rhone River canal in France, and the Rhine–Scheldt canal respectively connect the Ports of Rotterdam and Antwerp, forming a major economic zone of Europe (Eski & Fiddelers, 2022).

IWT has made it possible to solve many of the navigation problems associated with land-based infrastructure, which suffer from poor surfacing, traffic congestion, environments unsuited to transport due to various risks, such as soil quality, which can cause landslides, and wadi flooding, leading to the blocking of roads built near this type of watercourse (Cheranchery et al., 2021). Canals and river restoration projects are recently gaining increased attention, both to improve the quality of life and to facilitate transportation. The capacity of such projects to enhance trade depends on several factors, such as governance and waterway characteristics, including navigability, operability, depth, and length, but also climate change (Caris et al., 2014; Jonkeren et al., 2014). Successful cases of canal revitalization can also provide factors for analysis; these experiments have become a model for sustainable development that will boost cultural and tourism values, improve climate and environmental conditions, and create a historic waterside landscape that is attractive, cost effective, and energy efficient.

River renewal projects are developing all over the world and help revive aquatic life in the ecological system, such as in the Cheonggyecheon River in Seoul, South Korea (Robinson & Ji, 2022). There, the restoration of a waterway of cultural and touristic value has improved the climate and environment, attracting millions of visitors each year with its historic waterside landscape (Yoon, 2022). This waterway has become a symbol of the transition of planning paradigms in the city of Seoul and a worldwide model of sustainable development (Lee & Jung, 2015). Opposing perspectives criticize the project's economic viability and sustainability, seeing it as a form of artificiality and superficiality that fails to protect nature in the city. Even in terms of ecological functionality, according to Kim et al. (2005), the renewal of animal and plant species has not been striking, raising questions about the quality of the water that feeds this watercourse (Kim et al., 2005; Kim & Jung, 2018).

Despite the critiques, Seoul's river rehabilitation project is often seen as a major driver for revitalizing the urban center while remaining it in contact with water and nature. This project can provide inspiration for converting existing rivers and wadis to artificial canals for river navigation. This will improve the mobility system to enhance urban flows and solve urban connectivity and sustainability problems in Skikda.

Indeed, Algeria is served by rivers that provide downstream communities with water for agriculture and industry, but they have not been used for transportation purposes, despite citizen interest in rehabilitating valleys, such as Bibi, Tanji, and others. The Safsaf River, along with its network of watercourses, holds historical significance and continues to serve as a source of irrigation (Hadef et al., 2022; Sakaa et al., 2022). Despite the growth of industries located near its estuary, where water flows directly into the Mediterranean Sea (Figure 2), the river remains in use.

Thus, the scenario to convert the Safsaf River to link the ports to the industrial zone and the hinterland could benefit from knowledge gained by a project approach that enables elements of prospective scenarios to be designed and organized from a vision of urban planning and mobility in the socio-ecological transition. This article uses the cartographic tool QGIS to collect information on the Safsaf River. QGIS will enable us to establish

(a) (b)

Figure 2. (a) Satellite view capturing the liquid discharges of the refinery in the estuary of the Safsaf River on the Mediterranean Sea and (b) industrial hydrocarbon installations on the banks of the Safsaf River.

scenarios for the prospective IWT for Safsaf River and to discuss them using MICMAC.

2. Material and Methods

To better understand the possibility of integrating an IWT in Skikda, we used the prospective method, defined as a strategic method to determine future probabilities (Abril Ortega & Arias Chávez, 2020). We have structured the research in two phases that complement each other: We first mapped the Safsaf valley, using the QGIS software. Then we processed the cartographic data to analyze the creation of an IWT using the MICMAC software. The hydraulic maps obtained by QGIS have allowed us to extract the characteristics of the Safsaf River and to envision revitalizing them, as well as to propose a range of scenarios to develop urban waterways in Skikda. On the basis of the results of the first step and of the scenarios proposed for the potential revitalization of the Safsaf River, we identified a series of variables for the IWT scenario in Skikda by using MICMAC.

QGIS and MICMAC are two very different but essential tools at each stage of this research. QGIS provided the foundation to perceive and understand the morphology and the geographical characteristics of the Safsaf valley. MICMAC helped us structurally analyze the potentialities of the river network of the Safsaf valley. However, MICMAC does not provide specific factors as a decision support tool; instead, it gives users the possibility of determining their own factors in relation to their project, thus giving more objectivity to the research. This is why the choice of factors must be part of a rigorous theoretical and practical framework, and in line with the objectives of the research. MICMAC's structural analysis is based on stimulating reflection within the group to facilitate the study of the performance of the various factors (variables).

Our research provides a theoretical framework for answering questions about the importance of waterways in urban planning, and the reasons for proposing an IWT in Skikda. The introductory review will influence the use of both research tools QGIS and MICMAC, whose use will be presented separately from each other, while their results will be complementary because part of defining the design variables for the MICMAC analysis will be based on the data from the theoretical framework and the QGIS mapping. Therefore, the latter two will directly influence the behavioral evaluation of each variable in the structure matrix, from which we will obtain a direct influence map (DIM) and a direct influence graph (DIG).

2.1. The Prospective Method With the MICMAC Tool

The MICMAC tool is used for prospective structural analysis, which consists of developing a series of factors likely to influence a prospective scenario under study, and then assessing their mutual interaction (Khan et al., 2020). These factors (as variables) will be introduced into the MICMAC database to form the study matrix. Open-source MICMAC software is used to examine the impact of relationships between the variables of the matrix (Venegas et al., 2022), identifying dependency and mobility relationships (Balouli, 2022) in order to classify the variables of the system according to their strong or weak impact on the prospective scenario (Benjumea-Arias et al., 2016), thus offering the opportunity to improve the urban strategy according to the contribution of the different factors.

Based on the three pillars of sustainable development—economy, society, and environment—we have selected a set of characteristics of the smart port-city and considered them factors influencing the scenario of the IWT for the Safsaf River. These factors include opening up the port to the city, competitiveness, optimization and digitalization, the creation of ecosystems, the reduction of greenhouse gas emissions, and self-sufficiency through the production of clean energy (Ghennaï et al., 2022). The analysis factors for MICMAC in this research are also designed according to the benefits mentioned in the literature review in this article, such as the improvement of housing and transportation, facilitation of trade, and an increase in e-governance, navigability, operability, accessibility, and security.

Thus, the analysis focuses on the impact of the revival of the Safsaf River, one of the most important rivers in Skikda (Boubelli et al., 2018), and the development of a new transport system in the city. Table 1 presents the key factors that need to be considered in the development of scenarios for the prospective of converting the Safsaf River into an artificial IWT. In line with the three pillars of sustainable development, we defined 21 variables that can influence the transition of the Safsaf River into a navigable waterway, and that also have an impact on the integration of river transport in Skikda.

By considering these factors as variables within the MICMAC database (La Prospective, n.d.), the software generated a matrix table that illustrated the interdependence between factors based on their mutual influences. This matrix allowed us to define the direct influence of the ranges indicated by a standard scale, provided by the MICMAC software, from 0 to P, where 0 = no influence, 1 = weak influence, 2 = moderate influence, 3 = strong influence, and P = potential influence. The influence of each factor on the other factors proposed for the scenarios of integration of the Safsaf IWT, will be evaluated by projecting its potential impacts on the rest of the factors of the DIM matrix, according to the rating scale provided by MICMAC, which ranks the influence of the study factors from 0 to P. In addition, the specificities of Skikda's context will be taken into consideration, particularly its status as a port city with an important cultural heritage and natural landscape on the one hand and an industrial-oil reality and petroleumscape on the other. In this study, we have limited the research to direct influences, which will be presented in a DIM, elaborated in four sections, where the variables of each section share influences with specific characters mentioned in Figure 3.

2.2. Direct Influence Map Zones

The result of the analysis of the influences of the factors developed and proposed in this article for the scenarios of integration of the Safsaf IWT, based on the dimensions of sustainable development, will be presented in matrix form in MICMAC, and then the software will generate this matrix in a DIG. Reading the graph is based on the legend provided by the software, which determines the degree of influence between the factors of the proposed scenario through the degradation of the line linking the factors together, from the most important influence, represented by a bolder line, to the weakest influence, represented by a finer line. The importance of the DIG resides in its ability to visually present the impact relationships between the factors of the scenario. The aim is to give an idea of which factors have a high or low impact, enabling the integration strategies of the prospective scenario Safsaf IWT to be improved, focusing on the success factors and enhancing the scenario's weakness factors.

3. Results

3.1. Results of Mapping of the Safsaf Valley by QGIS

Prospective scenarios for the integration and supply of the prospective Safsaf IWT require hydrological data,

Table 1. Table of variables for converting the Safsaf River into a canal.

	Dimensions of Sustainable Development							
	Economy	Short label		Society	Short label		Environment	Short label
1	Wealth creation	1Wealthcra	8	Passengers shipping	8Psnrshipg	15	Energy efficiency	15Enrgyeff
2	Growth in port activity	2Grprtactv	9	Employment	9Employmnt	16	Development of the seascape	16Dvlpscpe
3	Maritime freight chain	3Mritfreit	10	Governance	10Govrnenc	17	Reducing pollution	17Rdcpolut
4	Competitiveness and attractiveness	4Cmptvatrc	11	Safety	11Safety	18	Ecosystem and biodiversity	18Ecos&bio
5	Sustainable investment	5Sustinvst	12	Water, identity, and culture	12Wtridnty	19	Climate change	19Climatch
6	Feasibility and viability of the project	6Feaviabty	13	Social equity	13Eqitysoc	20	Preservation of natural resources	20NturlSrc
7	Reconstruction costs	7Recnstcst	14	Social facilities	14Socfacil	21	Management of natural risks	21MngRisks

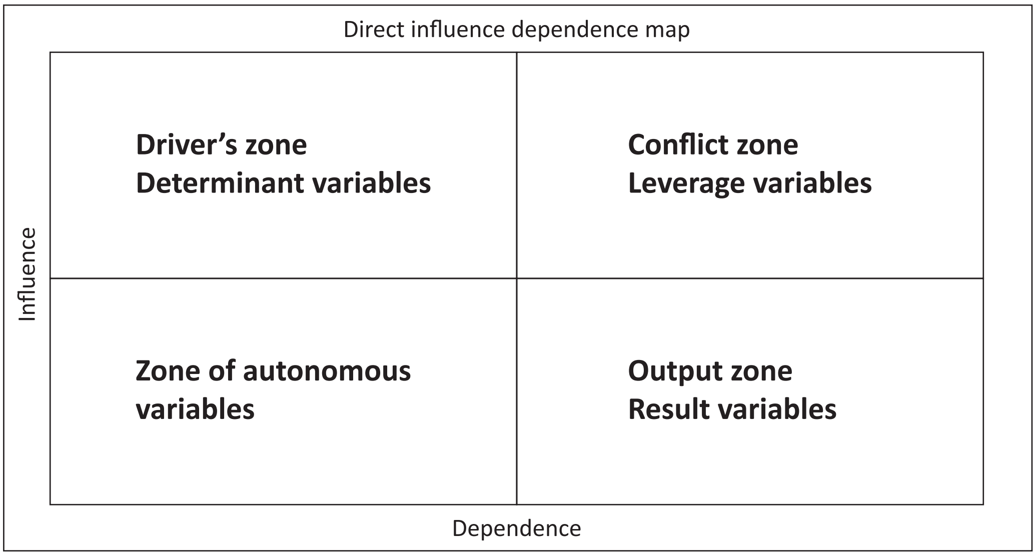

Figure 3. The specifics of the DIM zones that define the level of strength of the study variables in MICMAC.

which are obtained using mapping. The result is the map in Figure 4, generated by QGIS, which shows the morphology of the Safsaf River, its various courses and branches, its current supply from the Zerdaza Dam, and the estuary where the river flows into the Mediterranean Sea. Figure 6 projects the possible scenarios for the prospective canals, the maps also show the municipalities crossed by the Safsaf River, such as the municipalities of Al-Hadaiek, Ramdane Djamel, Salah Bouchaour, and El-Harrouch, in Zardaza to the south; Sidi Mezghiche, Bouchtâta, and Aïn Zouit in the west; and Hammadi Krouma, Beni Bechir, and Filfila in the east. The map in Figures 4 and 5 shows that the veins of this valley form a rich network capable of connecting many municipalities and urban and peri-urban areas of Skikda. It presents an attractive hydrodynamic landscape.

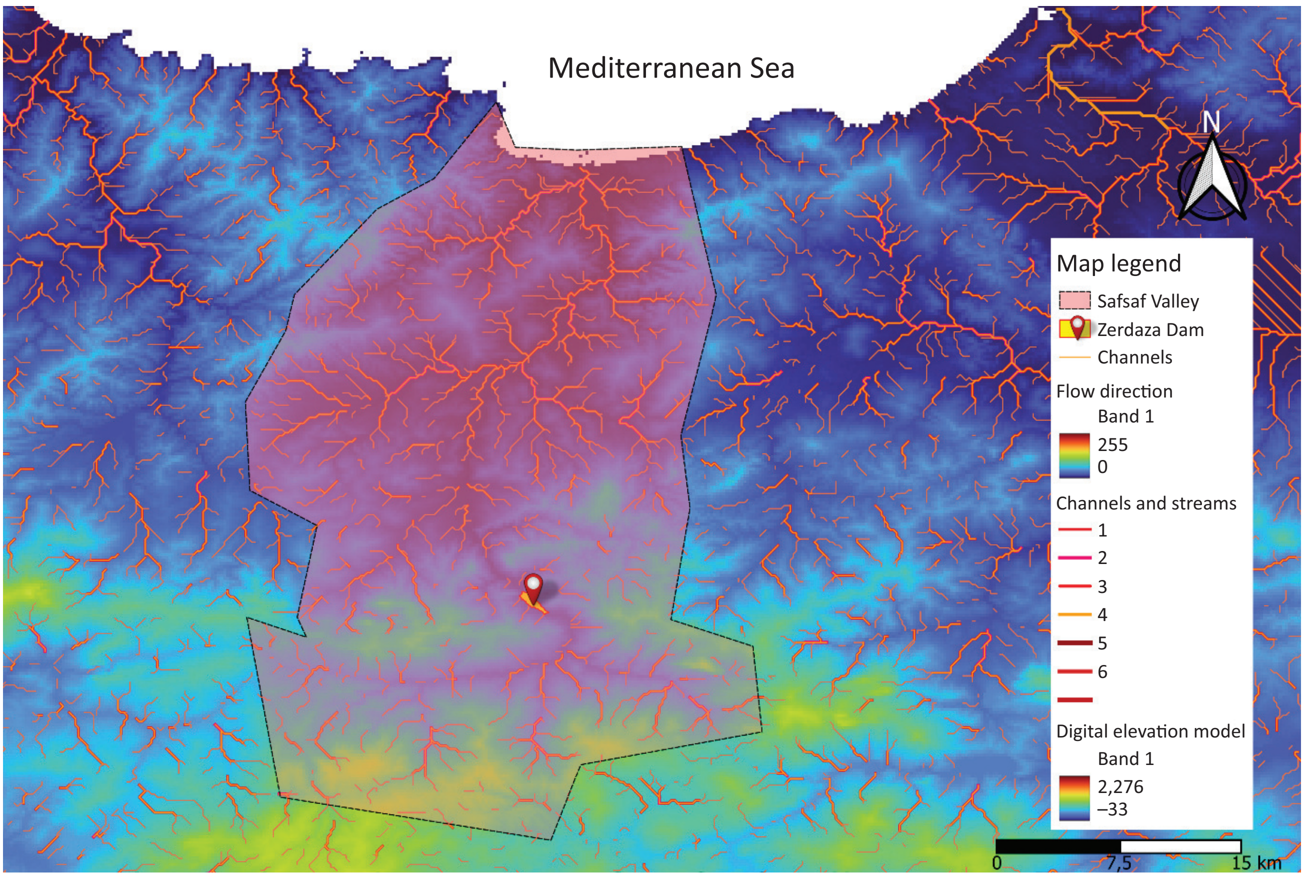

Figure 4. The trajectory of watercourses in Skikda's Safsaf valley.

Figure 5. Potential for the development of existing waterways into inland waterway shipping canals in the Safsaf River of Skikda.

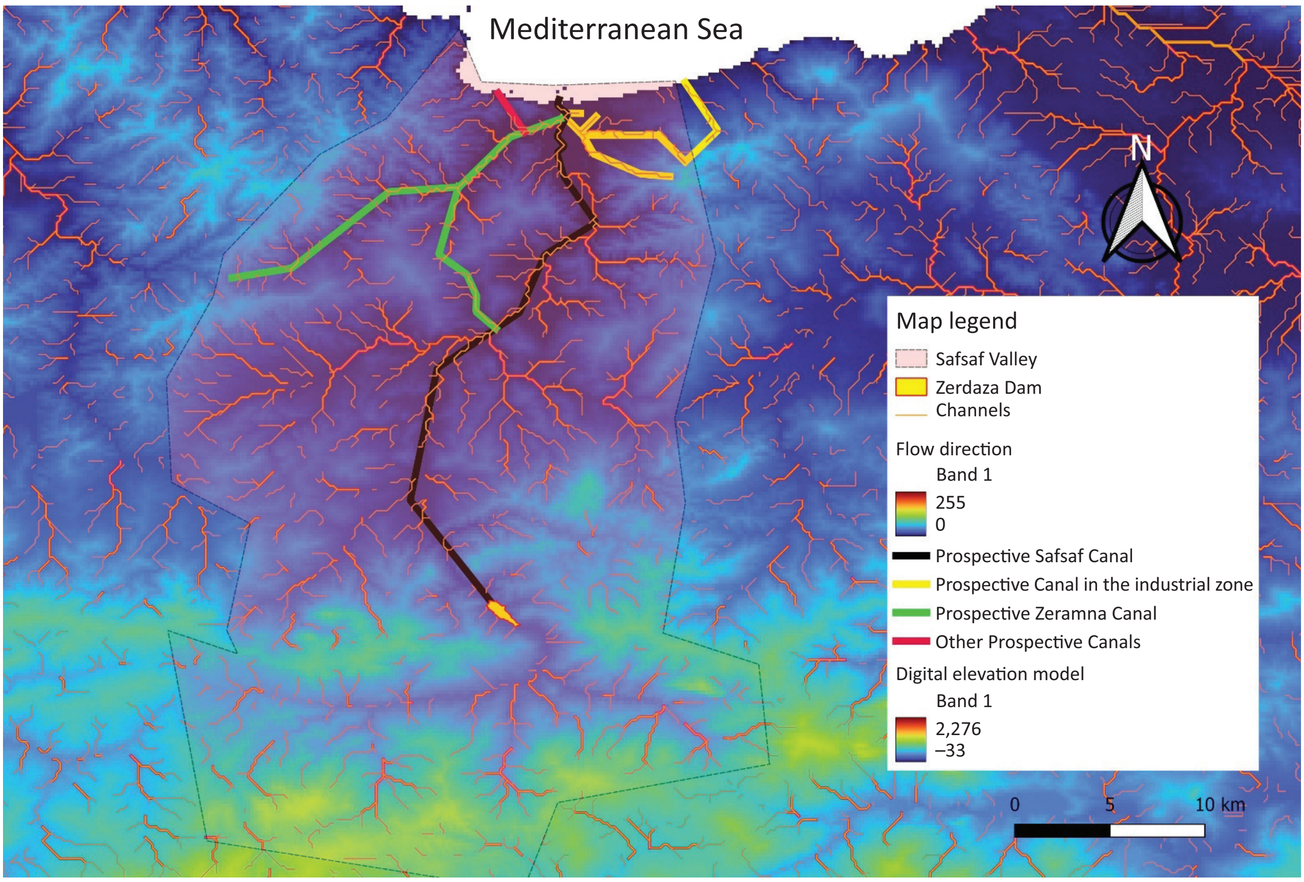

Figure 6. The trajectory of the prospective inland waterway shipping canals within the valey of Skikda.

The geographical characteristics of the Safsaf River would allow it to accommodate an artificial navigable canal. Upstream of the Safsaf River is the dam of Zerdaza; downstream is the Mediterranean Sea. In fact, the Zerdaza Dam and the Mediterranean Sea can constitute two sources of supply for the prospective Safsaf Canal, each with its own direction of water flow, opposite to the other. This makes it possible to feed the prospective Safsaf Canal, depending on the choice of the direction of the water source, where water can flow in one of the two directions, naturally or artificially. The choice of feed direction is based on several potential feed scenarios for the prospective Safsaf Canal. Salt water taken from the Mediterranean can be a source of supply for the prospective Safsaf Canal, which can be exploited either by levelling the canal at a certain depth for a certain distance, equipping it with systems that control the direction of flow, or by feeding the treatment plants that can supply fresh water to the canal.

As long as the Safsaf River is connected to the Zerdaza Dam, the latter can serve as an ideal source, ensuring an optimal flow to the prospective canal. However, the exploitation of water from Zerdaza to other destinations disrupts irrigation and the drinking water supply for the population of the municipalities of El-Harrouch, Aïn Bouziane, and Mjez-Edchiche, whose supply of potable water comes mostly from the Zerdaza Dam (Bomani, 2022). Thus, the fresh water from this dam is crucial for the stability of the local community and therefore it is essential to think about ensuring an artificial flow to the Safsaf River, without causing a shortage of supply problems. It is necessary to look for alternative ways of providing a water flow to the Safsaf River throughout the year, avoiding any possibility of water supply crises among local populations. In this context, several integrated proposals for the artificial supply of the prospective inland waterway can be provided, singly or in combination, to ensure the quantity required to feed the prospective Safsaf Canal:

- During some years in the rainy seasons the dam of Zerdaza has experienced a maximum increase in the water level, exceeding its technical capacity. The dam has had to be emptied, and water was wasted. Due to the age of the dam, built between 1929 and 1945, rehabilitating and extending this hydraulic infrastructure could contribute to increasing the capacity of the dam. Collecting this larger volume of water would make it possible to feed the prospective canal without disrupting the population's water supply.
- Almost every rainy season, the Safsaf River and the Zeramna River flood neighboring districts. A significant amount of rainwater could be collected in collinear reservoirs, allowing it to be preserved for use during the dry seasons, when it could contribute to the water flow of the prospective canal in the Safsaf River.
- A new dam could be constructed that would be dedicated to irrigation and the local population's water supply, reserving Zerdaza Dam as the supply of the prospective inland shipping canal.
- Small valleys and gorges could be redirected to flow into the Safsaf River.
- Underground water could be exploited.
- It is possible to reverse the natural direction of the water flow, so that it would flow from the estuary of the Safsaf River instead of from the Zerdaza Dam by digging a channel obliquely under sea level. This would ensure the flow of salt water to a certain depth inside the canal, taking into account solutions for flood control.
- Operating Mediterranean water desalination plants could ensure a flow of fresh water in the future inland waterway and thus preserve the ecosystem and local agriculture.

3.2. Results of the Analysis of the Prospective Scenario of Integration of the Inland Waterway Transport Safsaf in Skikda by MICMAC

Table 2 presents a matrix of the authors' evaluation, according to the level of impact of each of the variants on the others, for the scenario of integration of the Safsaf IWT in Skikda.

The factors developed in this article for the prospective scenarios of integration of the Safsaf IWT will be considered as study variables and will be entered into the MICMAC database in matrix form. With this MDI composed of 21 × 21 variables, MICMAC proceeds to analyze the influence of each variable on the other variables of the MDI, which describes the relationships between the variables and their strengths through two main graphs generated by MICMAC: the DIM (Figure 7) and the DIG (Figure 8). The DIM defines the strength of variables, classifying them in a plane divided into four sections: strong influence zone, conflict zone, exit zone, and autonomous zone. The DIG can be the result of processing data by MICMAC, in different percentages: 5%, 25%, 50%, 75%, or 100%. The DIG translates the relationship between variables into a gradient line, in size and color, aiding understanding of the relationship and influence of key factors in the prospective scenario.

4. Discussion

The first section, located at the top right of the DIM, presents the zone containing the variables of strong influence, defined as the driving variables that have a significant impact on the other factors involved in the scenario. Most variables in this zone are related to the economic pillars of sustainable development, such as wealth creation. However, the feasibility and viability of the canal strongly influence the transition of the mode of transport in Skikda through the growth of port activities and inland waterways freight. The improved qualities of

Table 2. Table of matrix of direct influences (MDI), for a prospective structural analysis by MICMAC of the factors developed in this article on the basis of smart port-city and sustainable dimensions, and which influence the scenario of integration of the Safsaf IWT.

	1: 1Wealthcra	2: 2Grprtactv	3: 3Mritfreit	4: 4Cmptvatrc	5: 5Sustinvst	6: 6Feaviabty	7: 7Recnstcst	8: 8Psnrshipg	9: 9Employmnt	10: 10Govrnenc	11: 11Safety	12: 12Wtridnty	13: 13Eqitysoc	14: 14Socfacil	15: 15Enrgyeff	16: 16Dvlpscpe	17: 17Rdcpolut	18: 18Ecos&bio	19: 19Climatch	20: 20NturlSrc	21: 21MngRisks
1: 1Wealthcra	0	3	3	3	3	3	2	3	4	3	2	2	3	3	2	3	2	2	1	2	2
2: 2Grprtactv	4	0	3	3	3	3	2	3	3	3	2	2	2	2	3	2	2	2	2	2	2
3: 3Mritfreit	4	3	0	3	3	3	3	4	3	3	3	2	2	3	3	3	3	2	2	3	3
4: 4Cmptvatrc	4	3	3	0	3	3	2	3	3	3	3	2	2	2	3	3	2	2	2	2	3
5: 5Sustinvst	4	3	3	3	0	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
6: 6Feaviabty	4	3	4	3	4	0	3	4	3	3	3	3	3	3	3	4	3	4	3	3	3
7: 7Recnstcst	2	2	3	2	4	3	0	3	0	2	3	1	3	3	0	3	2	3	2	4	4
8: 8Psnrshipg	4	3	4	3	3	3	2	0	3	3	3	4	3	3	3	4	3	2	3	3	3
9: 9Employmnt	2	2	2	2	3	2	0	2	0	2	0	1	4	2	2	2	0	0	0	0	2
10: 10Govrnenc	3	2	4	2	3	3	2	3	2	0	3	2	3	3	3	3	2	3	3	3	3
11: 11Safety	3	3	4	3	3	3	3	4	2	3	0	2	3	3	4	2	3	2	2	2	4
12: 12Wtridnty	4	3	3	3	3	3	2	4	3	3	3	0	3	3	2	4	3	3	3	3	3
13: 13Eqitysoc	2	2	3	2	3	3	2	3	3	3	2	2	0	3	2	2	1	1	1	3	3
14: 14Socfacil	2	2	3	2	3	3	3	3	2	3	2	0	3	0	3	3	2	2	2	2	2
15: 15Enrgyeff	3	3	3	3	4	3	2	3	3	3	3	3	3	3	0	3	3	3	4	3	4
16: 16Dvlpscpe	4	3	3	3	4	3	2	4	3	3	3	3	3	3	3	0	3	3	3	3	4
17: 17Rdcpolut	2	2	2	3	4	3	2	3	2	3	4	3	3	2	3	3	0	3	4	3	3
18: 18Ecos&bio	2	2	2	2	3	3	2	3	2	3	2	3	2	2	3	4	3	0	4	3	3
19: 19Climatch	2	1	3	2	3	3	2	2	2	3	2	2	2	2	3	2	0	3	0	3	3
20: 20NturlSrc	4	3	4	3	4	3	4	4	2	3	2	3	2	3	3	4	4	4	4	0	3
21: 21MngRisks	3	3	4	3	3	3	4	3	2	3	4	2	2	2	2	3	3	3	3	3	0

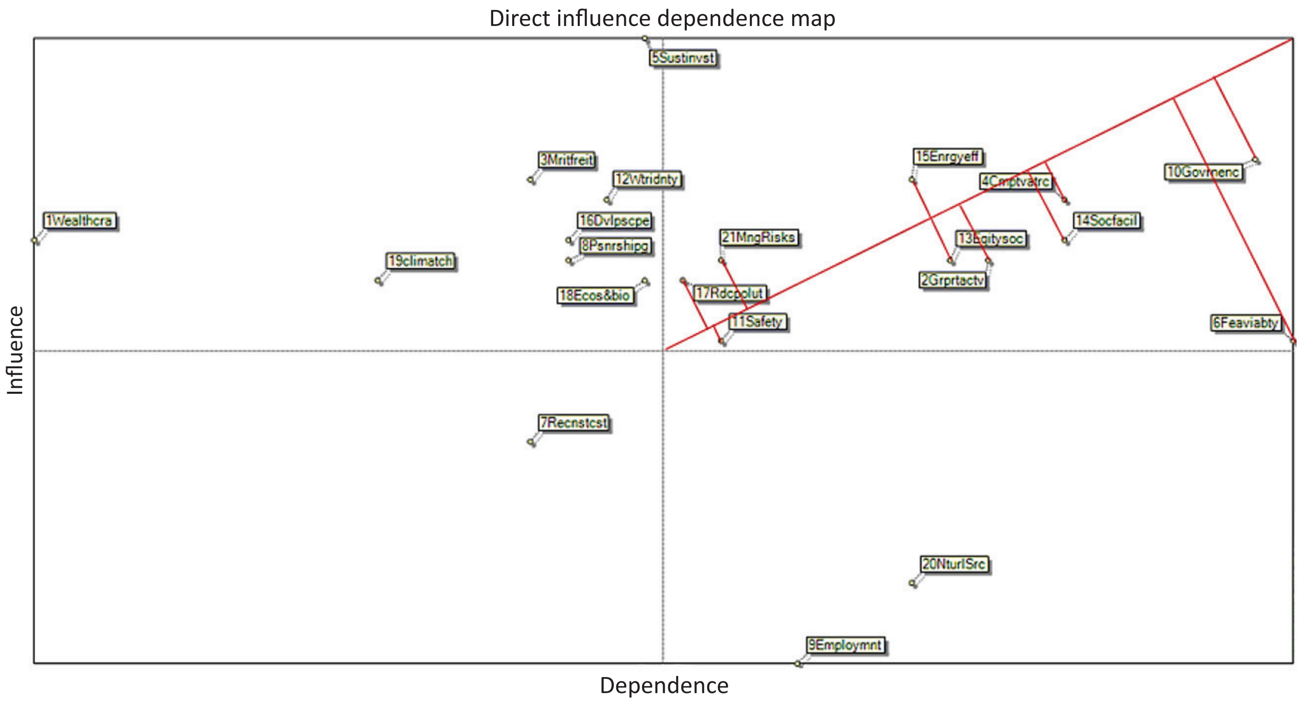

Figure 7. View of DIM for the prospective inland shipping canal the Safsaf River.

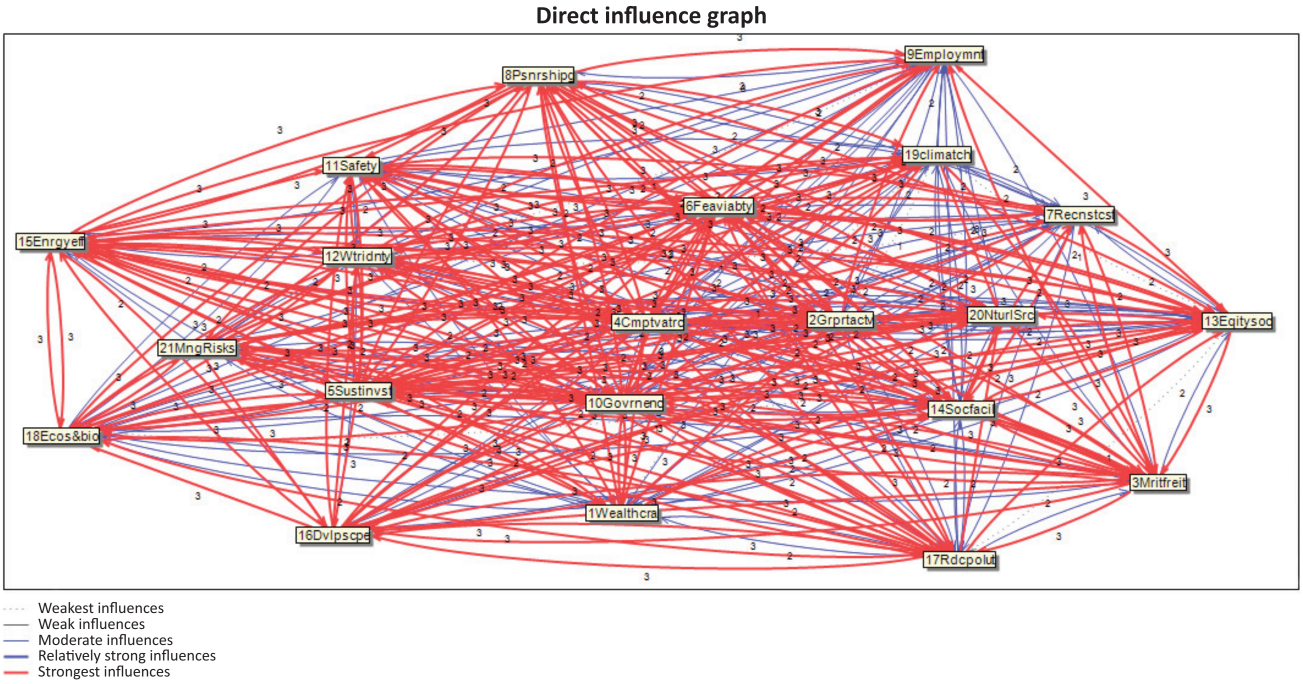

Figure 8. The analysis map of the study matrix MDI, generated by MICMAC, in the form of the DIG (at 100%) for the prospective inland shipping canal in the Safsaf River.

inland navigation strengthen the position of the prospective shipping canal, and will facilitate its integration in the socio-economic layer of Skikda. The quality of the water that will feed the canal will also be important to consider in the revitalization of the ecosystem, raising questions about the ability of these waters to continue to supply the agricultural regions inland of Skikda.

Moreover, the regeneration of waterways is a sustainable investment that will improve the attractiveness of Skikda through the recovery of the ecosystem and aquatic biodiversity, allowing the revival or introduction of activities related to water, such as fishing, walking, tourism, and swimming. Therefore, the new sociocultural structure of the prospective Safsaf Canal would lead to a radical change of the current landscape, enhancing the area's water identity, absorbing oil industry pollution, and resolving the quadruple urban barrier in Skikda (Ghennaï et al., 2022).

The second section at the upper left of the DIM presents the conflict zone, the most important field for the prospective scenario, as it combines the variables, known as the relay variables, that are both the most influential and also dependent; hence the role of strategic factors, because they have the ability to strongly influence the other variables (Benjumea-Arias et al., 2016). Aiming to extract the most influential factors in this scenario, we use the strategic diagonal, which separates the conflict zone diagonally, and then the variables will be classified according to their location relative to the vector. The variables closest to the vector are the most strategic factors in the prospective scenario (Abril Ortega & Arias Chávez, 2020). As a result, we observe that the factors of competitiveness, security, reducing pollution, and improving energy efficiency have a direct influence on the scenario, as they provide the attractiveness of maritime transport of goods and passengers, thereby ensuring the continuity of port activities. Other factors appearing in the second zone, the conflict zone, are also strategic, such as the growth in port activities, social equity, social facilities, feasibility, and viability. Indeed, improved urban mobility, supported by the feasibility and viability of the new maritime functions of the inland shipping system, will reflect high standards for services and will improve access times to social facilities in ways that improve social equity in Skikda.

The lower left section of the DIM shows the variables known in the prospective MICMAC method as output or an excluded variables zone, which contains the low mobility but dependent outcome variables: employment and natural resources. These two factors influence the other factors of the scenario. Among them, employment is one of the indications of viability of the potential canals, while natural resources critically impact the system's feasibility, as the exploitation of water from Zerdaza Dam can negatively affect the irrigation flow and the population's drinking water supply. Therefore, the use of alternatives is recommended, such as a hillside basin, a seawater desalination program, and urban and industrial wastewater treatment. Those would be more reliable and sustainable methods of feeding the prospective Safsaf Canal.

The last area, located in the lower left part of the DIM, is the autonomous zone of dependent variables with low influence on the other variables in the MDI, where only one variable appears: the cost of reconstruction. This factor supports the feasibility of the prospective scenario by saving the costs of cleaning the flooded neighborhoods. This would be accomplished through the recovery of rainwater and redirecting it to feed the Safsaf River. However, this factor has little influence on the prospective Safsaf Canal, as the variable of the cost of reconstruction is potentially related to the inconstant Skikda pluviometry, which varies from one season to another.

The DIG divides the influence relationships between the variables in the MDI into two categories: strong and weak. Strong relationships are presented by red links, and weak relationships by blue links. According to this graph, it can be observed that there is a strong relationship of influence mainly between the competitiveness and attractiveness variables (development of the seascape, sustainable investment, water-related local identity, and culture), while the weak relationships of influence between the variables in the MDI are between employment and reconstruction costs. Thus, this graph provides an opportunity to examine the weak relationships and strengthen them to establish consolidated relationships between the different variables of the scenario matrix and determine the key variable that will contribute to the success of the prospective scenario, hence the prospect of a more dependable inland shipping system in Skikda.

The use of the prospective method with the MICMAC tool allowed us to develop a matrix made up of many factors involved in the prospective scenario. The software classifies these variables according to their influence and dependence in a DIM and translates them into a DIG. This method allows a deep vision of the importance of each variable and thus of the potential for integrating an inland navigation canal in Skikda. Consequently, the prospective method tools enable understanding of the role and influences of the key factors in a scenario and the achievement of the objectives of the prospective of the Safaf canal, under the aegis of the three pillars of sustainable development. This will help bring about a reliable transition in Skikda to a clean and smart inland shipping system.

5. Conclusion

According to this research, the prospective canal will be possible to integrate in Skikda, thanks to the adaptive hydrological characteristics of the natural watercourse of the Safsaf valley, and the maritime identity of the Mediterranean people, especially the inhabitants of Skikda, who have a historical link with water (Ghennaï & Madani, 2022). This research makes it possible to rethink not only the integration of an IWT in the Safsaf River, but also the integration of a large system of navigation by canals in Skikda, exploiting their natural potential as watercourses, and with respect to the Bibi and Tanji Rivers, which have a very attractive natural heritage, promoting a sustainable fluvial tourism economy.

This research combines two mapping methods. One is a geographical spatial mapping by QGIS to provide data necessary for the second method by building a matrix multiplication for a structural analysis by MICMAC, which in turn provides maps of direct and indirect influences. In this context, the prospect of an IWT in Skikda by the prospective method involves the exploitation of the mapping of the Safsaf valley, generated by QGIS, thus the prospecting and discussion of several possible paths to the integration and revival of the prospective Safsaf IWT, in accord with the characteristics of the valley and the municipalities of Skikda. Then, the choice of the factors, based on the three pillars of sustainable development—society, economy and environment. The influence of these factors, considered the variables of the study, will help determine the success or failure of the prospective scenario, according to the orientations of the smart port-city.

In examining the influential relationships between these factors, this study can give stakeholders a more detailed and clear view of a scenario's effectiveness, abilities, limitations, and its strengths and weaknesses. Decision centers can then work to address the weaknesses in order to minimize as much as possible the project's shortcomings and deficiencies. In this regard, the use of the foresight method in the case of Skikda has been able to provide results that allow us to form a better sense of the possibility and effectiveness of integrating of an IWT in the Safsaf River by extracting success factors and the ones that could lead to failure. This allows us to propose to the stakeholders efficient and sustainable orientations based on strategic foresight. Thus, this process is a form of smart thinking that encourages the promotion of collective thinking based on digitized methods, within the framework of sustainable development, through the digitalization of the planning process. It is part of the transition to a smart port-city.

An inland shipping canal in Skikda should promote the integration of an intermodal dynamic of maritime/canal transport system, linking the ports to the waterways in the industrial zone, as well as to the inaccessible sides of Skikda. Thus, the pressure on the city center will be reduced, and a fast flow to the university and the popular districts located in the valley of the Safsaf River will be ensured, connecting several of the municipalities of Skikda. In this way, the prospective canal will connect and homogenize the various urban entities, becoming a major factor in the development of Skikda. In addition, the integration of the Safsaf IWT Canal offers the potential to recover the ecological functions of the Safsaf River; the reactivation and regeneration of the watercourse will contribute to the improvement of the environment and help to moderate the temperature increases that result from the fumes of the refinery in Skikda. As a result, the canal will develop a dynamic aquatic landscape, promoting the porosity of the city and contributing to the creation of wealth in a sustainable manner.

In addition, safety is an attractive measure for risk management challenges associated with reclaiming a waterway in the heart of an urban fabric, especially since inland shipping is safer and cleaner than automobile transport (Fan et al., 2021). In addition, the plan to integrate a waterway in Skikda—a smart inland shipping system—should be adapted to the industrial and polluted context of the city, promoting the reduction of pollution and the creation of an energy autonomous navigation service.

Ever since this region was colonized by the French, engineers have focused on draining the rivers of Skikda rather than exploiting them for their beneficial effects. Since independence, urban strategy has encouraged the damming and coverage of Skikda's rivers. This research encourages decision-makers to adopt a different strategy, based on the prospect of a successful recovery of the Safsaf River. An integrated scenario of an inland shipping system in an industrial city like Skikda can change the fate of the city and make it a model for other Algerian cities. Ultimately, even if decision-makers have overlooked opportunities to harness the power of canals to revitalize the role of water, citizens still believe that the prospective Safsaf Canal can become an example of sustainable urban transition and a source of inspiration for a new urban thinking that aims to improve the livability of cities through water.

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Conflict of Interests

The authors declare no conflict of interests.

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About the Authors

Amira Ghennaï (Dr. Arch) is an architect with a PhD in architecture from the University of Setif. She is a member of the PUViT laboratory at the Setif Institute of Architecture in Algeria, and a member of the international LDE team at the PortCityFutures Center in the Netherlands. Her current research focuses on the architecture, urban design, heritage, and history of port cities, with particular focus on the Mediterranean context.

Said Madani is prof. Dr. Arch., and head of the Laboratory PUViT at Ferhat Abbas University Setif 1 in Algeria. He is a member of the Scientific Council of the Institute of Architecture and Earth Sciences and a member of the international LDE team at the PortCityFutures Center in the Netherlands. In teaching architecture and urban design, his areas of interest include the design process for the production of the built environment. His current research focuses on the transfer of architectural and urban knowledge, with a particular emphasis on urban public space and port cities.

Carola Hein is professor and head of history of architecture and urban planning at Delft University of Technology, professor at Leiden and Erasmus Universities, and UNESCO Chair for Water, Ports, and Historic Cities. She is director of the LDE PortCityFutures Center. She has published widely in the field of architectural, urban, and planning history and has tied historical analysis to contemporary development. Among other major grants, she received a Guggenheim, an Alexander von Humboldt, and a Volkswagen Foundation fellowship. She serves as IPHS President and IPHS Editor for *Planning Perspectives* and as Asia book review editor for *Journal of Urban History.* Her recent monographs and edited and co-edited books include: *Port City Atlas (2023)*, *Oil Spaces (2021)*, *Urbanisation of the Sea (2020)*, *Adaptive Strategies for Water Heritage* (2020), *The Routledge Planning History Handbook* (2018).