The Handbook of Environmental Chemistry 98

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Abdelazim M. Negm
Abdelkader Bouderbala
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Water Resources in Algeria - Part II

Water Quality, Treatment, Protection and Development

Springer

The Handbook of Environmental Chemistry

Volume 98

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Water Resources in Algeria - Part II

Water Quality, Treatment, Protection and Development

Volume Editors: Abdelazim M. Negm · Abdelkader Bouderbala · Haroun Chenchouni · Damià Barceló

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Series Preface

With remarkable vision, Prof. Otto Hutzinger initiated *The Handbook of Environmental Chemistry* in 1980 and became the founding Editor-in-Chief. At that time, environmental chemistry was an emerging field, aiming at a complete description of the Earth's environment, encompassing the physical, chemical, biological, and geological transformations of chemical substances occurring on a local as well as a global scale. Environmental chemistry was intended to provide an account of the impact of man's activities on the natural environment by describing observed changes.

While a considerable amount of knowledge has been accumulated over the last four decades, as reflected in the more than 150 volumes of *The Handbook of Environmental Chemistry*, there are still many scientific and policy challenges ahead due to the complexity and interdisciplinary nature of the field. The series will therefore continue to provide compilations of current knowledge. Contributions are written by leading experts with practical experience in their fields. *The Handbook of Environmental Chemistry* grows with the increases in our scientific understanding, and provides a valuable source not only for scientists but also for environmental managers and decision-makers. Today, the series covers a broad range of environmental topics from a chemical perspective, including methodological advances in environmental analytical chemistry.

In recent years, there has been a growing tendency to include subject matter of societal relevance in the broad view of environmental chemistry. Topics include life cycle analysis, environmental management, sustainable development, and socio-economic, legal and even political problems, among others. While these topics are of great importance for the development and acceptance of *The Handbook of Environmental Chemistry*, the publisher and Editors-in-Chief have decided to keep the handbook essentially a source of information on "hard sciences" with a particular emphasis on chemistry, but also covering biology, geology, hydrology and engineering as applied to environmental sciences.

The volumes of the series are written at an advanced level, addressing the needs of both researchers and graduate students, as well as of people outside the field of "pure" chemistry, including those in industry, business, government, research establishments, and public interest groups. It would be very satisfying to see these volumes used as a basis for graduate courses in environmental chemistry. With its high standards of scientific quality and clarity, *The Handbook of Environmental Chemistry* provides a solid basis from which scientists can share their knowledge on the different aspects of environmental problems, presenting a wide spectrum of viewpoints and approaches.

The Handbook of Environmental Chemistry is available both in print and online via www.springerlink.com/content/110354/. Articles are published online as soon as they have been approved for publication. Authors, Volume Editors and Editors-in-Chief are rewarded by the broad acceptance of *The Handbook of Environmental Chemistry* by the scientific community, from whom suggestions for new topics to the Editors-in-Chief are always very welcome.

Damià Barceló
Andrey G. Kostianoy
Series Editors

Preface

Algeria is a water-scarce country and, therefore, the concerning authorities are always looking for developing new water resources and management practices to satisfy the different and increasing needs of the Algerian communities. The developed water resources via desalination for saline water or brackish water for domestic or irrigation use or via treatment of wastewater for recycling or reuse are known as nonconventional water resources. The quality of the water helps in defining the treatment methods.

Therefore, the book titled “Water Resources in Algeria: Water Quality, Treatment, Protection, and Development” is written by Algerian experts who know well the facts of water resources in Algeria and the factors affecting natural water quality, treatment of wastewater, and protection of the water resources, in addition to the development of water resources to generate new sources (unconventional source such as desalination) to update and enhance the existing knowledge on unconventional water resources in Algeria. The book consists of 11 chapters including the introduction and the conclusion chapters, and the conclusion part, which is included as another chapter. The main themes of the book include: (a) Water Quality and Modeling (WQM) is covered in three chapters, (b) Treatment and Protection (TP) is covered in four chapters, and (c) Development and Future of Water Resources (DF) is covered in four chapters.

The chapter “Predicting Water Quality Indicators from Conventional and Nonconventional Water Resources in Algeria Country: Adaptive Neuro-Fuzzy Inference Systems Versus Artificial Neural Networks” is an overview of water resources modeling for the purpose of prediction via Kalman filter (KF). This kind of model can support not only the stochastic nature of the hydrological processes but also their temporal variability as well as the nonlinear character of the hydrological system. Such models are mostly required in water resources design and management because they provide a helpful tool for decision- and policy-makers in Algeria. While the chapter “Organic Chemical Characterization of Water of the Northwestern Algerian Dams” deals with predicting water quality indicators from conventional and unconventional water resources in Algeria using “adaptive neuro-fuzzy inference systems versus artificial neural networks.” Additionally, the chapter

"Wastewater Reuse for Irrigation Purposes: The Case of Aïn Témouchent Region" is devoted to the organic chemical characterization of water of the Northwestern Algerian Dams as a case study.

Four chapters are presented to enhance the existing knowledge on the theme "Treatment and Protection" of water resources in Algeria. The chapter "Protection of Water Resources in Mining Sites in Northeast of Algeria" deals with the wastewater reuse for irrigation purposes with a focus on the case of the Aïn Témouchent Region. It shows that anthropogenic disturbances like municipal solid waste discharges and agricultural and industrial activities play a major role in determining the quality of surface waters. The chapter "Physicochemical and Bacteriological Quality of Surface Water Resources Receiving Common Wastewater Effluents in Drylands of Algeria" is devoted to deal with the protection of water resources in mining sites with a focus on the case of North-East of Algeria. The chapter "Valorization of Oily Sludge in Arzew Refinery" is concerned with the assessment of water quality and pollution of surface water resources due to its crucial effect on aquatic environments. It deals with the physicochemical and bacteriological pollution of surface water resources receiving common wastewater effluents in the drylands of Algeria. The chapter "Kalman Filter for Spatio-temporal Modeling and Prediction of Algerian Water Resources Variability: Case Study of Precipitation and Stream Flows at Monthly and Annual Scales" focuses on the valorization of oily sludge in the Arzew Refinery to protect the environment as it is one of the pillars of sustainable development.

When it comes to the "Development and Future of Water Resources" theme, the chapter "Hydrograph Flood Forecasting in the Catchment of the Middle Cheliff" presents an overview of water resources in steppe regions in Algeria based on field study. In the field, two questions appear in the mind: What are the potentialities of Algerian water resources? and What are the procedures to avoid the rapid depletion of these resources? Because of many reasons, the answer to these questions does not depend only on the actual and the available statistics on water resources but also on the actual climate situation and the actual population growth. The chapter showed that water resources were limited in terms of quantitative availability and quality. The chapter "Overview of Water Resources in Steppe Regions in Algeria" deals with development prospects in the steppe region of Naâma (Western Algeria) due to the fact that water resources are at the center of a large number of interests including food security, agriculture, biological diversity, desertification, land use planning, poverty, health, peace, conflict, etc. The chapter emphasizes that the participation of all levels of stakeholders promotes more equitable and sustainable decisions in the area.

Furthermore, the chapter "Water Resources, State of Play, and Development Prospects in the Steppe Region of Na'ama (Western Algeria)" deals with desalination in Algeria based on photovoltaic power plant for TMM (Tahlyat Myah Magtaa) of Oran, as a case study. Photovoltaic energy has undeniable advantages, particularly for its cleanliness and durability. Also, it can be used in various applications such as agriculture and desalination. The success of future development of water resources depends on solutions that implement strategies for reducing high energy consumption such as in seawater desalination, the reuse of wastewater, and the introduction of drip irrigation. The chapter "Desalination in Algeria: Photovoltaic Power Plant for TMM (Tahlyat Myah Magtaa) of Oran as a Case Study" ends the third theme by dealing with hydrograph flood forecasting in the catchment of the middle Cheliff as a case study due to the fact that Algeria is among the Mediterranean countries that is most vulnerable to floods caused by streams overflowing and crossing towns and suburban areas.

The book ends with a conclusion chapter to summarize the main conclusions of the chapters and their recommendations.

The editors want to thank all the authors for their contributions to make this book a source of knowledge on the water quality, treatment, protection, and development of water resources in Algeria. Thanks are also extended to both reviewers of the chapters and the Springer team who worked hard for a long period to produce this book and to make our dream a reality. Special thanks to the editorial board of the *Handbook of Environmental Chemistry* series for their critical evaluation of the book proposal that improved the book contents.

The editors welcome any comments, feedback, and/or new chapters to be included in the next editions. Please send your feedback and your constructive comments and/or your new chapter to the editors via email.

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29 March 2020

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Introduction to "Water Resources in Algeria: Water Quality, Treatment, Protection and Development"

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Abstract This chapter summarizes the main contents of the chapters presented in the book "Water Resources in Algeria: Water Quality, Treatment, Protection and Development" according to its three themes. Consequently, the latest finding of research on water quality and modelling, wastewater treatment and reuse and protection of water resources. Also, key information on the development and future of water resources in Algeria were highlighted. The editors believe that the contained information are important to support the sustainable development in Algeria as an arid country in the MENA region.

Keywords Algeria, Desalination, Modelling, Sustainable development, Water pollution, Water protection, Water quality, Water reuse, Water treatment

1 Background

"Water is life"; as long as water is available and of good quality, it sustains life on earth including human livelihood. However, the deterioration of water quality by any mean or the disturbance of water biogeochemical cycle, causing changes in water availability and/or quantity, can directly harm human health or severely damage the environment with negative socioeconomic repercussions that affect agriculture, ecosystem integrity and human well-being [1, 2]. Within the frame of sustainable development, it is crucial to maintain water available, sufficient and of good quality. This requires first the understanding of both surface water and groundwater characteristics [3–5] and also implements all the mechanisms and policies to protect and ensure wise uses of water resources including treatment and reuses of wastewater or desalination [3].

Water overuse, misuse and abuse are the main cause of water shortage in many areas. Water pollution is another form of water unavailability resulted from high population growth rate often combined with significant urban sprawl [1, 6]. The management and conservation of water resources represent a real challenge under climate change, desertification and increasing water demand, especially in arid and semiarid regions [7, 8]. Indeed, the aims of current book are to deal with aspects water quality, treatment, protection and development of water resources in Algeria.

The book started with the introduction part which consists of the current chapter, where the main technical elements of each chapter are summarized and presented under its relevant theme. In part I of the book [3] and in its second chapter [9], a summary of the different components of the Water resources in Algeria was presented based on the Scopus database. In this part of the book, the following main themes are covered in 11 chapters:

– Water Quality and Modelling
– Treatment and Protection

– Development and Future of Water Resources

The next sections present briefly the main technical elements of each chapter under its related theme.

2 Chapters' Summary

2.1 Water Quality and Modelling

This theme is covered into three chapters. Chapter 2 is titled "Kalman Filter for Spatio-Temporal Modelling and Prediction of Algerian Water Resources Variability: Case Study of Precipitation and Streamflows at Monthly and Annual Scales". The main target of the chapter is the application of discrete Kalman filter for spatiotemporal modelling and prediction of surface water variability in Algeria. The recursive structure of its algorithm and its ability to integrate the effects of measurement and system noise to produce optimal predictions make its particularity. Also, the chapter focuses on surface water resources in Algeria already negatively impacted by climate change. This impact results in water scarcity affecting all components of the hydrological cycle, particularly rainfall. The spatial and temporal variability of this shortage is an additional complexity that presents a real challenge for water managers. For a better understanding of situations where everything changes over time and space, dynamical spatiotemporal forecasting models are highly recommended. One of the most used dynamic models in stochastic estimation from noisy measurements is the Kalman filter (KF). The discrete KF is a recursive technique for estimating the state of a system in the presence of noise; it describes the recursive solution to the problem of linear filtering of discrete data. This technique provides optimal estimates in the least-squares sense. In addition, it has several advantages. One of these advantages is that stationarity is not a prerequisite. This is interesting because it allows for changes in the model parameters and variances, which is a way that accommodates the non-linear response of hydrologic systems. Another advantage of KF is the recursivity in the time domain which offers the possibility of real-time prediction. But the big advantage of KF is to provide with the prediction error at each update, and this is a manner to measure the quality of the provided estimates accurately.

While Chap. 3 is titled "Predicting Water Quality Indicators from Conventional and Non-Conventional Water Resources in Algeria Country: Adaptive Neuro-Fuzzy Inference Systems Versus. Artificial Neural Networks", the chapter is aiming to achieve (1) modelling chemical oxygen demand (COD) at Wastewater Treatment Plant (WWTP) and (2) dissolved oxygen concentration (DO) at a drinking water treatment plant using two data-driven models: the adaptive neuro-fuzzy inference system (ANFIS) and artificial neural networks (ANN). The use of data-driven models for predicting several water quality parameters at drinking and wastewater treatment plants has gained much popularities, and several applications can be found in the literature. In the present study, two well-known models, namely, adaptive neuro-fuzzy inference system (ANFIS) and artificial neural networks (ANN), were applied and compared in order to predict two water quality indicators: (1) chemical oxygen demand (COD) at Sidi Marouane Wastewater Treatment Plant (WWTP), east of Algeria, and (2) dissolved oxygen concentration (DO) at the drinking water treatment plant of Boudouaou, Algeria. The two models were calibrated during the training phase and later validated using a validation dataset. By comparing a series of input combinations using several water quality variables, the accuracy of the models was evaluated and compared with the results obtained using the standard multiple linear regression model (MLR). The obtained results indicated that (1) ANFIS model optimized using the subtractive clustering algorithm have achieved more accuracy compared to the ANN and MRL models, (2) the MLR model is not suitable for modelling the DO and COD and the have provided low accuracy during the training and the validations phases.

On the other hand, Chap. 4 is titled “Organic Chemical Characterization of Water of the Northwestern Algerian Dams”. The chapter focuses on making (1) an organic chemical characterization of surface water of some dams belonging to two watersheds located in northwestern Algeria and which are generally used for human consumption and for irrigation purposes, (2) to identify the polluted dams and assess spatial and temporal variability of the analysed parameters. This is due to the fact that among the major problems of water quality of dams are the anthropogenic effects (municipal waste discharge, agricultural and industrial activities) as a result of releasing wastewaters through rivers. This could partially be overcome by identifying polluted sources and enforcing the laws governing the conditions for the wastewater discharge into natural watercourses. Maintaining standards of the water quality of dams requires the control of pollutant flows not only at the dams but also at the watershed level, especially with regard to nutrient and metal contents.

Linked to the intensification of human activities on the watershed level (e.g. industry, agriculture, urban discharges), the increase in nutrients brings about an acceleration of the natural process of eutrophication and often a rapid disturbance of ecosystem equilibrium state.

For example, among nutrients, phosphorus is an element whose excess in water is responsible for phytoplankton blooms and the resulting nuisances. Not treating the problem of nutrients at the source is to transfer them through rivers to dams and other aquatic systems.

Like other regions, in northwestern Algeria, dam waters are suffering from the deleterious effects of pollution; thus the monitoring of water quality is necessary to protect soil, plants, water bodies and human health. When interventions on watersheds are insufficient or late, it becomes necessary to act directly on the water bodies without having first made a precise diagnosis and an overall analysis of the initial nuisances and side effects.

2.2 Treatment and Protection

The treatment and protection theme is covered in Chaps. 5–8. Chapter 5 is titled “Wastewater Reuse for Irrigation Purposes: The Case of Aïn Témouchent Region”. The prime objective of this work concerns the characterization of wastewater and purified water of Aïn Témouchent wastewater treatment plant (WWTP), which uses an activated sludge treatment process. The second one is to make a comparison of the analysed parameters with the standards to state if treated water can be safely discharged into the natural environment and reused for irrigation purposes.

To increase the supply of a water resource to face scarcity, authorities must think about how to increase its yield taking into account its quality especially when wastewater is reused. Nowadays, it is well-known that the release of wastewater into natural habitats has severely deteriorated soils and aquatic environments and its reuse in agricultural irrigation have become a constraint particularly in semiarid and arid regions. Actually thanks to the existing advanced treatment processes, pollutant concentrations can be reduced to non-hazardous levels, and water of better quality can be produced not only to minimize environmental impacts but also for other uses that do not require high quality as that of drinking water. Algeria has become aware of the urgent need for the construction of sewage treatment infrastructures in order to recycle water for various uses. Among the treatment plants operated by National Sanitation Office (ONA) through Algeria, some including Aïn Témouchent WWTP are concerned with the reuse of treated wastewater in agriculture. To characterize wastewater (at the entrance) and cleaned water (at the exit) of the WWTP of Ain Témouchent, physical and organic chemical analyses were carried out. This analysis allowed exploring the nature of the existing polluting loads in water and their variations. For safety water reuse, monitoring and regular testing of the clean water were made to ensure the international standards and avoid environmental and health risks.

Consequently, Chap. 6 is dealing with the “Protection of Water Resources in Mining Sites in North-East of Algeria” to show the impact of the mining industry on the environment in Algeria. In Algeria, protection measures have not been applied at the level of active or abandoned mining sites; therefore, the study developed in this chapter highlights the impact of metal exploitations on the environment and human health and proposes solutions to minimize the environmental problems generated by the mining industries in Algeria as an example to help decision-makers and concerning authorities to proceed further with other industries involved in water pollution.

Environmental damage associated with mineral extraction has an increasing impact on the mining industry and the workforce it employs. The mining sector in Algeria is experiencing a real expansion nowadays. This development has led to a real scourge characterizing the degradation of the environment. Indeed, the mining activity generates several sources of pollution such as acid mine drainage and release of heavy metals. Through this chapter, the authors have shown the impact of mercury on the abandoned site of Azzaba located in northeastern Algeria; this problem has been raging for years. No protective measures were undertaken at the site. Investigations revealed that it turned out that the pollution of the site is of anthropogenic origin. The authors indicated that in addition to the area of Tebessa, Algeria has mining sites favouring the extraction of iron and at the same time generating severe pollutions of draining rivers and soil, which is the case for the mines of Boukhadra, Ouanza and also the Khanguet iron mine, which have been closed for years.

On the other hand, Chap. 7 entitled "Physicochemical and Bacteriological Quality of Surface Water Resources Receiving Common Wastewater Effluents in Drylands of Algeria" aims at determining water physicochemical and biological quality of Wadis receiving common wastewater effluents in the region of Biskra (NE Algeria) [5]. The survey investigates water microbiological quality and examines how water physicochemical factors influence microbiological characteristics in water of the Wadis studied. In arid environments, water is not only a rare resource but also exposed to different types of pollution, primarily from domestic and industrial activities. The authors focus on the assessment of water physicochemical and bacteriological quality of Wadis receiving heavy load of urban effluents in the region of Biskra in northeastern Algeria. This treatise explores the impacts of water characteristics on the spatial and temporal variations of existing pathogenic bacteria in Wadi water. The chapter reports alarming organic pollution of Wadi waters of the region of Biskra, which represent a real risk to the health of riverine populations as well as the aquatic system and its biocoenosis [10].

An overall scheme was adopted to make this investigation successful, including selection of water sampling stations, sample collection and physicochemical and microbiological analyses supported by appropriate statistical analyses [4].

The analysis of water physicochemical characteristics revealed that the Wadis surveyed have poor water quality due to high faecal pollution that exceeds reference standards established by FAO and WHO. Thus, the light was shed on the severity of the environmental situation caused by sewage effluents, including negative impacts on the soil, agricultural lands, crops, human health and the aquatic environment with its associated lifeforms.

Moreover, Chap. 8 is titled "Valorization of Oily Sludge in Arzew Refinery". The main objective of this chapter is to thermally treat oily sludge from the oil industry at the level of the RA1/Z refinery and then make a characterization of sludge by x-rays fluorescence (XRF) to determine the mineralogical composition mass in the form of oxides, e.g. percentages (% SiO_2, % CaO, % Fe_2O_3, % K_2O, etc.). X-rays diffraction (XRD) was conducted for sentencing phases, for example, silica, crystalline or amorphous [11]. Fourier transform infrared spectroscopy in attenuated total reflection (FTIR-ATR) was applied to determine functional groups (e.g. O–H, C–H, C–Cl, Br–C, C–I, C–N, N–H, etc.). Finally detection of heavy metals by atomic absorption spectroscopy (AAS) was carried out. This study aims to determine the sources of heavy metals in industrial wastewater which predicts sludge quality characteristics. The chapter highlighted several origins that can be identified as polluting source including industrial activities.

On the other hand, the refinery station generates another waste (mud) which is rich in oily sludge of toxic nature and carcinogenic and can be neither stored nor put in discharge. The sludge treatment is a difficult process in the fight against pollution. Indeed, the scrubber can resolve this difficult problem that faces many challenges: scarcity of land available for disposal and filing, and adhering to the environmental and public hygiene requirements. Moreover, economically, this problem is illustrated by the importance of the costs it takes both in investment and operating. Oily sludge with a significant calorific value which represents 90% of methane (CH_4) can be considered as an interesting fuel resource. However, the impacts related to its combustion in poor conditions can be drastic and fatal to the environment.

2.3 Development and Future of Water Resources

This theme is covered in four chapters from Chaps. 9 to 12. Chapter 9 is titled "Overview of Water Resources in Steppe Regions in Algeria". Steppe rangeland regions in Algeria are the most suffering lands from water stress. This chapter gives a point situation of actual and future water supply status under the rapid population growth rate and effects of climate change on the renewing of water resources. According to the authors of the chapter, water policy in Algeria in the beginning of the year 2000 focused only on the capital of Algeria "Algiers" and some geostrategic cities, viz. Oran, Constantine, Annaba and Tlemcen. The results of this policy resulted in the realization of 11 desalination stations and a lot of dams located across the country. After the long drought that hit Algeria, another problem appeared in Steppe regions which is the water penury due to losing several water boreholes because of the increase of the drawdown of the water table. This chapter provides an overview of the actual and future situation of water supply, by application of two scenarios, the first one supposes a normal evolution of water production across the population and demographic growth up. The second scenario assumes an effect of climate change which led to a reduction in water production (reduction of rainfall, surface runoff and groundwater recharge). The simulation assumes a simple linear model. The deficit for each scenario was calculated to be about 13% and will start in 2021 with a small rate and achieve 13% at the beginning of 2027. The authority in these regions works to increase the number of Boreholes without taking into consideration the aquifer potentiality. Similar to other chapters of the book, the chapter ends with some recommendations to solve this situation.

Additionally, Chap. 10 is titled "Water resources, state of play and prospects for development in the steppe region of Naâma (Western Algeria)". The region of Naâma is part of the semiarid territory of the South Mediterranean, it undergoes contrasting climatic influences where the rainfall is insufficient and irregular, the inter-annual and seasonal variations are very marked and the intense evaporation and the high temperatures are with a greater amplitude or less contrast. The region is rich in surface and also underground water resources (rivers and Wadis, reserves of Chotts Chergui and Gharbi, groundwater reserves, etc.). It has significant groundwater potential, especially around El Chergui and El Rharbi Chotts, in Naâma syncline and in Ain Sefra-Tiout Valley. The chapter presents a diagnosis of the current state of water resources and their challenges through the analysis of various natural, climatic and anthropogenic constraints in the steppe region of Naâma (western Algeria). The region is facing serious challenges such as growing water scarcity exacerbated by population explosion and urbanization, resource misallocation, environmental degradation and poor water management that requires to adopt a novel approach of water resources management [11].

Although the issue of water resources is vital, it is still persistent and the levels of agricultural and pastoral production are still rather modest compared to the important needs of a growing region. Consequently, the rational management of water resources is a necessity, even an obligation, in order to ensure a harmonious and sustainable development that requires for its success a combination of technical, economic and financial and institutional solutions. The chapter highlights the necessity to launch economic programmes that respect the efficiency of water use and revise allocations of resources in order to answer the increasing needs in the steppe rangelands of Algeria.

The next two chapters are, therefore, focusing on the development of new water resources.

Chapter 11 is titled "Desalination in Algeria: Photovoltaic power plant for TMM (Tahlyat Myah Magtaa) of Oran as a case study". The chapter is a contribution to the design and the integration of renewable energy sources in the Algerian central power grid, particularly in areas of high human concentration within the scope of a large project. It designs a photovoltaic plant for desalination station "El Magtaa" of Oran in Algeria.

A feasibility study was conducted to provide all the technical and financial elements to the project owner and stakeholders. Also, the chapter estimates expected production (taking into account environmental constraints) and the evaluated possible constraints of the connection to the grid with regard to the location of the site.

The project certainly requires huge investments which will surely influence the cost of producing a unit of water (say one m^3) measures such as the use of local products and optimization of consumption to reduce the cost of water production.

On the other hand, flood forecasting is essential to understand and assess the availability of water resources and to assess the risk of floods [3]. Consequently, Chap. 12 with the title "Hydrograph flood forecasting in the catchment of the middle Cheliff" is focused on the study of the hydrographs of the extreme flood in the middle Cheliff watershed by the analysis of the peak output, the form of the hydrographs, the fall and boarding times, in the aim to understand these hydrographs of hydrological extremes flows and to detect the areas vulnerable to the flood hazard.

Algeria is among Mediterranean countries most vulnerable to floods caused by overflowing streams crossing towns and suburban areas. These floods occur suddenly, with difficulty to predict them, and they are generally linked to intense rainy episodes and are manifesting on middle size basins. The concept of modelling in flood-duration-frequency has been established on an objective basis, and its extension towards ungauged watershed supplies a theoretical frequency description of the multi-duration of flood quantiles. In addition to hydrological variables, two indices of the watershed flood regime are essential to be determined, which are the maximum instantaneous flow of 10-year return period and flood characteristic duration of watershed “D”.

The chapter recorded two or three exceptional peak events of theoretical return period close of the centennial for all stations studied and which flows on the large durations are a little scarcer, even very rare for one of them. Six durations are considered, giving six series of threshold flows between 1.5 and 15 h for the Rouina basin, 2–20 h for the Ouahrane basin, 1.5–15 h for Tikazel basin and 3–30 h for Allala basin. The knowledge of the flow threshold permit to trace the synthetic mono-frequency hydrographs, which are essential components of hydrodynamic model entry in order to determine the risk of any flooding that is characterized by a return period, as the station of Sidi Akkacha (Allala), which is characterized by a very important quintile for the longer return periods, and also the case of station Bir Ouled Tahar (Rouina-Zeddine).

The book ends with the chapter numbered 13 that includes the conclusions and recommendations.

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Part I
Water Quality

Predicting Water Quality Indicators from Conventional and Nonconventional Water Resources in Algeria Country: Adaptive Neuro-Fuzzy Inference Systems Versus Artificial Neural Networks

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Abstract Monitoring water quality is of great importance and mainly adopted for water pollution control of conventional and nonconventional water resources. Generally, water quality is evaluated using several indicators, including chemical oxygen demand (COD), biochemical oxygen demand (BOD), and dissolved oxygen concentration (DO). In the present investigation, two artificial intelligence techniques, namely, adaptive neuro-fuzzy inference system (ANFIS) and artificial neural networks (ANN), were applied for predicting two water quality indicators: (1) chemical oxygen demand (COD) at Sidi Marouane Wastewater Treatment Plant (WWTP), east of Algeria, and (2) dissolved oxygen concentration (DO) at the drinking water treatment plant of Boudouaou, Algeria. The models were developed and compared based on several water quality variables as inputs. Three ANFIS models, namely, (1) ANFIS with fuzzy c-mean clustering (FCM) algorithm called ANFIS_FC, (2) ANFIS with grid partition (GP) method called ANFIS_GP, and (3) ANFIS with subtractive clustering (SC) called ANFIS_SC, were developed. The ANFIS models were compared to standard multilayer perceptron neural network (MLPNN) and multiple linear regression model (MLR). Results obtained demonstrated that (1) for predicting COD, ANFIS_SC is the best model, and the coefficient of correlation (R), Wilmot's index (d), root-mean-square error (RMSE), and mean absolute error (MAE) were calculated as 0.805, 0.880, 6.742, and 4.944 mg/L for the validation dataset. The worst results were obtained using the MLR model with R, d, RMSE, and MAE equal to 0.750, 0.840, 0.7658, and 5.916 mg/L for the validation subset, and (2) for predicting DO concentration, the best results were obtained using ANFIS_SC with R, d, RMSE, and MAE equal to 0.856, 0.922, 1.528, and 1.123 mg/L for the validation subset, respectively.

Keywords ANFIS, Chemical oxygen demand, COD, Dissolved oxygen, DO, MLPNN, Modeling, Water quality indicators

1 Introduction

Over the year, the control of water pollution is becoming of great importance, and several regulations have been put in place [1]. Monitoring wastewater treatment plant (WWTP) using online sensors has become an essential and crucial task to handle rapid and seasonal variations that occur during all the months of years [2]. Consequently, real-time supervision of the process of WWTP is nowadays a challenge [3]. To deal with these challenges, WWTP must be highly efficient [4]. Evaluation of the WWTP performances is mainly based on the measure of water quality indicators (WQI), which are generally hard to measure regularly [5]. In the last few years, soft computing models have been largely employed for modeling and forecasting water quality indicators (WQI) in several water ecosystems. Chemical oxygen demand (COD), biochemical oxygen demand (BOD), and dissolved oxygen concentrations (DO) were the most important WQI that have received great importance, and modeling chemical oxygen demand in wastewater treatment plant (WWTP) is broadly discussed in the literature [6–13].

Ay and Kisi [6] compared several machine learning approaches in modeling daily COD measured at the upstream of a WWTP in Turkey, using discharge (Q) and three water quality variables as inputs: (1) suspended solid (SS), (2) temperature (T), and (3) pH. The proposed models included (1) multiple linear regression (MLR), (2) multilayer perceptron neural network (MLPNN), (3) radial basis function neural network (RBFNN), (4) generalized regression neural networks model (GRNN), (5) adaptive neuro-fuzzy inference system techniques with grid partitioning, (6) adaptive neuro-fuzzy inference system techniques with subtractive clustering, and (7) a new model called MLPNN embedded k-means clustering (K_MLP). The authors demonstrated that the K_MLPN using three input variables (SS, T, and pH) provided the best accuracy with a coefficient of determination (R^2) equal to 0.88 in the validation phase. Kisi and Parmar [7] applied three data-driven models, namely, (1) least square support vector machine (LSSVM), (2) multivariate adaptive regression splines (MARS), and (3) M5 model tree (M5Tree) for modeling monthly COD in India. According to the results obtained, the authors demonstrated that the MARS and LSSVM performed better than the M5Tree. Nadiri et al. [8] proposed a new model called supervised committee fuzzy logic (SCFL) for predicting COD in WWTP in Iran. The proposed model is a combination of the artificial neural network (ANN) paradigm and several individual fuzzy logic (FL) models: Takagi-Sugeno, Mamdani, and Larsen. According to the results obtained, the authors demonstrated that a linear combination of several FL models outperforms the individual FL model.

Moral et al. [9] applied the standard MLPNN for predicting effluent COD at the Iskenderun WWTP, Turkey. Yilmaz et al. [10] compared three data-driven models, GRNN, RBFNN, and MLPNN for predicting the effluent COD using influent COD, hydraulic retention time (HRT), and influent cyanide concentration (CN). MLPNN was found to be the best model compared to the two others, with an R^2 equal to 0.876 in the validation phase. Pai et al. [11] compared ANFIS and MLPNN for predicting effluent COD at WWTP in Taiwan. The authors selected four water quality variables as inputs, the influent SS, TE, and pH, in addition to the influent COD. According to the results obtained, the ANFIS model was found to be slightly better than the MLPNN. Perendeci et al. [12] proposed the use of the ANFIS model for predicting the effluent COD using the COD measured at previous 10 days and reported very encouraging results with an R^2 equal to 0.84. Singh et al. [13] compared several linear and nonlinear models for predicting weekly effluent COD at WWTP using four water quality variables as inputs measured at the influent of the WWTP. The proposed models were (1) partial least squares regression (PLSR),

(2) multivariate polynomial regression (MPR), and (3) MLPNN models, and it is observed that the MLPNN model has better performance than the other models with an R^2 equal to 0.84 in the test phase. Different modeling approaches can be found in the literature [14, 15]. Contrary to the COD, which has received great attention worldwide, modeling DO in DWTP is rarely reported in the literature. Hence, in the present study, we reported an application of the ANFIS, MLPNN, and MLR models for modeling DO in drinking water treatment plant (DWTP) and COD in WWTP.

2 Wastewater and Drinking Water Datasets

In the present study, effluent wastewater and drinking water data were obtained from two different stations (Fig. 1): (1) Sidi Marouane Wastewater Treatment Plant (WWTP) located at Sidi Marouane town, at about 12 km northeast of Mila Province, east Algeria.

Fig. 1 Location of Sidi Marouane Wastewater Treatment Plant (WWTP) and Boudouaou Drinking Water Treatment Plant (DWTP) in Algeria country

The WWTP is located near the Beni Harroun Dam Reservoir [16], and (2) Boudouaou Drinking Water Treatment Plant (DWTP) is located at Boudouaou province and is the principal DWTP in Algeria [17]. The DWTP has a capacity of 540,000 m^3 of water per day and provides drinking water to more than four million inhabitants [18]. The treatment consists essentially of preliminary disinfection, coagulation-flocculation, settling, filtration, and final disinfection [18, 19] (Fig. 2). Regarding the WWTP, the treatment scheme is based on the conventional activated sludge plant and consists essentially of coarse and fine screens, grit and grease removal, primary sedimentation tanks, activated sludge aeration tanks, secondary sedimentation tanks, and final clarification and chlorination facilities [16] (Fig. 3). As explained above, two different datasets were used in the present study for modeling COD and DO, respectively. The first dataset was collected from the Sidi Marouane WWTP. It is composed of 364 patterns and includes four input variables:

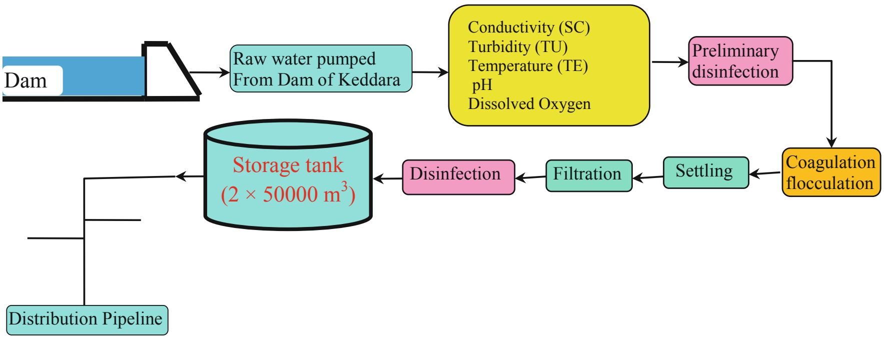

Fig. 2 Schematic diagram of Boudouaou Drinking Water Treatment Plant (scheme adopted from [12])

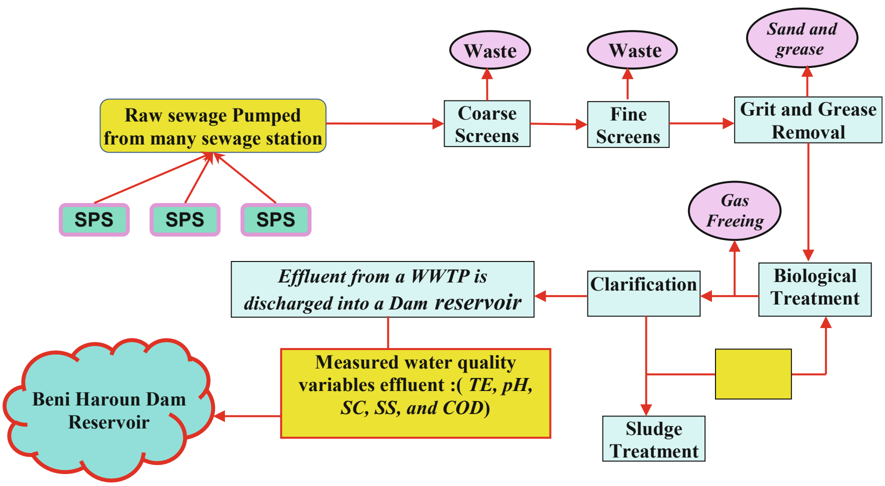

Fig. 3 Schematic diagram of Sidi Marouane Wastewater Treatment Plant (WWTP)

(1) effluent water temperature (TE), (2) effluent suspended solids (SS), (3) effluent specific conductance (SC), and (4) effluent pH. Consequently, the dependent variable (output) is the effluent chemical oxygen demand (COD), and the independent variables are TE, SS, SC, and pH. Of this 364 patterns, 255 (70%) were randomly selected as the model training subset, and 109 patterns (30%) were used as validation subset. The second dataset was collected from Boudouaou DWTP. It is composed of 902 patterns and includes four input variables: (1) raw water TE, raw water turbidity (TU), raw water SC, and raw water pH. Consequently, the dependent variable (output) is the dissolved oxygen (DO), and the independent variables are TE, TU, SC, and pH. Of these 902 patterns, 632 (70%) were randomly selected as the model training subset, and 270 patterns (30%) were used as validation subset.

In Table 1, we report the mean, maximum, minimum, standard deviation, coefficient of variation values, and the coefficient of correlation with COD and DO, i.e., X_{mean}, X_{max}, X_{min}, S_x, C_v, and R, respectively. Among the input variables for DO, TU has the highest variation, while for the COD, SS data have higher variation than the others (see the variation coefficients, C_v in the table). On the other hand, the training ranges of DO (5.084–11.16 mg/L) and COD (23.217–49.8 mg/L) do not cover the validation ranges (5.266–13.2 mg/L for DO and 22.289–55 mg/L for COD). This may cause some extrapolation difficulties for the applied models. In the present study, COD and DO and all the input variables were normalized using the Z-score method [20, 21]:

$$Z_n = \frac{x_n - x_m}{\sigma_x} \tag{1}$$

where Z_n is the normalized value of the observation n, x_{n} is the measured value of the observation n, and x_m and σ_x are the mean value and standard deviation of the variable x. This normalization was applied because it considerably improves the performances of the AI models [22, 23].

3 Methodology

In the present study, three kinds of models were developed and compared: multilayer perceptron neural network (MLPNN), adaptive neuro-fuzzy inference system (ANFIS), and multiple linear regression (MLR). The flow chart for training and validation of the MLPNN, ANFIS, and MLR is shown in Fig. 4.

3.1 Multilayer Perceptron Neural Network (MLPNN)

Artificial neural network (ANN) is a mathematical model that learns from examples similar to human brain, and the structure of the artificial neuron was inspired from the function of the biological neuron. ANN is structured in several layers,

Table 1 Daily statistical parameters of the dataset

Variables	Subset	Unit	X_{mean}	X_{max}	X_{min}	S_x	C_v	R
Boudouaou Drinking Water Treatment Plant (DWTP)								
TE	Training	°C	16.611	25.900	10.600	3.433	0.207	−0.255
	Validation		16.665	26.200	10.200	3.518	0.211	−0.297
	All data		16.627	26.200	10.200	3.457	0.208	−0.268
pH	Training	/	7.765	8.600	7.200	0.248	0.032	0.381
	Validation		7.764	8.510	7.290	0.239	0.031	0.350
	All data		7.765	8.600	7.200	0.245	0.032	0.372
SC	Training	µS/cm	1,043.954	1,610.000	668.000	147.247	0.141	0.317
	Validation		1,053.570	1,555.000	699.000	144.105	0.137	0.366
	All data		1,046.833	1,610.000	668.000	146.300	0.140	0.332
TU	Training	NTU	7.215	32.400	0.440	4.424	0.613	0.370
	Validation		7.160	27.000	0.500	4.306	0.601	0.389
	All data		7.199	32.400	0.440	4.387	0.609	0.375
DO	Training	mg/L	5.084	11.160	0.148	2.973	0.585	1.000
	Validation		5.266	13.200	0.143	2.939	0.558	1.000
	All data		5.139	13.200	0.143	2.962	0.576	1.000
Sidi Marouane Wastewater Treatment Plant (WWTP)								
SS	Training	Mg/L	6.736	23.000	0.200	5.052	0.750	0.498
	Validation		7.511	29.000	0.400	5.927	0.789	0.493
	All data		7.261	39.500	0.200	5.628	0.775	0.347
TE	Training	°C	19.845	28.000	12.500	4.546	0.229	−0.130
	Validation		19.871	27.300	7.300	4.680	0.236	−0.153
	All data		20.212	28.000	7.300	4.492	0.222	−0.113
pH	Training	/	7.673	8.500	7.000	0.406	0.053	0.528
	Validation		7.684	8.520	7.000	0.387	0.050	0.630
	All data		7.619	8.520	7.000	0.343	0.045	0.345

(continued)

Table 1 (continued)

Variables	Subset	Unit	X_{mean}	X_{max}	X_{min}	S_x	C_v	R
SC	Training	μS/cm	1,553.059	1,815.000	1,210.000	107.548	0.069	−0.365
	Validation		1,548.587	1,791.000	1,210.000	120.216	0.078	−0.547
	All data		1,602.226	1,970.000	1,210.000	116.764	0.073	−0.295
COD	Training	mg/L	23.217	49.800	5.900	11.564	0.498	1.000
	Validation		22.289	55.000	4.500	11.341	0.509	1.000
	All data		20.566	59.000	3.500	10.702	0.520	1.000

X_{mean} mean, X_{max} maximum, X_{min} minimum, S_x standard deviation, C_v coefficient of variation, R coefficient of correlation with DO/COD, *TE* water temperature, *SS* suspended solids, *SC* specific conductance, *TU* turbidity in Nephelometric Turbidity Unit (NTU), *COD* chemical oxygen demand, *DO* dissolved oxygen

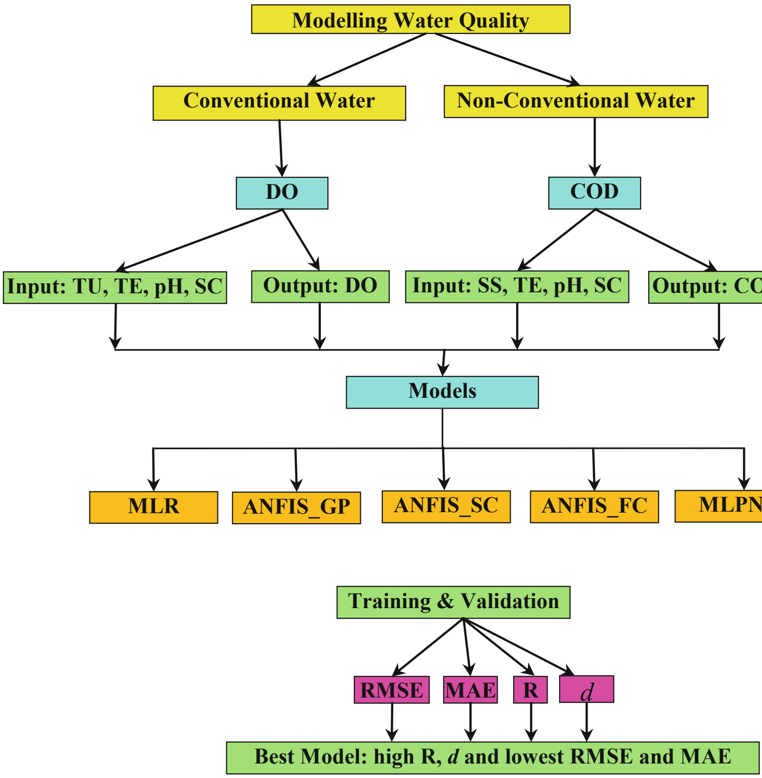

Fig. 4 Flow chart for the proposed MLPNN, ANFIS, and MLR models

and generally, there is an input, an output, and several hidden layers, and the information flows from the input to the output layer in which a series of processing operations is carried out, using a multiplication, summation, and transformation using a nonlinear activation (transfer) function. The available information represented by a matrix of input variables designed as x_i that represent the independent variable is stored in the input layer, while the response variable (y) is fixed into the output layer [24]. The hidden layers are the most important part of the ANN model, and its success and its ability to solve a highly complex problem are attributed to the role accomplished by the neurons arranged in the hidden layer that are characterized by the presence of a nonlinear function, generally the sigmoid function. The connection between different neurons, in different layers, is achieved using the weights and bias, sometimes called connection strengths. Similar to any other statistical models, weights and bias represent the parameters of the ANN model that must be optimized and adopted using a learning algorithm, generally the back-propagation, during a training process. Development of ANN models is mainly governed by the presence of dataset. The most well-known ANN model is certainly the MLPNN [25] that is frequently used for nonlinear mapping of input variables to an output variable based on function approximation. The goal of the training process is the minimization of an objective function. Generally the mean square error (MSE) is estimated between the measured value and the calculated value via the model [24]. In the present study, we used a MLPNN model having only one hidden layer with sigmoid activation function and a linear activation function also called identity function for the unique neuron in the output layer. MLPNN is a universal approximator [26, 27].

From the input layer to the output layer (Fig. 5), the mathematical formulation of the MLPNN can be split into the following equations:

$$I_j = \sum_{j=1}^{n} x_i w_{ij} + \delta_j \tag{2}$$

where x_i is the input variable, w_{ij} is the weight between the input i and the hidden neuron j, Ij is the net internal activity level of neuron j in the hidden layer, and δ_j is the bias of the hidden neuron j.

$$E_j = f_1(I_j) \tag{3}$$

E_j is the output from neuron j in the hidden layer, and f_1 is the activation sigmoid function, represented by Eq. (4).

$$f_1(x) = \frac{1}{1 + e^{-x}} \tag{4}$$

$$O = \sum_{j=1}^{n} E_j w_{jk} + \delta_0 \tag{5}$$

w_{jk} is the weight of connection of neuron j in the hidden layer to unique neuron k in the output layer; O is the input of the output neuron k, and δ_0 is the bias of the output neuron k. Finally the output of the neuron k in the output layer is calculated using a linear activation function f_0:

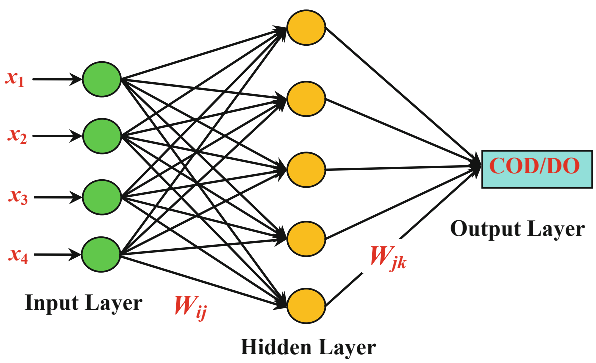

Fig. 5 Multilayer perceptron neural network (MLPNN) structure for modeling COD and DO concentrations

$$Y = f_2(O) \tag{6}$$

3.2 Adaptive Neuro-Fuzzy Inference System (ANFIS)

Adaptive neuro-fuzzy inference system designated as ANFIS is a data-driven model and belongs to the category of hybrid model, which combines two paradigms: the ANN and the fuzzy logic (FL) [28]. ANFIS is a nonlinear mathematical model that has a great capability of mapping any complex process characterized by a set of independent variables (inputs) and one dependent variable (the output). From the ANN approach, ANFIS is structured in several layers, and the information is circulated from the first to the last layer, while from the FL approach, ANFIS model uses the linguistic information and the concept of rules [28]. Among all the other artificial intelligence (AI) models, ANFIS needs a hybrid learning process to update the linear (consequent) and nonlinear (premises) parameters, composed of (1) back-propagation method for updating the nonlinear parameters found in the membership function and (2) the least squares (LS) for updating the linear parameters found in the IF-THEN rules base [28]. The hybrid algorithm is achieved in two steps: forward for updating the consequent parameters and backward pass for updating the premise parameters [28]. ANFIS general architecture is shown in Fig. 6. From Fig. 6, it is clear that the ANFIS model has five layers: two adaptive layers and three fixed layers. The first layer is used only for presenting the input variables. The fuzzy rule could be expressed as:

$$\text{Rule } 1 = \text{If } (x \text{ is } A_1) \quad \text{and} \quad (y \text{ is } B_1) \quad \text{Then} \quad (f_1 = p_1 x + q_1 y + r_1) \tag{7}$$

$$\text{Rule } 2 = \text{If } (x \text{ is } A_2) \quad \text{and} \quad (y \text{ is } B_2) \quad \text{Then} \quad (f_2 = p_2 x + q_2 y + r_2) \tag{8}$$

where x and y denote the inputs, A_i and B_i indicate the fuzzy sets, f_i are the outputs within the fuzzy region indicated by the fuzzy rule, and p_i, q_i, and r_i show the design parameters that are identified in the training phase.

Layer 1: the fuzzification layer with adaptive node

$$O_i^1 = \mu_{A_i}(x), \quad i = 1, 2, \tag{9}$$

$$O_i^1 = \mu_{B_{i-2}}(y), \quad i = 3, 4 \tag{10}$$

A_i (or B_{i-2}) is the linguistic label and $\mu_{A_i}(x)$, $\mu_{B_{i-2}}(y)$ fuzzy membership function.

For a Gaussian membership function, A_i can be computed as:

$$\mu_{A_i}(x) = \exp\left(-0.5 \times \{(x - c_i)/\sigma_i\}^2\right), \tag{11}$$

where σ_i, c_i are the premise parameters.

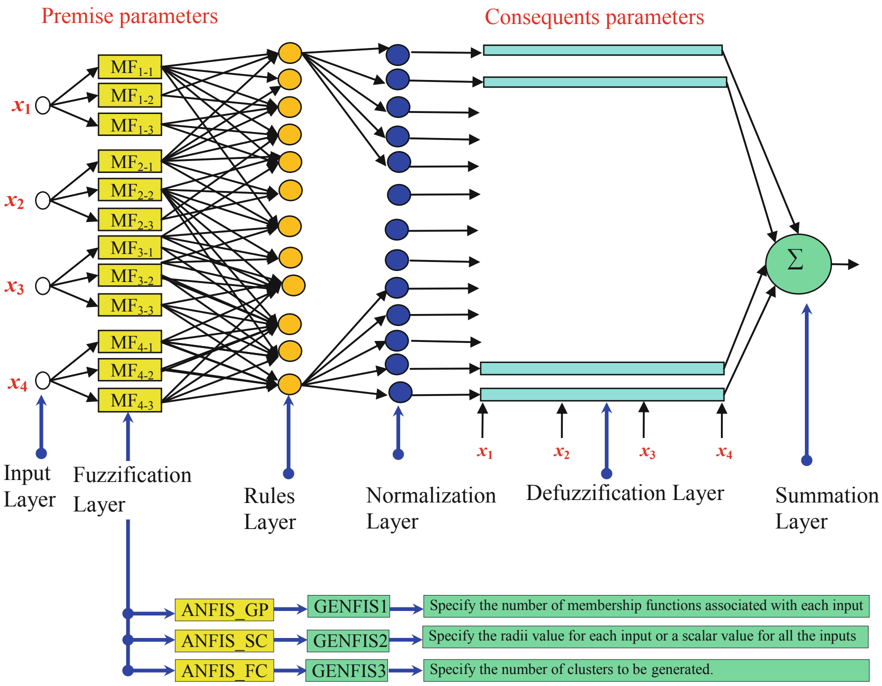

Fig. 6 ANFIS structure

Layer 2: the base rules layer

$$O_i^2 = w_i = \mu_{A_i}\mu_{Bi}, \quad i = 1, 2, \tag{12}$$

w_i is the firing strength of a rule. The node numbers in this layer equal the number of fuzzy rules.

Layer 3: the normalized firing strengths

$$O_i^3 = \overline{w}_i = (w_i/(w_1 + w_2)), \quad i = 1, 2, \tag{13}$$

Outputs of this layer are named as normalized firing strengths.

Layer 4: the defuzzification layer

$$O_i^4 = \overline{w}_i f_i = \overline{w}_i \, (p_i \, x + q_i \, y + r_i), \quad i = 1, 2 \tag{14}$$

where $\overline{w}_i$ the output of Layer 3 and p_i, q_i, and r_i are the consequent parameters.

Layer 5: the output of the ANFIS model

$$O_i^5 = \sum_{i=1} \overline{w}_i f_i = \left(\sum_{i=1} w_i f_i / (w_1 + w_2) \right). \tag{15}$$

ANFIS model can be built in three different forms: (1) ANFIS with grid partition method called ANFIS_GP, (2) ANFIS model with subtractive clustering called ANFIS _SC, and (3) ANFIS model with fuzzy *c*-means clustering (FCM) called ANFIS_FC. In the present study, ANFIS was developed using the software Matlab. For ANFIS_GP we used the GENFIS1 function; for ANFIS_SC and ANFIS_FC, we used GENFIS2 and GENFIS3 functions.

3.3 Multiple Linear Regression (MLR)

The multiple linear regression (MLR) is the well-known kind of linear models, and it represents an ideal relationship between a single variable called dependent (Y) and some explanatory variables (X_i) called independent variables. The relation between X_i and Y is given as:

$$\Psi = A_0 + A_1 \times x_1 + A_2 \times x_2 + A_3 \times x_3 + \ldots A_i \times x_i \tag{16}$$

where Ψ is the calculated or the predicted value of Y, A_0 is the intercept, and A_i are the partial regression coefficients associated with input variables.

3.4 Performance Assessment of the Models

In the present study, we used four performance indices to evaluate and compare the accuracy of the developed models: the coefficient of correlation (R), the Willmott index of agreement (d), the root-mean-squared error (RMSE), and the mean absolute error (MAE).

$$R = \left[\frac{\frac{1}{N} \sum (\mathrm{O}_i - \mathrm{O}_m)(\mathrm{P}_i - \mathrm{P}_m)}{\sqrt{\frac{1}{N} \sum_{i=1}^{n} (\mathrm{O}_i - \mathrm{O}_m)^2} \sqrt{\frac{1}{N} \sum_{i=1}^{n} (\mathrm{P}_i - \mathrm{P}_m)^2}} \right] \tag{17}$$

$$d = 1 - \frac{\sum_{i=1}^{N} (P_i - \mathrm{O}_i)^2}{\sum_{i=1}^{N} (|P_i - \mathrm{O}_m| + |\mathrm{O}_i - \mathrm{O}_m|)^2} \quad (18)$$

$$\mathrm{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (O_i - P_i)^2} \quad (19)$$

$$\mathrm{MAE} = \frac{1}{N} \sum_{i=1}^{N} |O_i - P_i| \quad (20)$$

where N is the number of data points, O_i is the measured value, P_i is the corresponding model prediction, and O_m and P_m are the average values of O_i and P_i [29–31].

4 Results

In the present work, we applied three types of models listed earlier: (1) the standard MLR, (2) the MLPNN, and (3) three types of ANFIS models, the ANFIS_GP, the ANFIS_SC, and the ANFIS_FC. The models were compared, and their performances were evaluated for modeling DO and COD concentrations. Several combinations of the water quality variables were selected, and in total five scenarios (Table 2) were compared. The performance of the models used in this study was computed using four performance criteria, including RMSE, MAE, R, and also the d. For the MLPNN models, the Levenberg-Marquardt (LM) algorithm was employed. For the hidden and output layers, the sigmoid and linear (identity) transfer functions were employed, respectively. The minimum number of the hidden neuron was one, and the maximum was 20, and a total of 100 epochs was adopted. By trial and error, we find that the optimal number of neurons in the hidden layer for both COD and DO was equal to 13 neurons. ANFIS is configured using three different identification

Table 2 The input combinations for different models

Models					Input combinations	
					Modeling DO	Modeling COD
MLR1	MLPNN1	ANFIS_SC1	ANFIS_GP1	ANFIS_FC1	TE, pH, SC, TU	SS,TE, pH, SC
MLR2	MLPNN2	ANFIS_SC2	ANFIS_GP2	ANFIS_FC2	TE, pH, SC	SS, TE, SC
MLR3	MLPNN3	ANFIS_SC3	ANFIS_GP3	ANFIS_FC3	TE, SC,TU	SS, pH, SC
MLR4	MLPNN4	ANFIS_SC4	ANFIS_GP4	ANFIS_FC4	pH, SC	SS, pH
MLR5	MLPNN5	ANFIS_SC5	ANFIS_GP5	ANFIS_FC5	SC,TU	SS, SC

methods: (1) grid partitioning using Genfis1 algorithm for ANFIS_GP, (2) subtractive clustering using Genfis2 algorithm for ANFIS_SC, and (3) fuzzy c-means clustering using Genfis3 algorithm for ANFIS_FC. For ANFIS_GP, the number of membership functions (MFs) for each input variable is two. The Gaussian curve membership function Gaussmf is used for input variables, and output membership function type is a linear type, and it is trained for 150 epochs. Using the grid partition method, the numbers of fuzzy rules exponentially increase with the increase of the number of MFs for each input variable, and it is hard to use this method if the number of input variables is rather than six because of computation time and/or memory limitations. Hence, the number of possible fuzzy rules is calculated as $(\text{MFs})^n$, where n is the number of input variables. For ANFIS_SC, contrary to the ANFIS_GP, the optimum number of MFs and consequently the number of fuzzy layers are determined using the subtractive clustering (SC) algorithm. The number of fuzzy rules generated using the SC algorithm is governed by one parameter: the radius value r_a, determined at the beginning of the training process. Large values of r_a generate fewer clusters and vice versa. Consequently, the number of fuzzy rules is equal to the number of clusters. In the present study, we determined the optimal value of r_a by trial and error, and the best values for DO and COD were 0.26 and 0.85, respectively. Finally, for the ANFIS_FC based on the fuzzy c-means clustering (FCM) algorithm, contrary to the SC algorithm, the number of clusters generated is known and fixed at the beginning of the training, and the number of fuzzy rules is equal to the number of clusters. In the present study, we determined the optimal number of the cluster by trial and error, and the best values for DO and COD were 20 and 3, respectively. Hereafter the results obtained are summarized and discussed.

4.1 Modeling DO at Boudouaou Drinking Water Treatment Plant

Table 3 shows the results obtained by the ANFIS, MLPNN, and MLR models applied and compared together. According to Table 3, acceptable accuracy between measured and calculated DO concentration was achieved by all the MLPNN and ANFIS models, while the MLR models perform worse with high (RMSE and MAE) and low (R and d) values. In the training phase as seen in Table 3, the best R and d across all compared models were achieved by the ANFIS_FC1 (R = 0.939, d = 0.968), followed by ANFIS_SC1 (R = 0.909, d = 0.951), the MLPNN1 (R = 0.901, d = 0.947) in the third place, and the ANFIS_GP1 (R = 0.894, d = 0.942) in the fourth place. The worst accuracy with low R and d was for the MLR1 model (R = 0.649, d = 0.766). As can be seen from Table 3, ANFIS_FC1 has the lowest RMSE and MAE values (RMSE = 1.021 mg/L, MAE = 0.710 mg/L), while MLR1 has the highest RMSE and MAE values (RMSE = 2.259 mg/L, MAE = 1.817 mg/L). Compared to the two other ANFIS models, it is clear that the ANFIS_FC1 model has smaller RMSE and MAE values and higher R and

Table 3 Performances of the developed models for modeling DO concentration

Models	Training				Validation			
	RMSE (mg/L)	MAE (mg/L)	*R* /	*d* /	RMSE (mg/L)	MAE (mg/L)	*R* /	*d* /
MLR1	2.259	1.817	0.649	0.766	2.275	1.824	0.635	0.768
MLR2	2.379	1.938	0.599	0.725	2.352	1.915	0.599	0.732
MLR3	2.661	2.319	0.444	0.574	2.654	2.311	0.431	0.566
MLR4	2.614	2.206	0.475	0.611	2.490	2.117	0.531	0.648
MLR5	2.452	2.013	0.564	0.687	2.383	1.953	0.584	0.705
MLPNN1	1.286	0.942	0.901	0.947	1.844	1.246	0.796	0.891
MLPNN2	1.669	1.214	0.827	0.900	1.854	1.315	0.779	0.878
MLPNN3	1.725	1.284	0.814	0.892	2.400	1.782	0.617	0.786
MLPNN4	2.249	1.767	0.653	0.772	2.154	1.756	0.681	0.780
MLPNN5	2.042	1.581	0.726	0.827	2.161	1.634	0.685	0.811
ANFIS_SC1	1.235	0.888	0.909	0.951	1.528	1.123	0.856	0.922
ANFIS_SC2	1.658	1.198	0.830	0.901	1.874	1.334	0.775	0.874
ANFIS_SC3	1.899	1.431	0.769	0.861	2.171	1.694	0.681	0.813
ANFIS_SC4	2.317	1.879	0.626	0.747	2.389	1.951	0.594	0.737
ANFIS_SC5	2.160	1.697	0.686	0.797	2.248	1.723	0.646	0.775
ANFIS_GP1	1.331	0.973	0.894	0.942	1.662	1.191	0.831	0.908
ANFIS_GP2	1.848	1.363	0.783	0.869	1.865	1.417	0.772	0.863
ANFIS_GP3	2.101	1.662	0.707	0.815	2.193	1.749	0.667	0.793
ANFIS_GP4	2.443	2.036	0.569	0.694	2.399	2.046	0.576	0.695
ANFIS_GP5	2.266	1.782	0.647	0.767	2.103	1.655	0.700	0.795
ANFIS_FC1	1.021	0.710	0.939	0.968	1.662	1.152	0.836	0.914
ANFIS_FC2	1.407	0.999	0.881	0.934	1.804	1.256	0.801	0.893
ANFIS_FC3	1.725	1.284	0.814	0.892	2.400	1.782	0.617	0.786
ANFIS_FC4	2.060	1.602	0.720	0.824	2.240	1.701	0.652	0.787
ANFIS_FC5	1.738	1.311	0.811	0.889	2.105	1.524	0.713	0.838

d values than the ANFIS_GP1 and ANFIS_SC1 models. In the validation phase as seen in Table 3, the best accuracy was achieved using the ANFIS_SC1. It is clear that the ANFIS_SC1 model has smaller RMSE and MAE (RMSE = 1.528 mg/L, MAE = 1.123 mg/L) and higher R and d values ($R = 0.856$, $d = 0.922$) than the ANFIS_FC1, ANFIS_GP1, MLPNN, and MLR models. Also, the ANFIS_FC1 model has a lower RMSE and MAE, and slightly higher *R* and *d* than the ANFIS_GP1 model, and was again better than the MLPNN1 and MLR1 models. This indicates that in general, the ANFIS model is a good modeling tool for DO than MLPNN and MLR. It is also clear from Fig. 6 that the ANFIS models have less scattered estimates than the MLPNN and MLR models. This indicates that in general, the ANFIS model is a good modeling tool for DO compared to MLPNN and MLR. From Table 3, the second input combination provides better accuracy than the third input combination. Similarly, fifth input combination has better performance than the fourth one. Comparison of these combinations shows that the SU variable is more effective on DO than the pH variable.

4.2 Modeling COD at Sidi Marouane Wastewater Treatment Plant

Table 4 illustrates the obtained results from all five developed models for predicting COD. From these results, it can be observed that MLPNN, ANFIS_SC, ANFIS_FC, and ANFIS_GP have promising accuracy during the training and validation phases; for all the five combinations, the ANFIS_FC1 has the best accuracy in the training phase. However, during the training or validation phases, the models with two input variables (combination 4 and 5) give low efficiency, low (R and d) and high (RMSE and MAE) values. Also, the models with first and third input combinations give good results compared to the three other combinations; this is certainly due to the inclusion of the pH variable as input. Taking into account the four statistical indices, the ANFIS_FC1 model with four input variables (SS, TE, pH, and SC) gives the best estimation (R = 0.771, d = 0.860, RMSE = 7.362 mg/L, MAE = 5.471 mg/L)

Table 4 Performances of the developed models for modeling COD concentration

	Training				Validation			
	RMSE	MAE	*R*	*d*	RMSE	MAE	*R*	*d*
Models	(mg/L)	(mg/L)	/	/	(mg/L)	(mg/L)	/	/
MLR1	8.476	6.656	0.680	0.785	7.658	5.916	0.750	0.840
MLR2	9.431	7.546	0.579	0.693	8.810	7.280	0.651	0.760
MLR3	9.084	7.242	0.619	0.733	8.235	6.788	0.704	0.790
MLR4	9.192	7.344	0.607	0.721	8.645	7.040	0.663	0.757
MLR5	9.602	7.808	0.557	0.671	8.932	7.491	0.637	0.739
MLPNN1	7.824	5.896	0.736	0.837	6.971	5.069	0.790	0.870
MLPNN2	8.390	6.383	0.688	0.795	7.986	6.029	0.710	0.815
MLPNN3	7.454	5.690	0.765	0.854	7.883	5.768	0.726	0.837
MLPNN4	8.254	6.397	0.700	0.807	8.219	6.185	0.689	0.803
MLPNN5	8.647	6.768	0.664	0.773	8.574	6.596	0.655	0.764
ANFIS_SC1	7.922	6.054	0.729	0.828	6.742	4.944	0.805	0.880
ANFIS_SC2	8.565	6.691	0.672	0.781	8.052	6.000	0.704	0.805
ANFIS_SC3	8.235	6.399	0.702	0.807	7.462	5.525	0.755	0.837
ANFIS_SC4	8.678	6.899	0.661	0.772	8.066	6.167	0.705	0.793
ANFIS_SC5	8.859	7.013	0.643	0.757	8.421	6.411	0.671	0.767
ANFIS_GP1	7.689	5.873	0.747	0.841	7.128	5.119	0.779	0.867
ANFIS_GP2	8.263	6.308	0.700	0.805	7.684	5.731	0.736	0.829
ANFIS_GP3	8.083	6.224	0.715	0.816	7.328	5.502	0.765	0.845
ANFIS_GP4	8.657	6.881	0.663	0.774	8.186	6.277	0.693	0.789
ANFIS_GP5	8.823	6.941	0.646	0.761	8.174	6.273	0.696	0.782
ANFIS_FC1	7.362	5.471	0.771	0.860	7.299	5.356	0.767	0.864
ANFIS_FC2	7.987	6.116	0.723	0.824	8.615	6.435	0.665	0.796
ANFIS_FC3	7.579	5.712	0.755	0.850	7.432	5.344	0.757	0.854
ANFIS_FC4	8.262	6.384	0.700	0.807	7.966	5.983	0.712	0.815
ANFIS_FC5	8.681	6.720	0.661	0.774	8.268	6.443	0.685	0.781

among all the other models as shown in Table 4. According to the results in Table 4, it is clear that the MLR1 model has smaller R and d and higher RMSE and MAE in the training phase, compared to the MLPNN1 and the three ANFIS models, and provides the poorest accuracy. Some clear conclusions could be drawn from the Table 4 with respect to validation results. Firstly, for the entire five models developed, it can be concluded from the table that the poorest accuracy was obtained using the MLR1 model with the lowest R and d ($R = 0.771$, $d = 0.860$) and the highest RMSE and MAE (RMSE = 7.362 mg/L, MAE = 5.47 mg/L). Secondly, among the five input combinations (Table 2), the first (with all the input variables) is the best, and the fifth combination (SS, SC) is the worst. Thirdly, according to the results based on three ANFIS, the optimal models are ANFIS_SC1, ANFIS_FC1, and ANFIS_GP1, respectively. It is observed that the ANFIS_SC1 presented the lowest RMSE and MAE (RMSE = 6.742 mg/L, MAE = 4.944 mg/L) values and the highest R and d ($R = 0.805$, $d = 0.880$) values. Accordingly, ANFIS_SC1 is considered the optimal. It can simply be concluded that better performance results can be obtained with ANFIS_SC1. Fourthly and finally, the results of R, d, RMSE, and MAE suggest that the ANFIS_SC1 is slightly better compared to that of MLPNN1 and the MLPNN1 is slightly better compared to those of the ANFIS_FC1 and ANFIS_GP1. From Table 3, the third input combination has better accuracy than the second input combination. Moreover, the fourth input combination shows better performance than the fifth one. Comparison of these combinations indicates that the pH variable is more effective on COD than the TE and SC variables. It can be observed from Fig. 7 that the ANFIS_SC1 model has less scattered estimates than the other models. The slope and bias of its (ANFIS_SC1) fit line equation are, respectively, closer to the 1 and 0 with a lower R compared to MLPNN1, ANFIS_FC1, ANFIS_GP1, and MLR1 models (Fig. 8).

5 Discussion

In the present paper, we developed two artificial intelligence models, ANFIS and ANN, for predicting COD and DO in WWTP and drinking water treatment plant, respectively. Hereafter, we discussed the obtained results in comparison to the results reported in previous similar studies in the literature. Especially, we focused on the results related to the COD. Among all the developed models in our study, ANFIS represents the best accuracy compared to the ANN. Various researchers have attempted to develop models for COD using effluent and affluent water quality variables. The supervised committee fuzzy logic (SCFL) model proposed by Nadiri et al. [8] achieves an R^2 equal to 0.82, significantly superior to 0.648 obtained using ANFIS model in our study. Kisi and Parmar [7] utilized MARS, LSSVM, and M5Tree models for modeling COD and demonstrated that an $R^2 = 0.71$ is obtained using MARS model. In another study, Ay and Kisi [6] compared ANN, GRNN, and RBFNN models for COD estimation, and they obtained an R^2 equal 0.88. Similar to our approach, Pai et al. [11] compared ANFIS and ANN models for COD and demonstrated that ANFIS provided an R^2 equal 0.86 which is superior to the

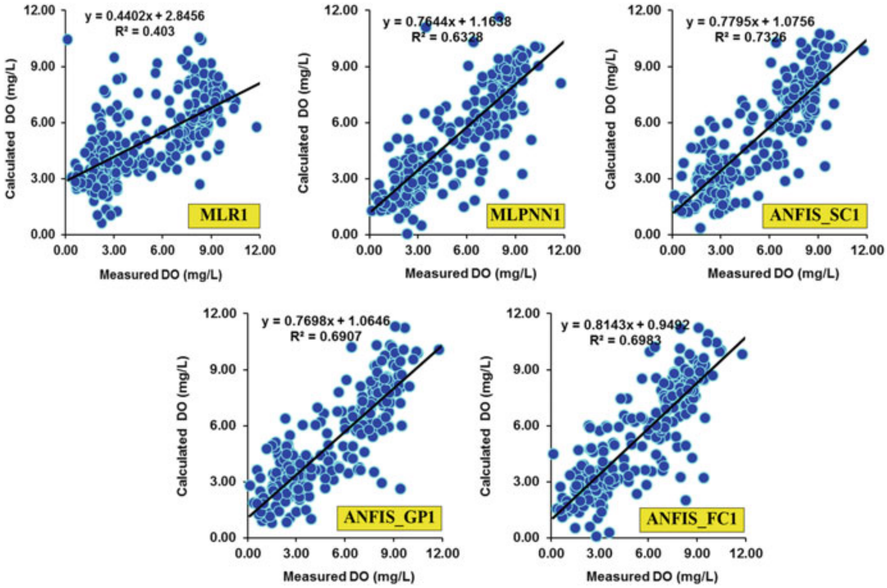

Fig. 7 Scatterplots of predicted versus measured values of dissolved oxygen concentration (DO) using MLPNN1, MLR1, ANFIS_SC1, ANFIS_FC1, and ANFIS_GP1 models in validation phase

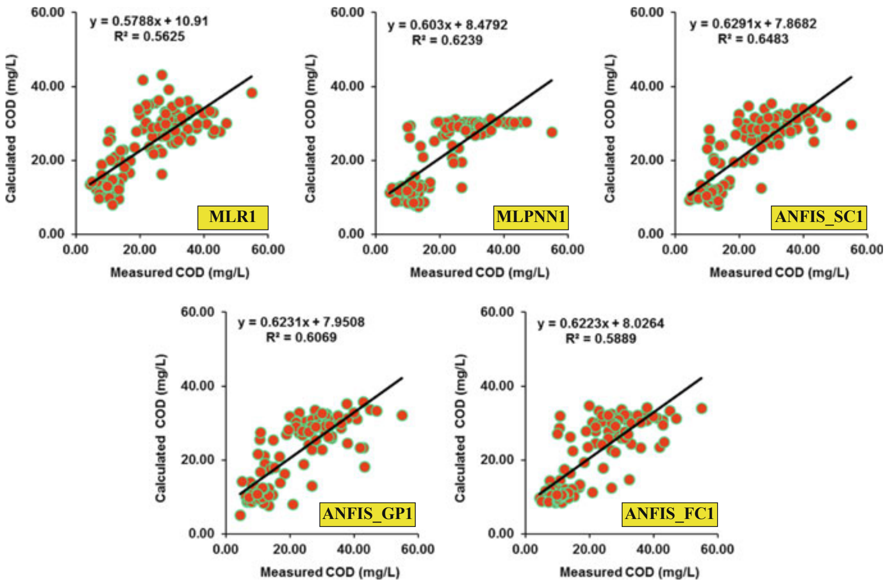

Fig. 8 Scatterplots of predicted versus measured values of chemical oxygen demand (COD) using, MLPNN1, MLR1, ANFIS_SC1, ANFIS_FC1, and ANFIS_GP1 models in the validation phase

R^2 (0.648) obtained using our model. Singh et al. [13] reported that ANN model had an R^2 of 0.84. In the study conducted by Yilmaz et al. [10], MLPNN model was more accurate than GRNN and RBFNN, with an R^2 equal 0.876. Finally, the ANFIS model proposed by Perendeci et al. [12] provided an R^2 equal 0.84. From the discussion reported above, it is clear that our models worked less accurate than the models proposed in the literature, and this is certainly related to the quality of the data used for developing the models.

6 Conclusions

In the present investigation, MLPNN, MLR, and three ANFIS models, namely, ANFIS_GP, ANFIS_SC, and ANFIS_FC, were developed to model two water quality indicators: (1) chemical oxygen demand (COD) and (2) dissolved oxygen concentration (DO). The models were developed using several water quality variables measured at daily time step at WWTP and DWTP, respectively. The input variables used for predicting COD are daily water temperature (TE), suspended solids (SS), specific conductance (SC), and pH, while the input variables used for modeling DO were turbidity (TU), TE, pH, and SC. From the results obtained in the present investigation, some conclusions can be drawn and are summarized as follows:

1. By comparing several combinations of the input variables for modeling DO concentration, the best results were obtained by the ANFIS_SC with TE, pH, SC, and TU inputs, followed by the ANFIS_FC in the second order, ANFIS_GP ranked third, MLPNN ranked fourth, and the MLR model in the last place.
2. In regard to modeling COD, the results showed that the ANFIS_SC with TE, pH, SC, and SS as inputs had the best results and it can be used to estimate COD with very acceptable accuracy, followed by the MLPNN, ANFIS_GP, ANFIS_FC, and MLR, respectively.

Another conclusion we can draw from the results obtained is that the accuracy of the proposed models is mainly dependent to the selection of the input variables, and to obtain good prediction accuracy, it is necessary that all the variables be included for the models.

7 Recommendations

Results obtained in the present study highlighted a number of points that need to be addressed in the future. Firstly, the quality of data must be improved, and the list of variables measured should be enlarged to other variables, notably to include chemical and physical variables that can be good predictors for COD. Secondly, the proposed models should be applied to other WWTP for further comparison of the models' performances.

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Organic Chemical Characterization of Water of the Northwestern Algerian Dams

Fatiha Hadji, Imen Guasmi, and Chahrazed Aggab

Contents

Abstract The aim of this study concerns the water quality of the western Algerian dams. Various analyses of water were made for ten dams belonging to Tafna and Macta watersheds. They are generally used for human consumption and for irrigation purposes.

The analyzed parameters were pH, dry residue (DR), dissolved oxygen (DO), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+),orthophosphate (PO_4^{3-}), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and organic matter (OM). Analyses were done monthly during 2013 and concerned ten dams of the aforementioned basins.

Waters of the dams were very alkaline with values ranging between 7.01 and 8.97, and important DR concentrations were observed at Sarno dam (Macta watershed) located upstream of the confluence of Mekerra and Sarno wadis and where

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values were between 2,700 and 4,000 mg L^{-1}. The highest BOD_5, COD, and MO contents were recorded at Hammam Boughrara dam situated within Tafna watershed with maximum BOD_5 and MO in July and maximum COD in December. The organic pollution index (2.25–4.00) and COD/BOD_5 (3.7–7.2) values indicated moderate to strong pollution and reveal that all waters were more or less difficult to biodegrade.

Keywords Dams, Quality, Standards, Water, Watersheds, Western Algeria

1 Introduction

In order to meet the needs of fresh water for different uses, the most logical solution is the surface water storage in dams. To ensure its independence and guarantee its water resource needs [1], Algeria has already taken this problem very seriously. In 1962, there were only 15 dams to store 450 million m^3 of water mainly for irrigation use. Currently, there are 79 [2] for a total capacity of about 8 billion m^3 of water. These dams are located within 17 watersheds (Fig. 2) which some of them are the aim of this study, (1) the endorheic basins occupying the High Plains whose waters are largely lost by evaporation in the chotts. The annual flow is estimated at 700 hm^3 and (2) the Saharan basins with an average intake of 650 hm^3 per year [1]. This surface water collected in dams may be polluted and contain important levels of salts, toxic ions, heavy metals, and organic residues [3]. Accumulation of these pollutants when in water and soils may cause a threat to agricultural production and the environment [4]. For example, release of phosphorus and nitrogen into water-courses then in dams can lead to severe pollution problems, such as eutrophication [5, 6], which cause profuse algal blooms, excessive growth of harmful plants, oxygen depletion, habitat degradation, and problems related to water treatment [7, 8]. In addition to contributing to eutrophication, forms of nitrogen such as ammonia, nitrite, and nitrate have the potential for direct toxicity [8, 9].

Organic matter content in water comes generally from crop wreckage, food waste, other degradable solid wastes [10], and fecal matters [11]. Algal and phytoplankton growth is enhanced by nutrients which are supplemented by fertilizers and finally results in eutrophication [12].

Monitoring the water quality for human consumption and/or irrigation purpose becomes necessary to protect human health, soil, plants, and water bodies and to prevent the deterioration of irrigation and treatment infrastructures [13].

Many studies have been published concerning the assessment of water quality in rivers [14–19] and dams [20–25] using physical, chemical, and biological parameters and permitted (1) the assessment of water quality in these water bodies and (2) the identification of the pollutants discharged into and their effects on water quality. This way of doing can give warnings to consumers in order to prevent dangerous and unhealthy situations.

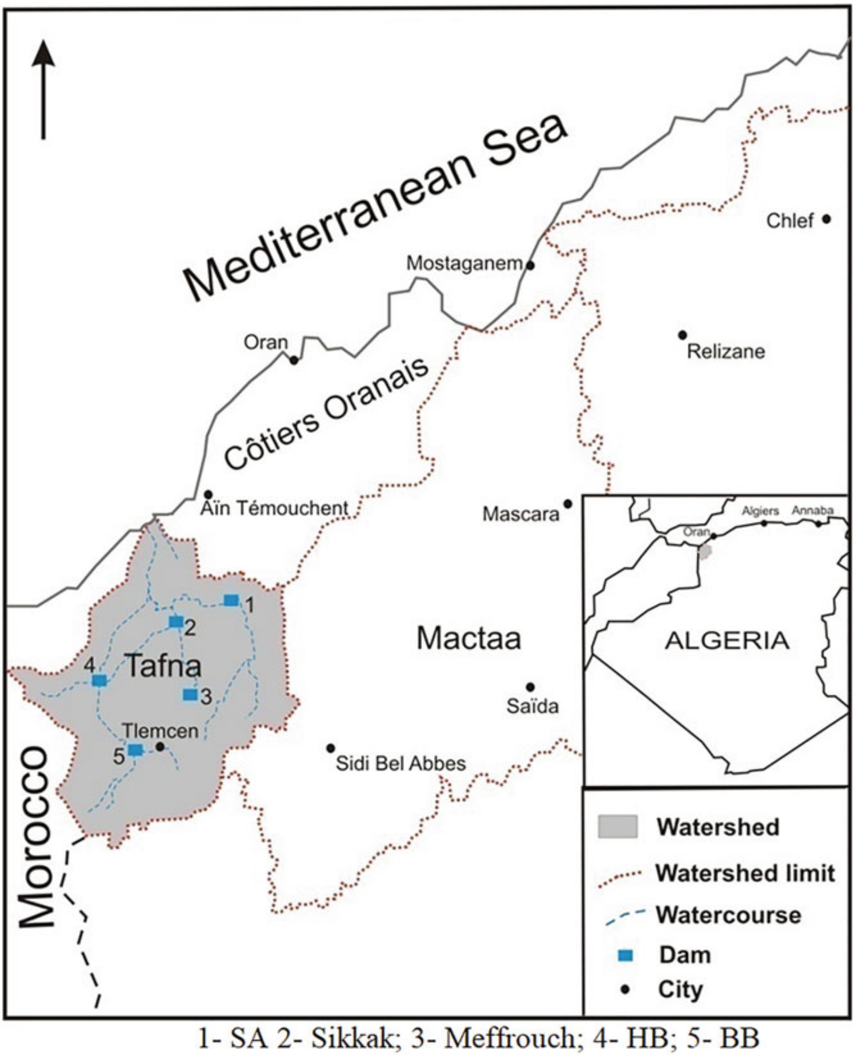


Fig. 2 Location of Tafna watershed dams

The aim of this study concerned the assessment of water quality of ten dams belonging to Tafna and Macta watersheds. The prime objectives were to evaluate physical and organic chemical characteristics of water, to identify polluted dams, and to assess the difference in water quality of dams and watersheds. The second objective was the assessment of spatial and temporal variability in the water quality and their suitability for irrigation purposes.

2 Materials and Methods

The study dams (Fig. 1) are located in the northwest of Algeria. They administratively belong to four wilayas: Tlemcen, Ain Temouchent, Mostaganem, Sidi Bel-Abbes, and Mascara. Their basins are limited by the Oran coastal watersheds at north, by Morocco at west, by Chott Ech Chergui watershed at south, and to the east by Chelif watershed .The dams covered by this study are included in Tafna (5) (Fig. 2) and Macta (5) (Fig. 3) watersheds.

Table 1 summarizes the dams of concern, the watersheds they drain, and the water use.

The analyzed parameters were pH, dry residue (DR), dissolved oxygen (DO), nitrate (NO_3^-), nitrate (NO_2^-), ammonium (NH_4^+), phosphate (PO_4^{3-}), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), and organic matter (OM). Analyses were done monthly during January–December 2013 year.

For Tafna watershed, analyses concerned water dams of Sidi-Abdelly (SA), Sikkak, Meffrouch, Hammam Boughrara (HB), and Beni Behdel (BB) (Fig. 2). As for Macta basin, analyzed water concerned Fergoug, Bouhanifia, Ouizert, Cheurfa, and Sarno dams (Fig. 3). These surface waters are generally used for human consumption and irrigation purposes (Table 1).

3 Results and Discussion

Tables 2 and 3 summarize the minimum and maximum values of the analyzed parameters of the water dams.

3.1 Physical and Chemical Characterization

3.1.1 Variations in pH and Dissolved Oxygen

The recorded pH values in Tafna (7.36–8.97) (Fig. 4a) and in Macta (7.01–8.62) (Fig. 4b) watershed dams show that all water dams are alkaline (Tables 2 and 3).

Depletion of dissolved oxygen in water can encourage the microbial reduction of nitrate to nitrite and sulfate to sulfide and cause an increase in the concentration of ferrous iron [19]. Its consumption results from excessive algae growth and decomposition caused by phosphorus and nitrogen compounds [26]. Dissolved oxygen values (Tables 2 and 3) range from 36.3% to 154.3% in Tafna dams (Fig. 5a) where the highest values were recorded at HB (in January) and Sikkak (in July) dams. As for Macta watershed, DO levels were greater than in Tafna dams. They vary from 54.4 (in January) to 160.3% (in September) (Fig. 5b) in Cheurfa dam. DO can be affected directly by biochemical and chemical demands; the greater the BOD_5, the

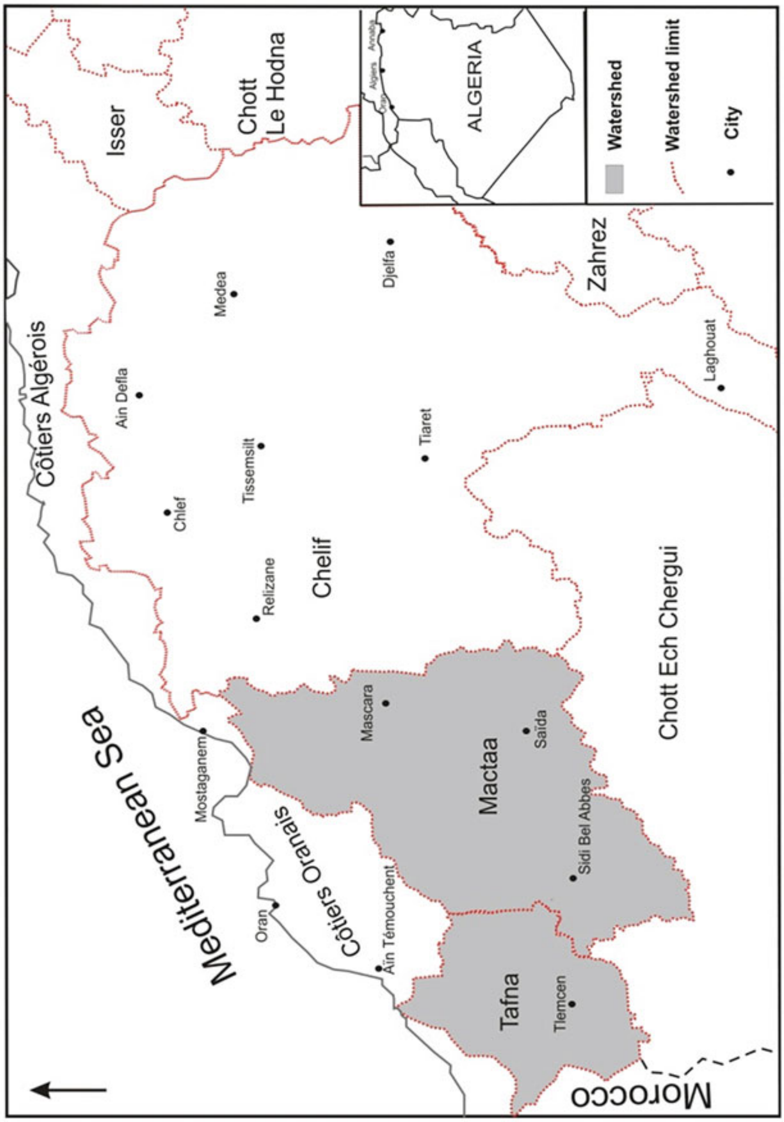
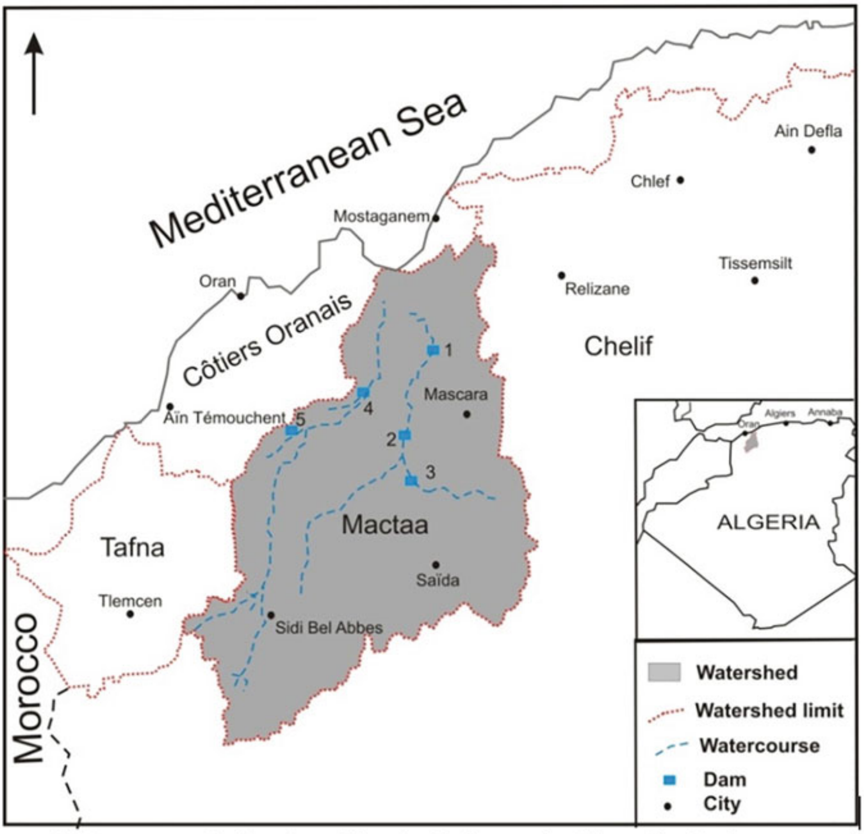


Fig. 1 Location of study area



1- Fergoug; 2- Bouhanifia; 3- Ouizert; 4- Cheurfa; 5- Sarno

Fig. 3 Location of Macta watershed dams

more rapidly dissolved oxygen is depleted in the water bodies. This means that less oxygen is available to aquatic life forms [27]. BOD_5 refers to the amount of oxygen required for the destruction of decomposable organic matter by biochemical processes. It is a measure of the dissolved oxygen consumed by microorganisms during the oxidation of reduced substances [27]. High BOD_5 levels can cause water quality deterioration and generate problems such as eutrophication leading to severe DO depletion [28].

3.1.2 Dry Residue

Dry residue contents are greater in Macta watershed dams (400–4,000 mg L^{-1}) than in Tafna one (200–1,200 mg L^{-1}) (Fig. 6a). Important concentrations were observed at Sarno dam (Fig. 6b) located upstream of the confluence of Mekerra and Sarno

Table 1 Different water uses of the study dams [2]

Watershed	Dam	Watershed surface (km^2)	Wadi	Use
Tafna	BB	1,016	Tafna	• Drinking water supply of Oran, Aïn Temouchent, and Tlemcen cities • Irrigation of Maghnia perimeter
	HB	90	Tafna	• Drinking water supply of Oran and Maghnia cities • Irrigation Tafna perimeter
	Meffrouch	1,138	Nachef	• Drinking water supply of Tlemcen city
	SA	248	Isser	• Drinking water supply of Oran and Aïn Temouchent cities
	Sikkak	4,000	Sikkak	• Drinking water supply of Tlemcen city • Irrigation of Hennaya plain
Macta	Cheurfa	7,850	Mebtouh	• Irrigation
	Fergoug	2,100	El Hammam	• Drinking water supply of Oran, Mohamadia, and neighboring localities; • Industrial water supply of Arzew city • Irrigation of Habra perimeter
	Ouizert	264	Sahouat	• Bouhanifia dam transfer
	Sarno	8,270	Sarno	• Water drinking supply of Sidi Hamadouche locality (Sidi Bel Abbes)
	Bouhanifia	4,190	El Hammam	• Water drinking supply of Sfisef and Bouhanifia localities • Irrigation of Hacine perimeter

Table 2 Minimum and maximum values of the analyzed parameters of Tafna dams

Parameter	SA	Sikkak	Meffrouch	HB	BB
pH	7.6–8.3	7.44–8.76	7.36–7.95	7.48–8.97	7.51–8.12
DR (mg L^{-1})	700–1,000	680–860	200–430	960–1,200	400–640
DO (%)	74.1–119	47.4–154.3	54.7–120	36.3–148.9	63.7–124.1
NO_3^- (mg L^{-1})	1–6	2–15	1–8	1–35	1–6
NO_2^- (mg L^{-1})	0.01–0.1	0.16–0.65	0.06–0.11	0.02–2.1	0.08
NH_4^+ (mg L^{-1})	0.05–0.25	0.05–1.02	0.06–0.38	0.07–4.46	0.22–0.83
PO_4^{3-} (mg L^{-1})	0.05–0.19	0.06–0.16	0.05–0.1	0.1–1.86	0.05–0.12
COD (mgL^{-1})	29–66	19–56	19–59	7.1–96	19–49
BOD_5 (mgL^{-1})	5.5–13	3.4–11.7	3.1–10.5	5.4–38	4.2–8.7
OM (mgL^{-1})	3.4–8.4	4.4–8.3	2.8–6	4.8–17.6	1.8–6.2
COD/BOD_5	4.5–6.2	4.5–7.2	4.5–6.7	4.4–5.7	4.5–6.7

wadis and where values were between 2,700 and 4,000 mg L^{-1} (Avg., 3,161.7 mg L^{-1}; SD, 668.8 mg L^{-1}) (Fig. 6a) during all the sampling period except in December (1,600 mg L^{-1}).

Table 3 Range of values of the analyzed parameters of Macta dams

Parameter	Fergoug	Bouhanifia	Ouizert	Cheurfa	Sarno
pH	7.57–8.33	7.01–8.29	7.65–8.48	7.59–8.62	7.77–8.37
DR (mg L^{-1})	1,400–2,260	400–1,500	600–1,360	1,000–2,200	1,600–4,000
DO (%)	74–152.3	87.5–141.1	70.4–154.3	54.4–160.3	76.8–120
NO_3^- (mg L^{-1})	1–9	1–8	1–18	1–20	1–11
NO_2^- (mg L^{-1})	0.03–0.90	0.02–0.26	0.03–0.80	0.03–0.80	0.01–0.14
NH_4^+ (mg L^{-1})	0.15–0.5	0.13–0.57	0.06–0.50	0.07–4.08	0.07–0.66
PO_4^{3-} (mg L^{-1})	0.08–0.30	0.02–0.15	0.04–0.19	0.22–1.30	0.04–0.22
COD (mg L^{-1})	56–94	47–96	47–125	75–154	38–67
BOD_5 (mg L^{-1})	10.5–22.7	8.7–19.4	11.5–23.7	17.1–37.9	7.9–15
OM (mg L^{-1})	5.50–15.40	5.3–9.4	4.7–13	1.7–20.5	7.8–11.2
COD/BOD_5	3.9–5.3	4.4–6.0	4.7–5.4	4.0–4.9	4.2–5.9

3.1.3 Variations in MO, BOD_5, and COD

In Tafna Basin, the highest BOD_5 (5.4–38 mg L^{-1}; Avg., 11.9 mg L^{-1}; SD, 9.4 mg L^{-1}) and COD (7.1–96 mg L^{-1}; Avg., 43.8 mg L^{-1}; SD, 21.7 mg L^{-1}) contents were recorded at HB dam with BOD_5 and COD maximum values in July and December, respectively (Fig. 7d). This dam receives, among others, wastewater of the complex of greasy substance via surface water flow of Mouillah wadi [29]. Organic matter contents were also maximum at HB dam (5.2–16 mg L^{-1}; Avg., 8.8 mg L^{-1}; SD, 3.8 mg L^{-1}) compared to those of Meffrouch (2.8–6.0 mg L^{-1}; Avg., 4.1 mg L^{-1}; SD, 1.1 mg L^{-1}), SA (3.4–8.4 mg L^{-1}; Avg., 5.2 mg L^{-1}; SD, 1.5 mg L^{-1}), Sikkak (4.4–8.3 mg L^{-1}; Avg., 6.3 mg L^{-1}; SD, 1.2 mg L^{-1}), and BB (1.8–6.2 mg L^{-1}; Avg., 4.0 mg L^{-1}; SD, 1.4 mg L^{-1}).

As for Macta watershed, maximum BOD_5 (17.1–37.9 mg L^{-1}; Avg., 24.1; SD, 6.4) and COD (75–154 mg L^{-1}; Avg., 104 mg L^{-1}; SD, 26.5 mg L^{-1}) values were found at Cheurfa dam (Fig. 8d). Organic matter levels were high than in Tafna dams. The maximum values (1.7–20.5 mg L^{-1}; 12.9 mg L^{-1}; 4.8 mg L^{-1}) were found at the aforementioned dam. The high contents of MO, BOD_5, and COD may probably be due to agricultural runoff, waste disposal, and wastewater effluent discharged into the watercourses feeding the dams.

3.1.4 Nitrate, Nitrite, and Ammonium

Nitrates come to water dams through surface water flow. They probably originate from the fertilizer uses as well as human and animal wastes. Nitrate concentrations range between 1 and 35 mg L^{-1} in the ten study dams. In Tafna watershed, nitrate ions were found in the following concentrations: HB (1–35 mg L^{-1}; Avg., 5.9 mg L^{-1}; SD, 9.6 mg L^{-1}) (Fig. 7d), Meffrouch (1–8 mg L^{-1}; Avg., 3.0 mg L^{-1}; SD, 1.9 mg L^{-1}) (Fig. 7c), SA (1–6 mg L^{-1}; Avg., 2.6 mg L^{-1}; SD, 1.5 mg L^{-1}), Sikkak (2–15 mg L^{-1}; Avg., 8.2 mg L^{-1}; SD, 5.2 mg L^{-1}) (Fig. 7b),

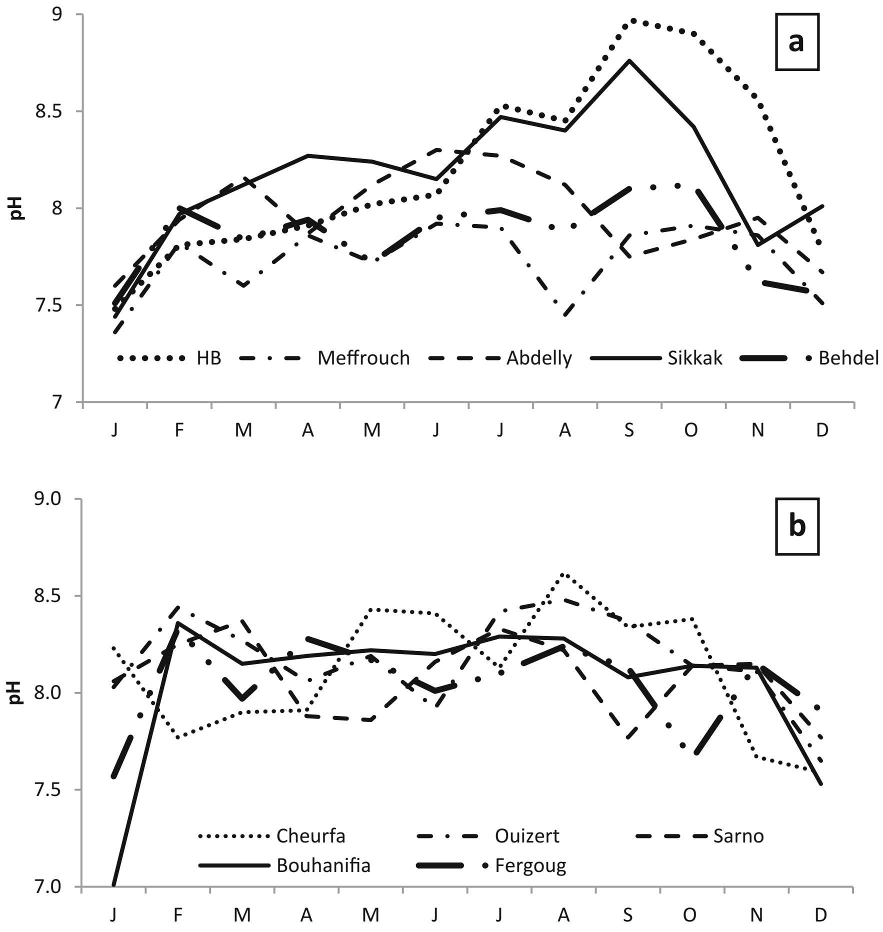


Fig. 4 pH spatial variations at (**a**) Tafna and (**b**) Macta dams

and BB (1–6 mg L^{-1}; Avg., 2.8 mg L^{-1}; SD, 1.5 mg L^{-1}) (Fig. 7e). The maximum content (35 mg L^{-1}) was recorded at HB during July.

In Macta watershed NO_3^- ions were found with the following concentrations: Cheurfa (1–20 mg L^{-1}; Avg., 9.3 mg L^{-1}; SD, 7.2 mg L^{-1}) (Fig. 8a), Ouizert (1–18 mg L^{-1}; Avg., 8.8 mg L^{-1}; SD, 6.7 mg L^{-1}) (Fig. 8c), Fergoug (1–9 mg L^{-1}; Avg., 4.6 mg L^{-1}; SD, 2.6 mg L^{-1}) (Fig. 8a), Bouhanifia (1–8 mg L^{-1}; Avg., 4.1 mg L^{-1}; SD, 2.4 mg L^{-1}) (Fig. 8b), and Sarno (1–11 mg L^{-1}; Avg., 3.3 mg L^{-1}; SD, 2.8 mg L^{-1}) (Fig. 8e).

Nitrites and ammonium ions were also present with concentrations varying from 0.01 to 2.1 mg L^{-1} and 0.06 to 4.46 mg L^{-1}, respectively (Figs. 7a–e and 8a–e). In Macta watershed, the concentration of NH_4^+ was at a maximum at Cheurfa dam during November. However, the values of this parameter were lower than those obtained in HB dam where NH_4^+ contents were between 0.07 and 4.46 mg L^{-1}(Avg.,

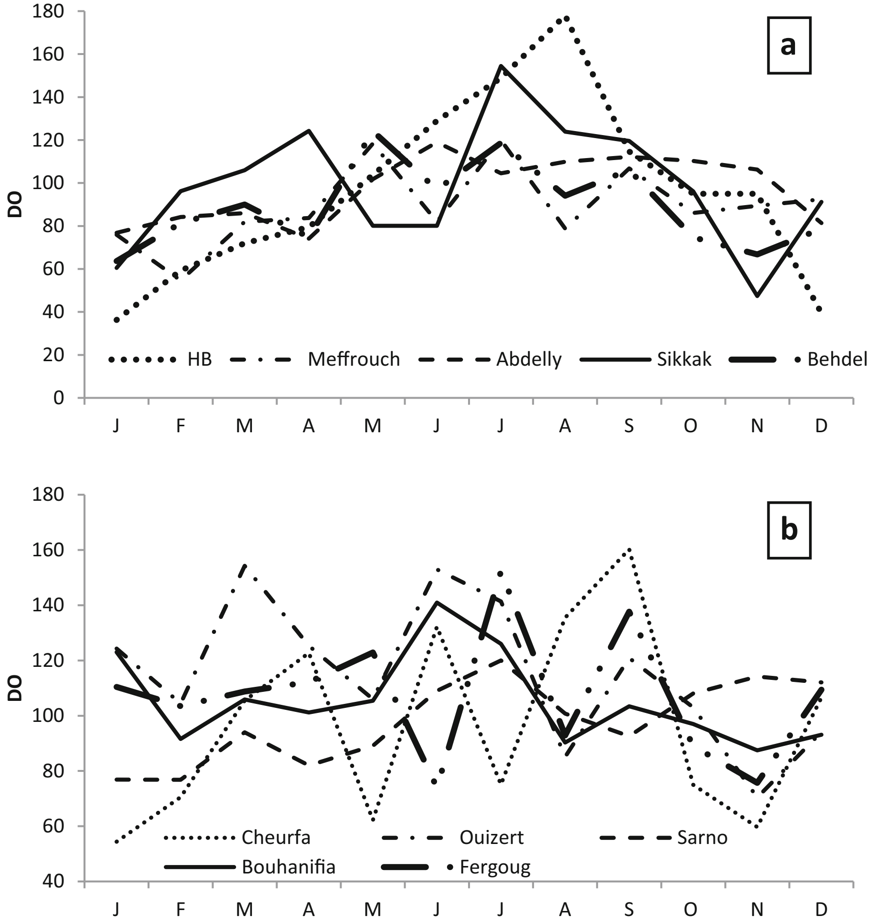


Fig. 5 DO spatial variations at (**a**) Tafna and (**b**) Macta dams

1.73 mg L^{-1}; SD, 1.71 mg L^{-1}). The highest values were recorded in HB dam during the first semester (Fig. 7d). Ammonium concentrations lowered during the sampling period inversely to pH values. These two parameters are negatively and well correlated ($r = -0.7$). The same situation was observed at SA with a correlation coefficient of −0.63.

3.1.5 Orthophosphates (PO_4^{3-})

At Tafna watershed, the maximum PO_4^{3-} concentration values ranging between 0.1 and 1.86 mg L^{-1} (average: 1.01 mg L^{-1}) were found at HB dam. The maximum value was recorded during March in the aforementioned dam. In the other dams belonging to Tafna watershed, PO_4^{3-} contents were less than 0.16 mg L^{-1} with

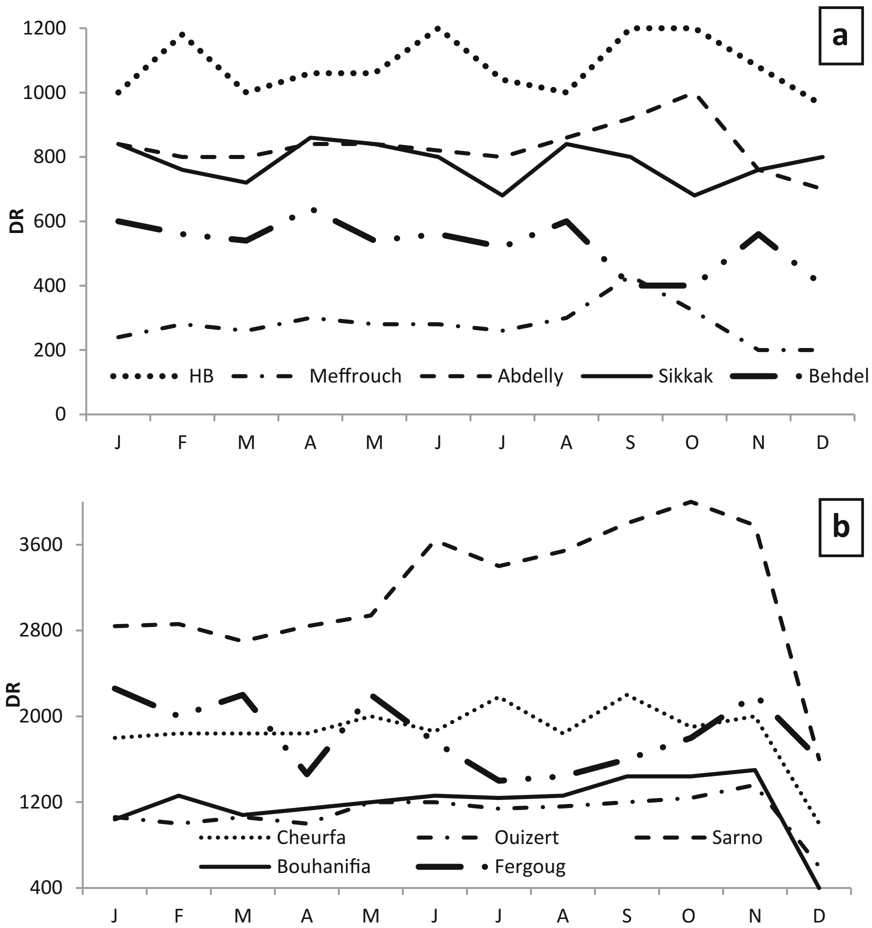


Fig. 6 DR spatial variations at (**a**) Tafna and (**b**) Macta dams

values ranging from 0.05 to 0.15 mg L^{-1} (average, 0.08 mg L^{-1}) at Meffrouch, 0.05 to 0.19 mg L^{-1} (average, 0.09 mg L^{-1}) at SA, 0.06 to 0.16 mg L^{-1} (average, 0.11 mg L^{-1}) at Sikkak, and 0.02 to 0.12 mg L^{-1} (average, 0.07 mg L^{-1}) at BB (Fig. 7a–e).

As for Macta, PO_4^{3-} concentration values recorded at Cheurfa dam were between 0.22 and 1.16 mg L^{-1} (average: 0.71 mg L^{-1}) (Fig. 8a–e). The yearly average PO_4^{3-} concentration values for the other dams were less than 0.71 mg L^{-1}; the calculated averages were 0.15, 0.13, 0.11, and 0.09 mg L^{-1} for Fergoug, Ouizert, Bouhanifia, and Sarno dams, respectively. The presence of phosphates in water dams is due to domestic wastewater discharges, particularly those containing detergents, fertilizer runoff, and industrial effluents.

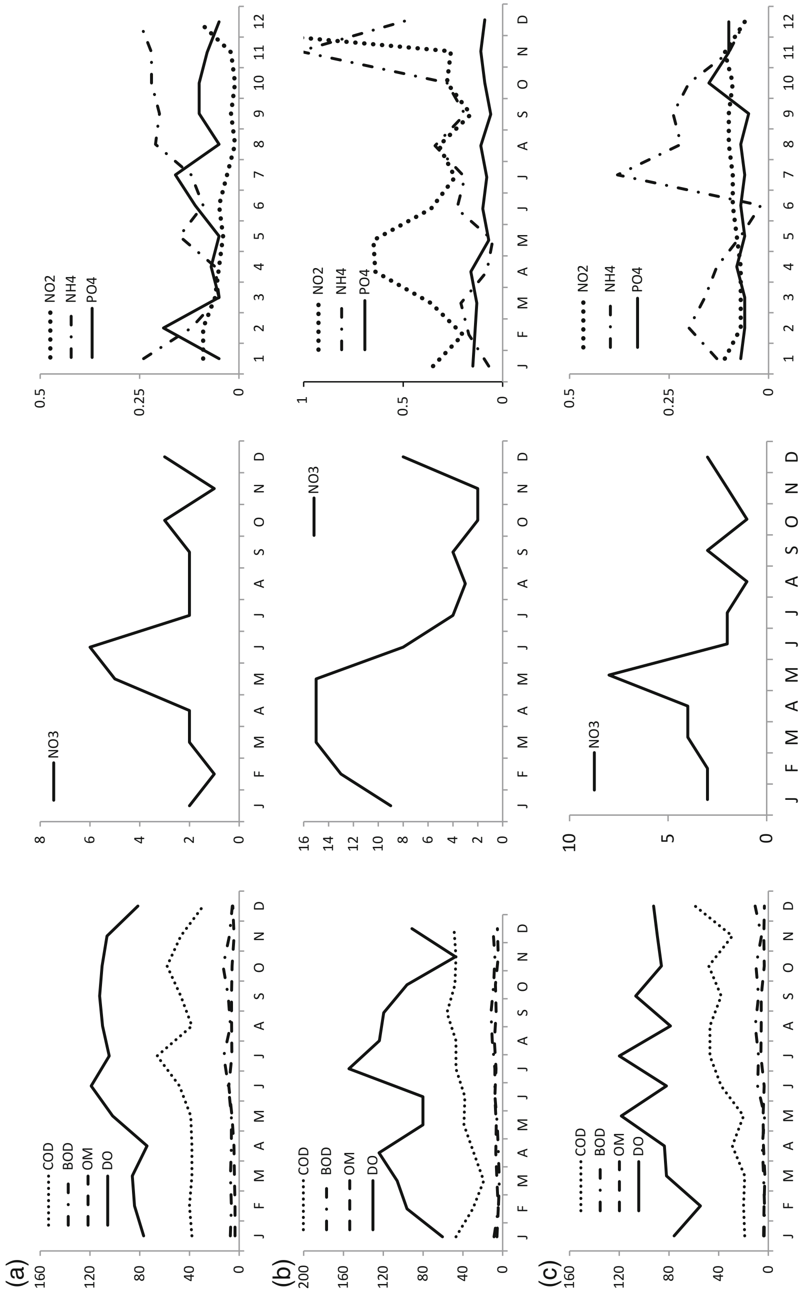


Fig. 7 Variations of organic parameters of **(a)** SA dam, **(b)** Sikkak dam, **(c)** Meffrouch dam, **(d)** Boughrara dam, **(e)** BB dam

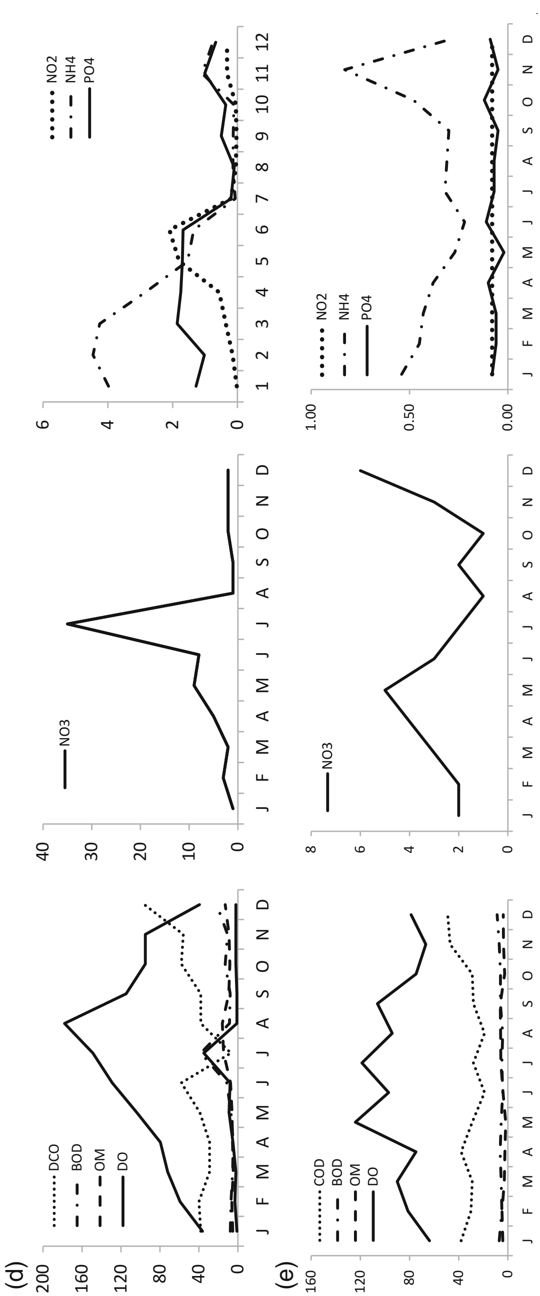


Fig. 7 (continued)

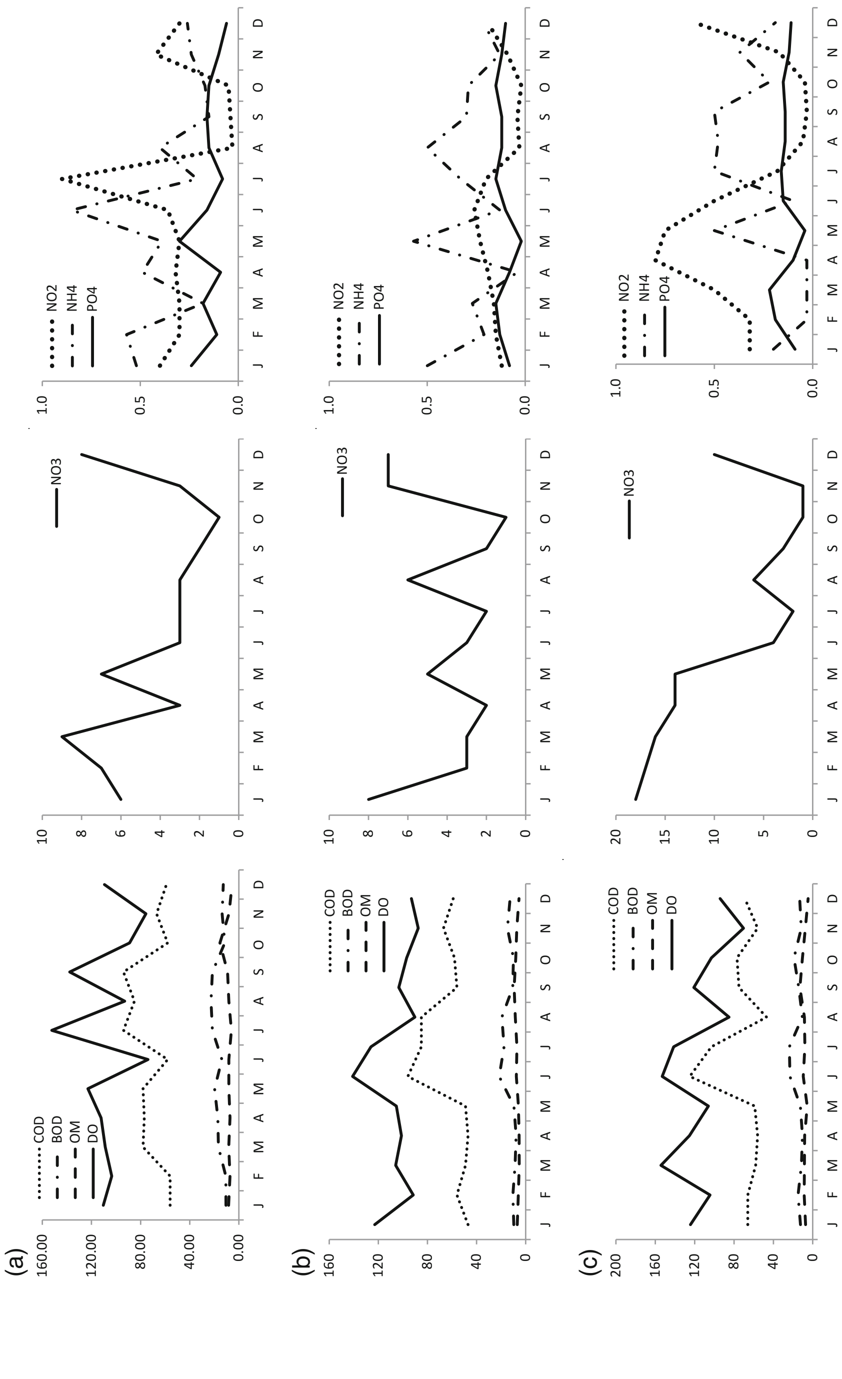


Fig. 8 Variations of organic parameters of **(a)** Fergoug dam, **(b)** Bouhanifia dam, **(c)** Ouizert dam, **(d)** Cheurfa dam, **(e)** Sarno dam

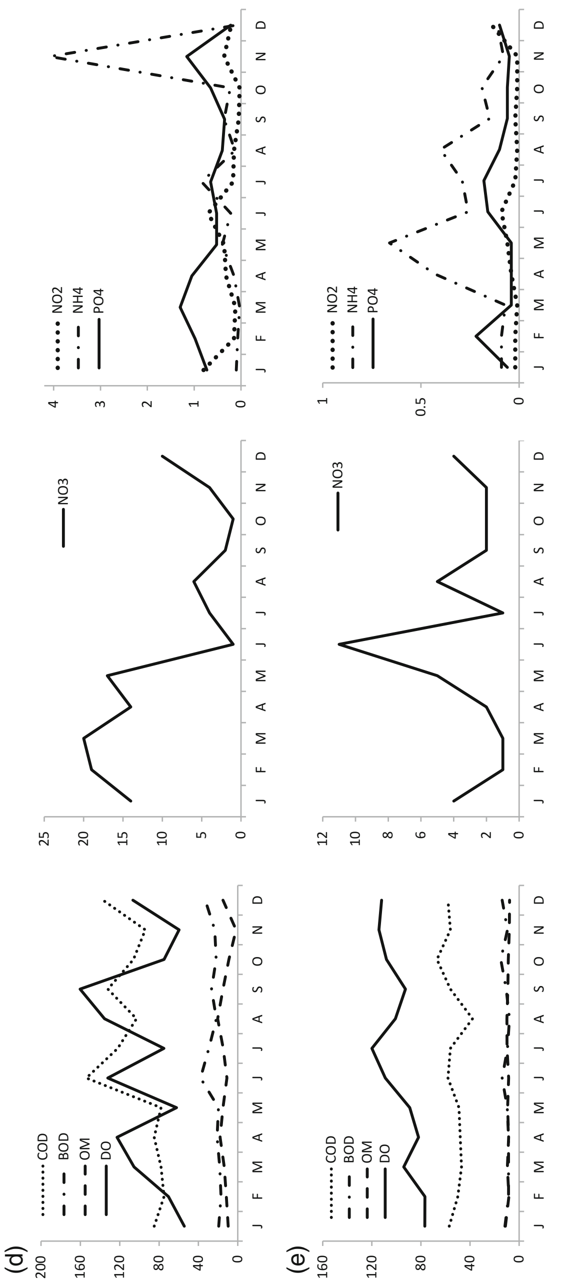


Fig. 8 (continued)

Table 4 Classes of parameters allowing the OPI calculation

Classes	BOD_5 (mg L^{-1})	Ammonium (mg L^{-1})	Nitrites (μg L^{-1})	Phosphates (μg L^{-1})
5	<2	<0.1	5	15
4	2–5	0.1–0.9	6–10	16–75
3	5.1–10	−2.4	11–50	76–250
2	10.1–15	2.5–6.0	51–150	251–900
1	>15	>6	>150	>900

3.2 Water Pollution

To understand the overall evolution of organic water pollution and the biodegradable matter proportion, we have calculated the organic pollution index (OPI) developed by [30] and the COD/BOD_5 ratio.

The principle of the OPI is to divide the pollutant values into five classes (Table 4), then to determine, from its own measurements, the corresponding class number for each parameter, and then to average it.

The limits of the OPI classes are as follow [30]:

5.0–4.6: no organic pollution

4.5–4.0: low organic pollution

3.9–3.0: moderate organic pollution

2.9–2.0: strong organic pollution

1.9–1.0: very strong organic pollution

The calculated OPI values for the ten dams during the study period indicated, generally, moderate to strong pollution. OPI values of SA (OPI, 3–3.75; average, 3.3), Meffrouch (OPI, 3.0–3.5; average, 3.25), and BB (3.0–3.5; average, 3.2) dams show that organic pollution is moderate. As for Sikkak (OPI, 2.5–3.25; average, 2.8), pollution is considered to be moderate from January to April and strong during the remainder of the year (Table 3, Figs. 9a and 10). Among the Tafna dams, HB dam water is the most polluted one. Calculated OPI values show a strong to very strong (March, July, and November) pollution.

Water of Fergoug (2–3.25; average, 3.25), Ouizert (2.25–3.0; average, 2.1), Cheurfa (OPI, 1.25–2.50; average, 2.6), and Bouhanifia (OPI, 2.25–3.25; average, 2.8) dams is generally strong polluted compared to that of Sarno dam (2.75–4.00; average, 3.40) which reveals a strong pollution during May and December months and moderate to low during the rest of the year (Table 3, Figs. 9b and 10).

Calculated COD/BOD_5 ratios vary between 3.7 and 7.2 (Table 5) and were greater than 3. They revealed that all waters are more or less difficult to biodegrade in the study dams. Water with BOD_5 levels greater than 10 mg/L are considered to be polluted and less than 4 mg L^{-1} to be reasonably clean [31].

In Macta watershed BOD_5 values were, in general, above 10 mg L^{-1} and can be considered to be polluted. As for Tafna dams, they generally vary between 4.8 and 21.6 mg L^{-1} and were more or less polluted except for Meffrouch (in January, February, March, and May) and Sikkak (in March) dams where BOD_5 contents were less than 4 mg L^{-1}.

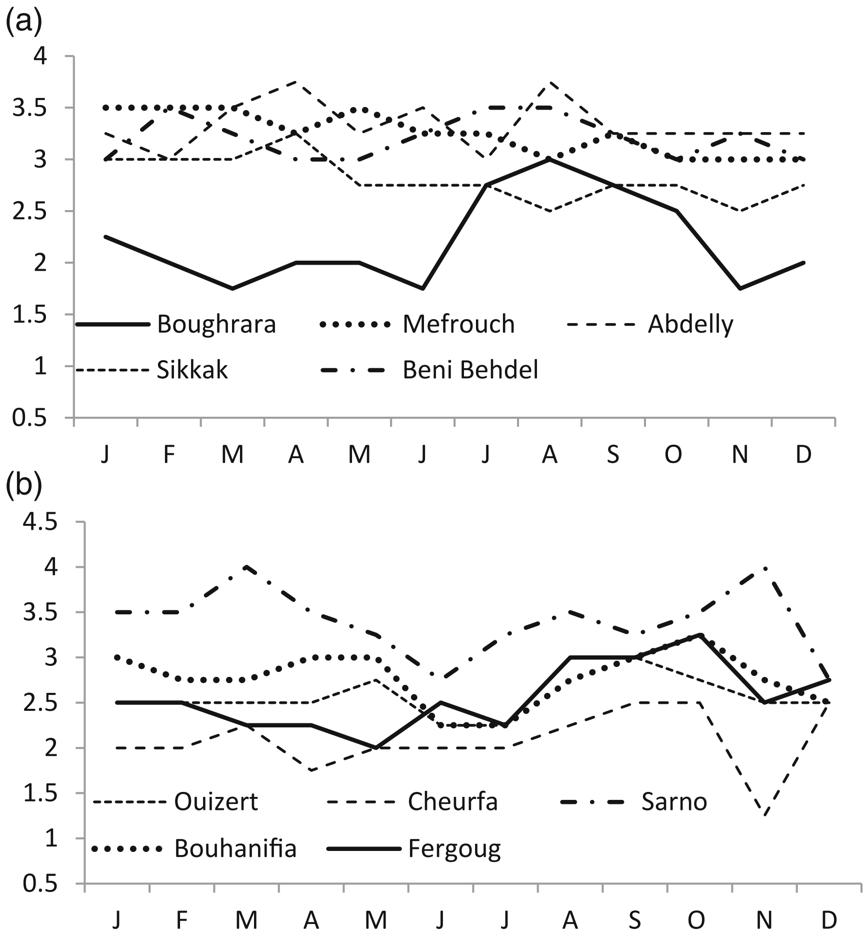


Fig. 9 OPI variation of (**a**) Tafna dams and (**b**) Macta dams

4 Conclusions

In this study, surface water quality data for 14 parameters collected from the monitoring of 10 dams located within two northwestern Algerian watersheds (Macta and Tafna) were monthly analyzed during 1 year (2003). The waters of all dams were alkaline, with pH values ranging between 7.01 and 8.97. The highest DR contents were found at Macta watershed. The maximum yearly average (3,161.7 mg L^{-1}) was recorded at Sarno dam located upstream of the confluence of Mekerra and Sarno wadis. In the other Macta dams, yearly averages were between 1,101.7 and 1,858.3 mg L^{-1}. Tafna watershed registered lesser contents varying between 279.2 mg L^{-1} at Meffrouch dam and 1,081.7 mg L^{-1} at HB.

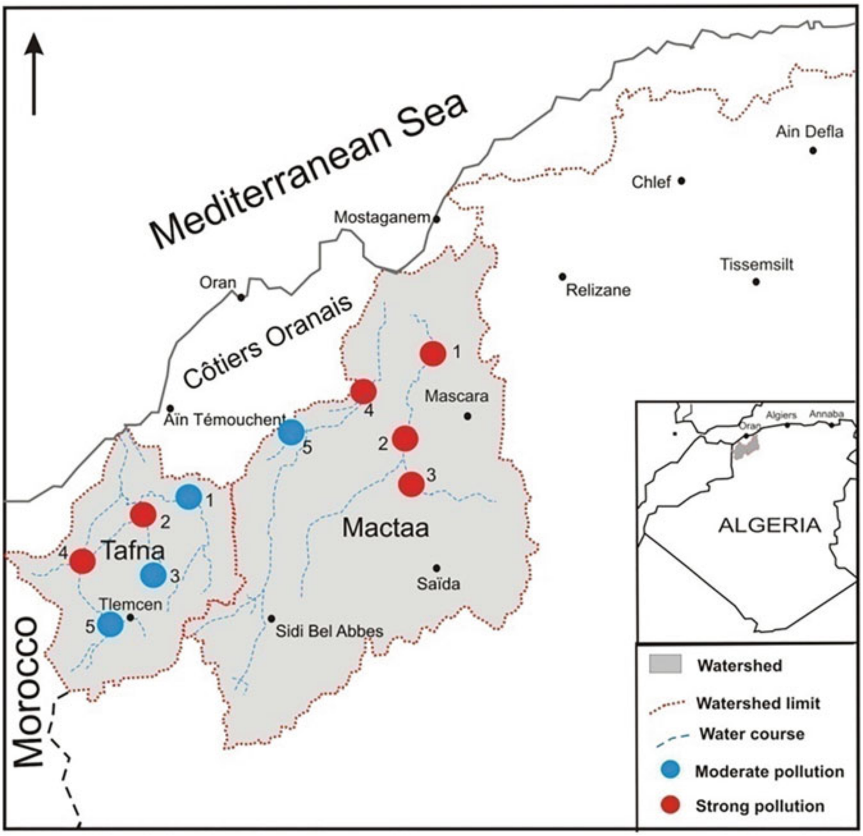


Fig. 10 Spatial variation of IPO

Table 5 OPI and COD/BOD_5 values of water of Tafna and Macta dams

Dam	OPI	COD/BOD_5	Pollution class
SA	3–3.75	4.5–6.2	Moderate
Sikkak	2.5–3.25	4.5–7.2	Moderate to strong
Meffrouch	3–3.5	4.5–6.7	Moderate
Boughrara	1.75–3	4.4–5.7	Moderate to strong
BB	3–3.5	4.5–6.7	Moderate
Fergoug	2.0–3.25	3.7–5.3	Moderate to strong
Bouhanifia	2.25–3.0	4.4–6.0	Moderate to strong
Ouizert	2.50–3.0	4.1–5.7	Strong to very strong
Cheurfa	1.25–2.50	4.0–4.9	Strong to very strong
Sarno	2.75–4.0	4.2–5.7	Weak to strong

As for BOD_5, COD, and MO average contents, they were maximum at Cheurfa (BOD_5, 24.1 mg L^{-1}; COD, 104 mg L^{-1}; 12.9 mg L^{-1}) and HB (BOD_5, 11.9 mg L^{-1}; COD, 43.8 mg L^{-1}; OM, 8.8 mg L^{-1}) dams and minimum at Sarno (BOD_5, 10.6 mg L^{-1}; COD, 53.3 mg L^{-1}; 12.9 mg L^{-1}) and Bouhanifia (MO, 6.9–10.6 mg L^{-1}) in Macta watershed and BB (BOD_5, 5.8 mg L^{-1}; COD, 31.9 mg L^{-1}; 4.0 mg L^{-1}).

The calculated organic pollution index values during the study period evidenced the pollution state of the dams. They indicated moderate to very strong pollution in the water of the two watersheds. In Tafna dams, OPI averages of SA, Meffrouch, and BB dams, exhibited moderate organic pollution. As for Sikkak, pollution is considered to be moderate from January to April and strong during the remainder of the year. Water of HB was strongly to very strongly polluted.

Waters of Fergoug, Ouizert, Cheurfa, and Bouhanifia dams were generally strongly polluted except that of Sarno dam, which indicated a strong pollution only during May and December months. Indeed, water of the two watersheds was more or less difficult to biodegrade.

5 Recommendations

To ensure good water quality in order to preserve dams against pollution, several measures must be taken.

Following the observations made during the processing of the acquired information, it is important to frequently analyze other water parameters at watershed and dams, such as heavy metals, to get more information and to identify the emerging water quality issues and the extent to which existing criteria and recommendations can address these problems.

More accurate monitoring is recommended for watercourses, and setting up of mandatory regulations for polluters by requiring them to clean their wastewater by sewage treatment plants before pouring them into streams is needed.

Necessary measures must be taken to avoid the eutrophication of the dams which is the consequence of the poor quality of water and the presence of pollution.

It is also important to create treatment plants for each dam inlet regardless of the destination of these waters, as it is necessary to adjust the treatment in relation to the water quality and according to their uses.

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Part II
Treatment and Protection

Wastewater Reuse for Irrigation Purposes: The Case of Aïn Témouchent Region

Fatiha Hadji, Fatima Sari, and Abderrahmane Khiat

Contents

Abstract The objective of this work concerns the characterization of wastewater and purified water of Aïn Témouchent wastewater treatment plant (WWTP) which uses an activated sludge treatment process. A quality parameter monitoring of the collected domestic effluents made it possible to characterize these waters. The analyses included temperature, pH, suspended matter (SM), dissolved oxygen (DO), chemical (COD) and biochemical (BOD_5) oxygen demands, turbidity, total

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nitrogen (TN), total nitrogen Kjeldahl (TNK), nitrites (NO_2^-), nitrates (NO_3^-), ammonium (NH_4^+), total phosphorus (TP), and orthophosphates (PO_4^{3-}).

Although heavily loaded with organic matter, wastewaters drained to the WWTP have COD/BOD_5 ratios indicating satisfactory biodegradability of the organic pollutants.

Comparison of the analyzed parameters with the standards of the Official Journal of the Algerian Republic (JORA) shows that cleaned water can be safely discharged into the natural environment. These parameters are also consistent with the JORA and WHO wastewater reuse standards for irrigation purposes.

Keywords Activated sludge, Clean water, Irrigation, Quality, Reuse, Wastewater, WWTP

1 Introduction

Surface water, groundwater, and soil qualities are one of the most severe matters of concern, and the most exposed water bodies to pollution are rivers because they are the discharge medium of industrial and municipal wastewater. The release of such unregulated wastewater has severely deteriorated such aquatic environment and has caused immense environmental problems not only to the environment but also to human beings [1].

Anthropogenic effects like municipal waste discharge and agricultural and industrial activities play a major role in determining the surface water quality in a given region [2, 3], and the application of regulations or standards becomes indispensable if not mandatory to reduce and prevent pollution [4]. Nowadays existing treatments can reduce the pollutant concentrations to nonhazardous levels and make it possible to obtain water of better quality from wastewater, thanks to the existing treatment processes. The treatment and disposal of wastewater do not only minimize environmental impacts but also can be used for irrigation purposes and in uses that do not require drinking water (e.g., recreational activities, industrial uses, aquifer recharge, firefighting, aquaculture, domestic uses, etc.) [5–14]. For example, water with a high BOD_5 and COD when released into the natural water bodies destroys the water quality that may support aquatic life [1] and then DO decreases.

The reuse of treated wastewater in agricultural irrigation has become a constraint especially in semiarid and arid regions in terms of quantity and from the contained nutrient benefits [15]. It allows the conservation of nutrients reducing the need for artificial fertilizers [16].

To face the water scarcity and the environmental deterioration, Algeria has become aware of the urgent need for the construction of sewage treatment infrastructures. Among the treatment plants operated by ONA (National Sanitation Office) through Algeria, some are concerned with the reuse of treated wastewater in agriculture. This chapter aims to monitor the quality of raw and purified wastewater of Aïn Témouchent WWTP and to compare them with the Official Journal of the Republic of Algeria (JORA) [17] standards for effluent discharges and that of the WHO [18] for wastewater reuse for irrigation purposes.

2 Material and Methods

To characterize wastewater (at the entrance) and cleaned water (at the exit) of the WWTP of Aïn Témouchent, physical and chemical analyses were carried out at the WWTP laboratory. These analyses allowed us the knowledge of the nature of the existing polluting loads in water and its variations. The samplings were done weekly and fortnightly during July 2016–March 2017 period. The physicochemical parameters, to be checked, are for weekly analyses the temperature, the dissolved oxygen, the electrical conductivity, pH, suspended matter (SM), and turbidity.

The parameters monitored bimonthly were chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), nitrogen forms (total nitrogen, nitrate, nitrite and ammonium), total Kjeldahl nitrogen (TKN), and phosphorus (total phosphorus "PT" and phosphates "PO_4^{3-}").

The sampling was done by an automatic sampler RPS20 with multi-fixed flasks (24) allowing the realization of an automated sampling as a function of the flow during the considered period (24 h). The samples are therefore mixed and homogenized to form the average sample before being transferred to the vials for analysis.

Measurements of temperature (T), pH, and electrical conductivity (EC) were made using an MM41 multimeter and dissolved oxygen (DO) by an O_2 meter which probe is introduced into a 600 ml beaker containing the water sample. The result to be marked is the value recorded on the display of the device after stabilization.

Determination of suspended matter was performed by the filtration method, and turbidity which is an indication of the presence of suspended particles in the water was determined using a turbidimeter.

BOD_5 was determined using an OxiTop measurement system. This system is more practical, is fast, and gives representative results. The determination of the COD was carried out by colorimetric determination with the potassium dichromate. Total phosphorus analysis was carried out by the LANGE LCK (348/350) vial test and total nitrogen by the LATON LCK (138/338) vial test.

The WWTP with a capacity which is expected to treat the pollution of more than 82,000 equivalent inhabitants and an inflow of 10,920 $m^3\ d^{-1}$ is intended to intercept and to purify domestic wastewater of 72,800 inhabitants. It is based on a low-load activated sludge biological process, i.e., process used for the treatment of domestic effluents that dominates small and medium communities. It has been selected to treat the carbon, nitrogen, and phosphorus feedstock, and the sludge is thickened and dewatered on a belt filter and drying bed.

3 Results and Discussions

In order to characterize the treated water and to control its quality with regard to its use for irrigation purposes, monitoring of physical and chemical parameters was carried out at the entrance and the exit of the studied WWTP during the years 2016 and 2017. All the results of the analysis presented here have dealt with the temperature, the pH, the conductivity (EC), the dissolved oxygen (DO), suspended matter (SM), biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonium (NH_4^+), nitrates (NO_3^-), nitrites (NO_2^-), total phosphorus (TP), and phosphates (PO_4^{3-}).

The maximum, minimum, average standard deviation values of the analyzed parameters for raw and purified wastewater are summarized in Table 1.

3.1 Water and Air Temperatures

At the entrance of the WWTP, the water temperature values of wastewater are between 6 and 19°C (average, 12.4°C; SD, 4°C) (Table 1), and at the outlet, they vary slightly from that of wastewater between 6 and 21°C (average, 12.7°C; SD, 4°C) (Table 1). The lowest temperature value was recorded during January and the highest one in August (Fig. 1). The highest values were observed during the warm season and the lowest one during the wet season.

Water temperature is an important factor in the aquatic environment that governs almost physical, chemical, and biological reactions. The values taken by the temperature are in a range favorable to the microbial activity (<30°C). This promotes biological purification and self-purification of wastewater.

Also, the air temperature average at the WWTP was 19.8°C (SD, 6°C). Its values oscillate between 8°C (January) and 28.5°C (August) (Fig. 2) during the study period.

Figure 2, representing water and air temperature variations, shows that these two parameters are intimately linked. This dependence is well evidenced by a correlation coefficient of 0.78.

The recorded wastewater temperature values are all below 30°C considered as the limit value for direct discharge into the receiving medium according to JORA.

3.2 pH

The role of pH is crucial for the growth of microorganisms and is an important parameter for the interpretation of corrosion in the pipelines of WWTPs. On the other hand, a temperature increase, decreasing the pH, participates in the acidification of the medium or conversely.

Table 1 Physical and chemical parameters of raw and treated wastewater

	Raw wastewater				Treated wastewater				JORA 2006	WHO 2012
Parameters	Min	Max	Average	SD	Min	Max	Average	SD		
T air (°C)	8	28.5	19.8	6	–	–	–	–	–	–
T water (°C)	6	19	12.4	4	6	21	12.7	4	30	–
pH	6.17	10.6	7.9	1	6.27	10.8	7.9	1	6.5–8.5	6.5–8.5
EC (μS cm^{-1})	1,240	2,730	1,870	295	1,460	2,550	1,755	239	–	<3,000
SM (mg L^{-1})	84	464	177	69	2	17	8.5	4	35	100–350
Turbidity (NTU)	80	395	166	65.4	3.11	19	8	4.1	–	–
DO (mg O_2 L^{-1})	0.46	4.46	1.84	1	6.49	9.63	8.43	0.6	–	–
BOD_5 (mg O_2 L^{-1})	130	480	226.4	74	2	8	4.9	1	30	110–400
COD (mg O_2 L^{-1})	243	628	409	98.8	18.7	43	26.5	7	120	–
TKN (mg L^{-1})	31.81	79.42	50.5	12.3	3.01	11.6	7.7	2.4	30	20–85
PT (mg L^{-1})	3.96	9.3	5.4	1.4	1.09	4.86	3	1.1	10	6–20
NO_3^- (mg L^{-1})	0.57	1.07	0.7	0.12	5.43	10.7	8.1	1.5	–	–
NO_2^- (mg L^{-1})	0.073	0.7	0.2	0.2	0.011	0.16	0.1	0.6	–	–
NH_4^+ (mg L^{-1})	19.35	64.37	39	10	2.21	2.9	1.1	0.6	–	–
PO_4^{3-} (mg L^{-1})	2.79	6.4	4.1	1.3	2.97	6.4	2.8	1.2	–	–

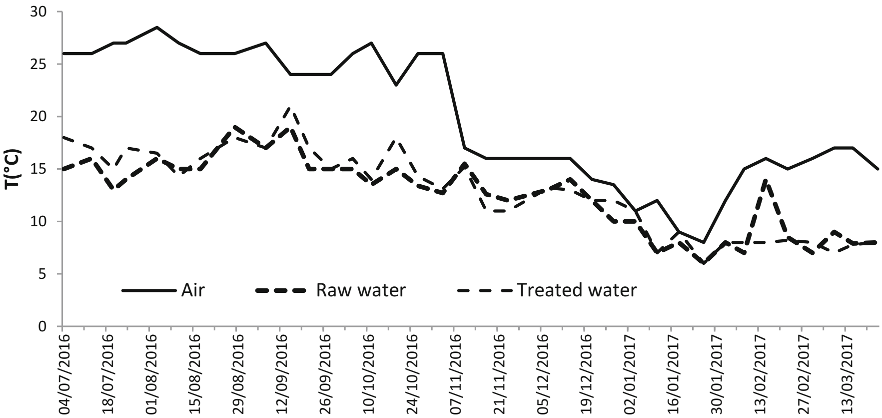

Fig. 1 Temporal variations of air and raw and treated wastewater temperatures

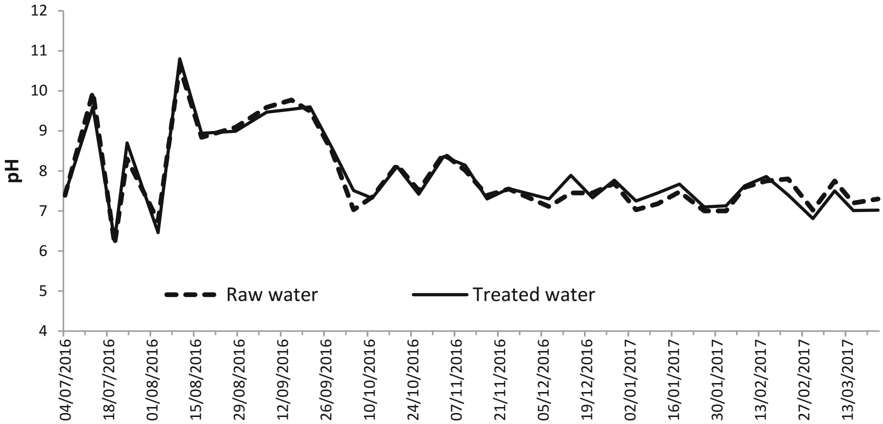

Fig. 2 Temporal pH variations of raw and treated wastewater

Figure 2 shows the pH variations of the wastewater at the inlet and outlet of the WWTP. The recorded pH values range from 6.17 to 10.6 (Table 1) for raw water and from 6.27 to 10.8 for treated water (Table 1) with an average of 7.9 and a standard deviation of 1. The pH values of treated water are, in general, within the range (6.5 and 8.4) of the JORA direct release limits. These values are also in line with the irrigation water standards advocated by the WHO for the reuse of wastewater.

3.3 Electrical Conductivity (EC)

The purpose of the EC measures is to control the quality of the wastewater; it reflects the degree of overall mineralization and tells us about the water salinity [19]. Its measurements can be used to monitor the processes in wastewater treatment that causes changes in conductivity such as biological phosphorus and nitrogen removal [20].

The EC results (Table 1 and Fig. 3) show that wastewater in the study WWTP is strongly mineralized with values varying between 1,240 and 2,730 μS cm^{-1} (average, 1,870 μS cm^{-1}; SD, 295 μS cm^{-1}) at the WWTP entrance. Treated water also shows higher values ranging from 1,460 to 2,550 μS cm^{-1} (average, 1,755 μS cm^{-1}; SD, 239 μS cm^{-1}). The lowest EC values were observed in February and coincide with periods of rainfall. This decrease is therefore most likely due to the dilution effect.

The comparison of the analyzed water conductivity values with the WHO water quality standards for irrigation is used to infer that this wastewater is acceptable for crop irrigation (low to moderate restriction).

3.4 Suspended Matter (SM)

The suspended matter is involved in the composition of water through its effects of ion exchange or absorption of trace elements as well as on microorganisms [21]. When water is treated, various viruses and bacteria can be attached to and migrate along with the solid particles; the elimination of suspended solids is related to the elimination of germs [22].

SM concentrations of the raw water recorded during the study period range from 84 to 464 mg L^{-1} with an average of 177 mg L^{-1} and a standard deviation of 69 mg L^{-1}.The maximum SM values were recorded in November for raw water, i.e., during the wet season (Fig. 4).

At the entrance of the WWTP, the levels in SM are very important. After purification, they decrease (Fig. 4) to reach concentrations between 2 and

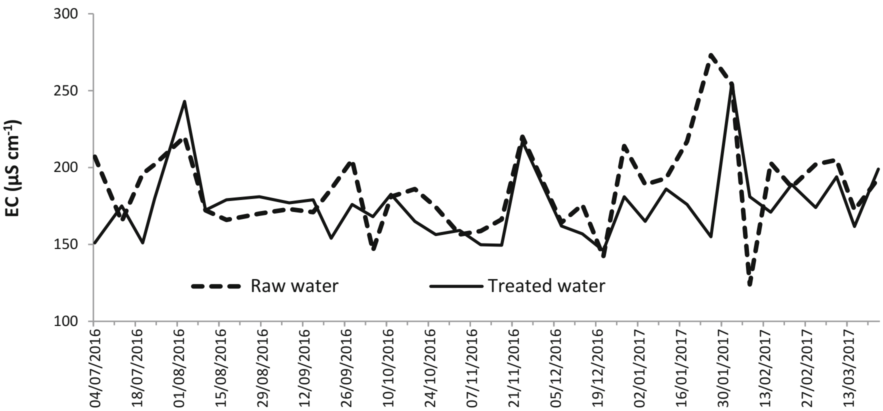

Fig. 3 Temporal EC variations of raw and treated wastewater

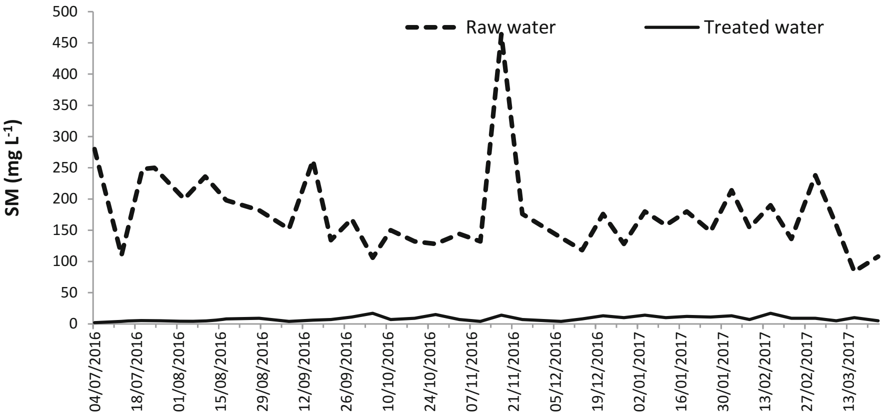

Fig. 4 Temporal SM variations of wastewater and treated water

17 mg L^{-1} with an average of 8.5 mg L^{-1} and a standard deviation of 4 mg L^{-1} (Table 1).

Being less than 35 mg L^{-1}, treated water is considered to be within the standard limit for the receiving environment according to JORA. Similarly, these values are below the lower limit of the standard (100–350 mg L^{-1}) recommended by the WHO for the reuse of wastewater in crop irrigation.

3.5 Turbidity

A high level of turbidity can lower the soil permeability and in turn pollute the soil surface through surface flow [23, 24] and can affect the performance of the irrigation facilities. In raw and cleaned water, turbidity values vary from 80 to 395 NTU (average, 166 NTU; SD, 65.4 NTU) and from 3.11 to 19 NTU (average, 8 NTU; SD, 4.1 NTU), respectively (Fig. 5).

3.6 Dissolved Oxygen (DO)

The dissolved oxygen levels in WWTP raw wastewater (Table 1) range from 0.46 mg O_2 L^{-1} (August) to 4.46 mg O_2 L^{-1} (January) with an average of 1.48 mg O_2 $L^{-1}$and a standard deviation of 1 mg O_2 L^{-1} (Fig. 6). For treated wastewater, DO content increases compared to that of wastewater. Its values are between 6.49 and 9.63 mg O_2 L^{-1}, with an average of 8.43 mg O_2 L^{-1} and a standard deviation of 0.6 mg O_2 L^{-1} (Table 1 and Fig. 6). This increase in DO concentration in waters is explained by the wastewater oxygenation in the aeration basins.

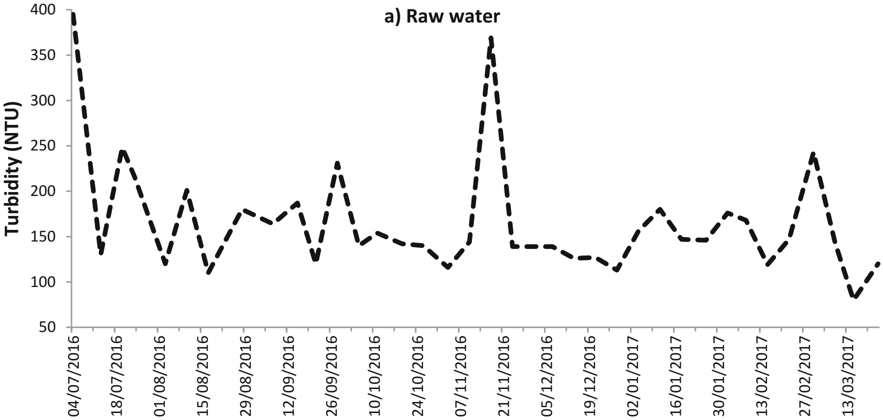

Fig. 5 Temporal turbidity variations of (**a**) raw and (**b**) treated wastewater

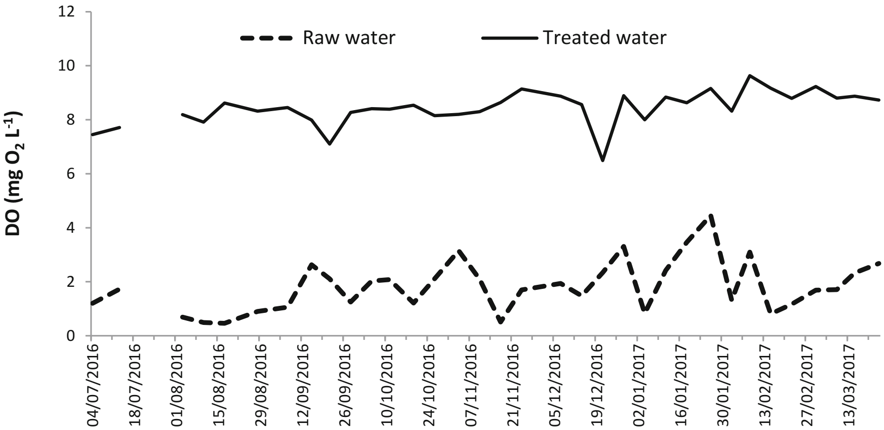

Fig. 6 Temporal DO variations of (**a**) raw and (**b**) treated wastewater

3.7 Biochemical Oxygen Demand for 5 Days (BOD_5) and Chemical Oxygen Demand (COD)

Biological oxygen demand (BOD_5) and/or chemical oxygen demand (COD) analyses are widely used as water quality parameters to assess organic pollutants in water bodies as well as the efficiency of wastewater treatment plants [25, 26].

BOD_5 refers to the amount of oxygen required for the destruction of decomposable organic matter by biochemical processes. It is directly correlated with organic matter in raw sewage [27]. In wastewater, BOD_5values are high. They range from 130 to 480 mg O_2 L^{-1} (average, 226.4 mg O_2 L^{-1}; SD, 74 mg O_2 L^{-1}) (Table 1 and Fig. 7).

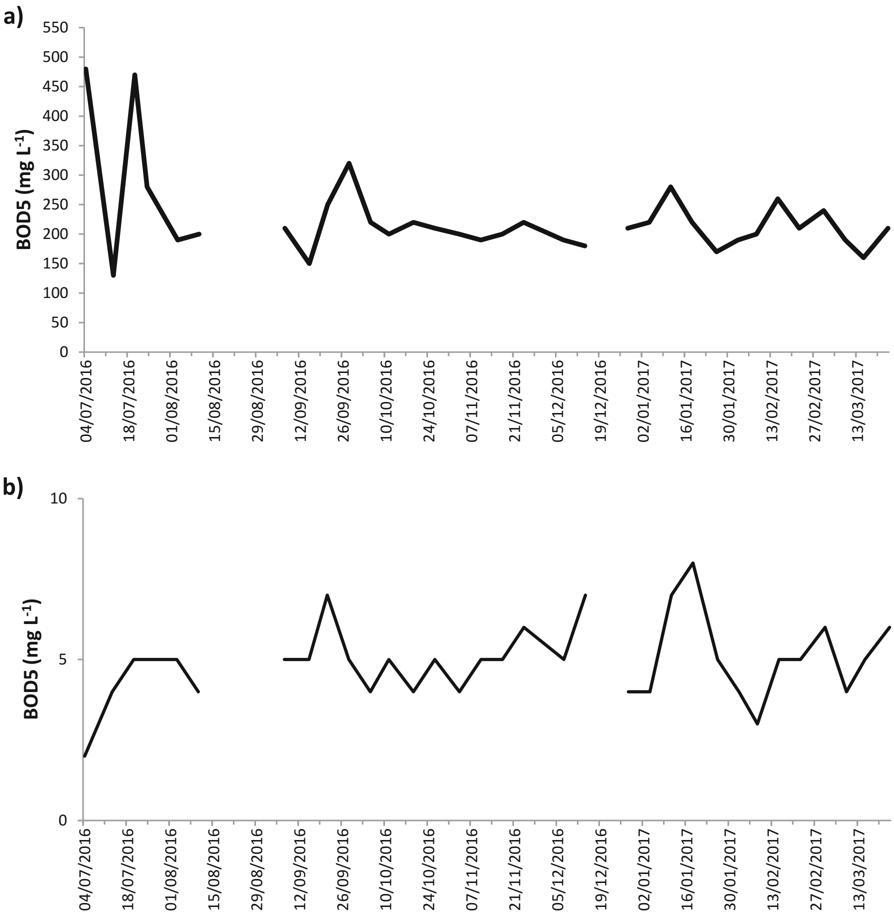

Fig. 7 Temporal BOD_5 variations of (**a**) raw and (**b**) treated wastewater

These results show that water of Aïn Témouchent city is heavily loaded by organic matter and exceed the allowed BOD_5 discharge level (JORA standards) in rivers (35 mg O_2 L^{-1}). This situation could, in general, have adverse effects on water quality if these waters are discharged into watercourses or used for irrigation purposes without prior purification. After purification, the BOD_5 values decrease and range between 2 and 8 mg O_2 L^{-1} (average of 4.9 mg O_2 L^{-1}; SD, 1 mg O_2 L^{-1}) (Table 1 and Fig. 7). They become consistent with the JORA wastewater discharge standard (35 mg O_2 L^{-1}) and are below the WHO lower limit (110–400 mg O_2 L^{-1}) for irrigation wastewater reuse.

COD is used to assess the concentration of organic or inorganic matter, dissolved or suspended in water, through the amount of oxygen required for their total chemical oxidation [28].

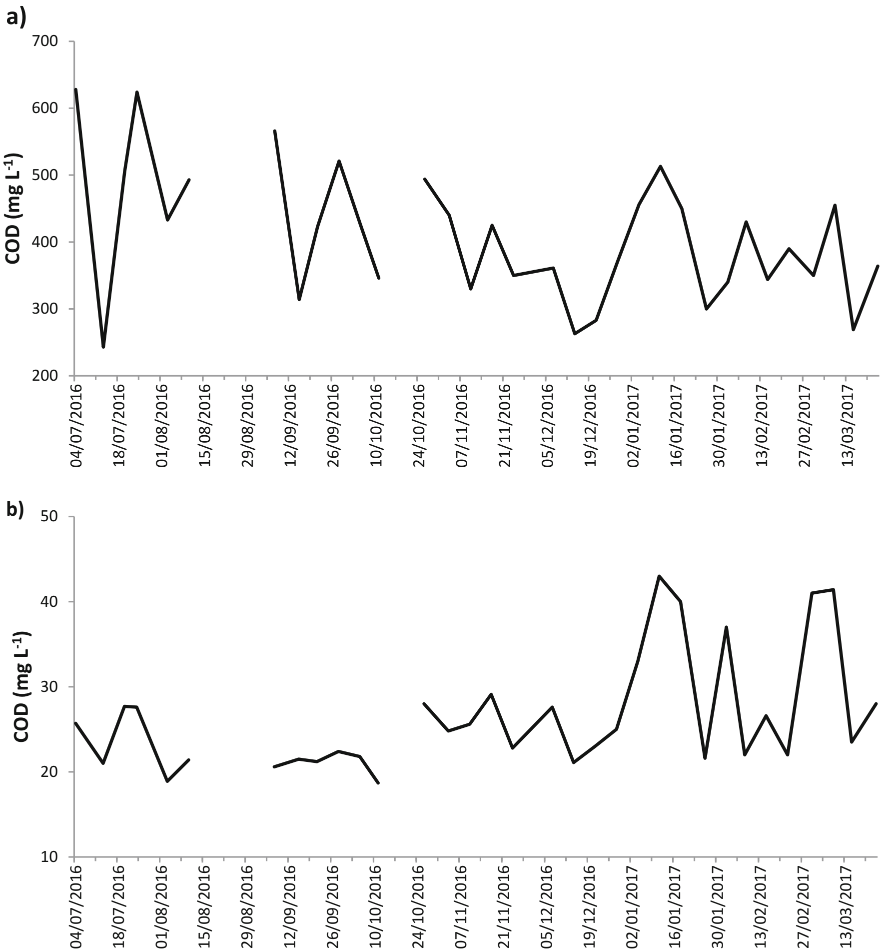

Fig. 8 Temporal COD variations of (**a**) raw and (**b**) treated wastewater

The obtained results show that the COD in water entering the WWTP vary between 243 and 628 mg O_2 L^{-1} in November and July, respectively (Fig. 8) (average, 409 mg O_2 L^{-1}; SD, 98.8 mg O_2 L^{-1}) (Table 1), indicating that Aïn Témouchent city wastewaters are heavily loaded with biodegradable and nonbiodegradable organic matter exceeding the average allowable value of 120 mg O_2 L^{-1} (JORA) authorized in watercourse discharges. This situation could, in general, have adverse effects on water quality due to the drop in oxygen content.

After treatment COD water content decreases sharply (Fig. 8), reaching values between 18.7 and 43 mg O_2 L^{-1} (average, 26.5 mg O_2 L^{-1}; SD, 7 mg O_2 L^{-1}).

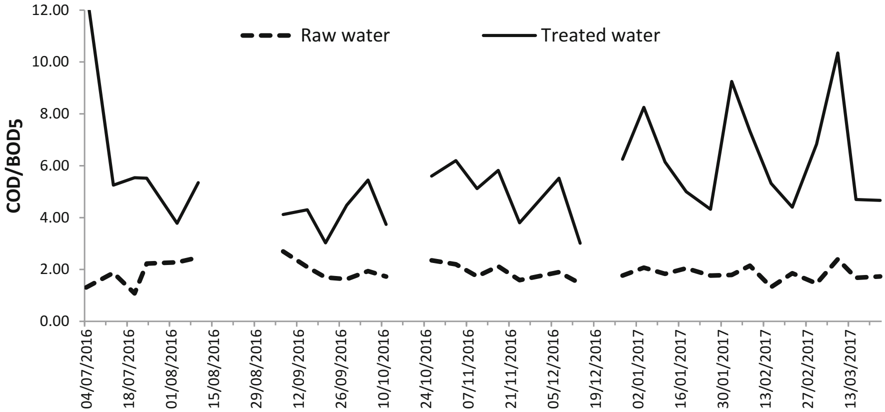

Fig. 9 Temporal COD/BOD_5 variations of raw and treated waters

These value ranges meet the JORA limit of 120 mg O_2 L^{-1} for wastewater discharged into the receiving environment.

The correlation between COD and BOD_5 in wastewater ($r = 0.64$) indicates the presence of biodegradable matter that is easily oxidable [24].

The COD/BOD_5 ratio is a measure of how much easily total biodegradable organic matter is present in the effluent. This biodegradability index is also very useful for monitoring the effectiveness of biological treatments [29].

The following rules are generally used:

– $COD/DBO_5 < 3$ easily biodegradable effluent
– $3 < DCO/DBO_5 < 5$ medium biodegradable effluent
– $DCO/DBO_5 > 5$ effluent and is not readily biodegradable or even nonbiodegradable [29]

Calculated COD/BOD_5 ratio (Fig. 9) varies from 1.08 to 2.70 (average, 1.83) in raw water, indicating that these effluents are easily biodegradable. After treatment, this ratio reaches values varying between 3.03 and 12.85 (average, 5.29), and then effluents remain in general not readily biodegradable.

3.8 *Total Nitrogen*

Nitrogen present in urban wastewater comes mainly from human waste. Urines contribute largely to this intake especially in the form of urea, uric acid, and ammonia. In addition, kitchen waters carry proteins containing amino acids and certain surfactants (detergents, softeners) which include in their molecules nitrogenous radicals [30]. Total nitrogen in the wastewater prior to treatment was from 32.5 to 80 mg L^{-1} (average, 50.6 mg L^{-1}; SD, 12.2 mg L^{-1}) (Fig. 10). The treatment

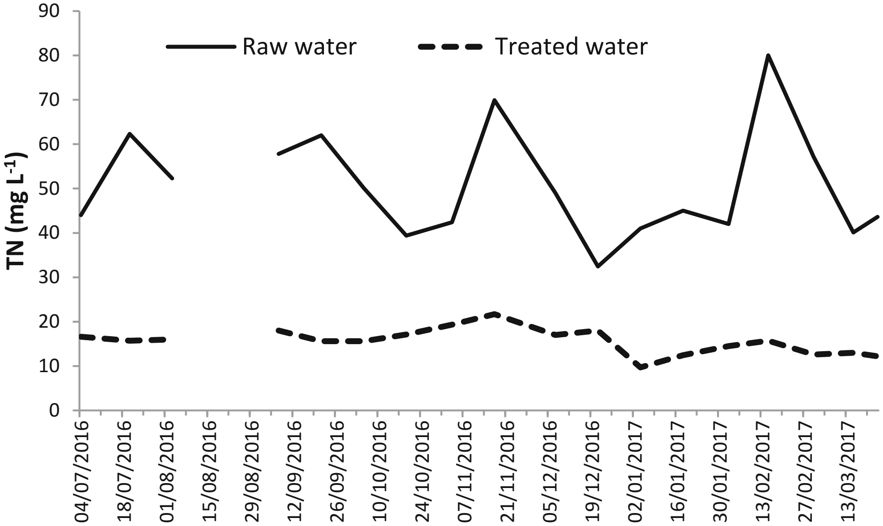

Fig. 10 Temporal TN variations of raw and treated wastewater

requirement had a significant influence on lowering the NT content from 9.7 to 19.4 mg L^{-1} (average, 15.6 mg L^{-1}; SD, 2.9 mg L^{-1}) (Fig. 10).

3.8.1 Total Kjeldahl Nitrogen (TKN)

Kjeldahl nitrogen does not represent all nitrogen but only all of its reduced organic and ammoniacal forms [29]. It is an indicator of environmental pollution, and its control makes it possible to follow the evolution of contaminations [29].

At the WWTP entrance, the NTK oscillates between 31.81 and 79.42 mg L^{-1} (average, 50.5 mg L^{-1}; SD, 12.3 mg L^{-1}). These values were recorded during December and February, respectively, (Fig. 11).

TKN values of treated wastewater are low compared to that of wastewater with contents varying between 3.01 and 11.4 mg L^{-1} (average, 7.7 mg L^{-1}; SD, 2.4 mg L^{-1}) (Table 1 and Fig. 11).

In addition, they are less than 30 mg L^{-1}, considered to be the limit value for direct release into the receiving medium according to JORA and to the lower limit of (20–60 mg L^{-1}) of the WHO standard as for their use for irrigation purposes.

3.8.2 Nitrites (NO_2^-)

Nitrites only started to be analyzed in January 2017. Their concentrations in the wastewater at the WWTP entrance vary between 0.073 and 0.7 mg L^{-1} (Fig. 12), with an average and a standard deviation of 0.2 mg L^{-1} (Table 1). There is not a

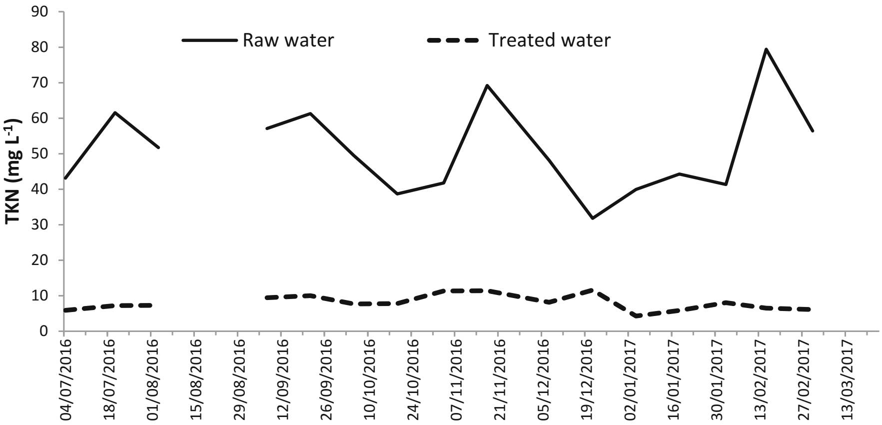

Fig. 11 Temporal TKN variations of raw and treated wastewater

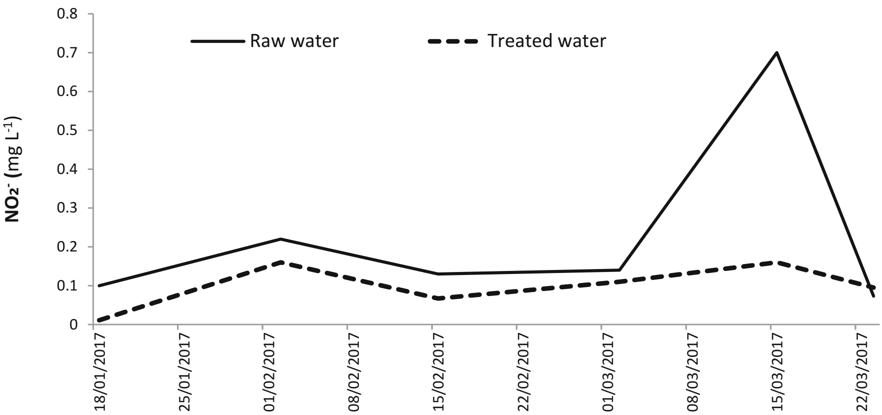

Fig. 12 Temporal NO_2^- variations of raw and treated wastewater

considerable variation in nitrite contents after purification. In cleaned water they range from 0.011 to 0.16 mg L^{-1} (Fig. 12) with an average of 0.1 mg L^{-1} and a standard deviation of 0.6 mg L^{-1} (Table 1).

The low concentrations of nitrite encountered in the studied wastewater could be explained by the fact that the nitrite ion (NO_2^-) is an intermediate compound, unstable in the presence of oxygen, whose concentration is generally much lower than that of the two forms related to it, nitrate and ammonium ions [21].

3.8.3 Nitrates (NO_3^-)

The monitoring of nitrate variation in raw wastewater from the WWTP of the Aïn Témouchent city (Table 1 and Fig. 13) shows that their NO_3^- contents vary between

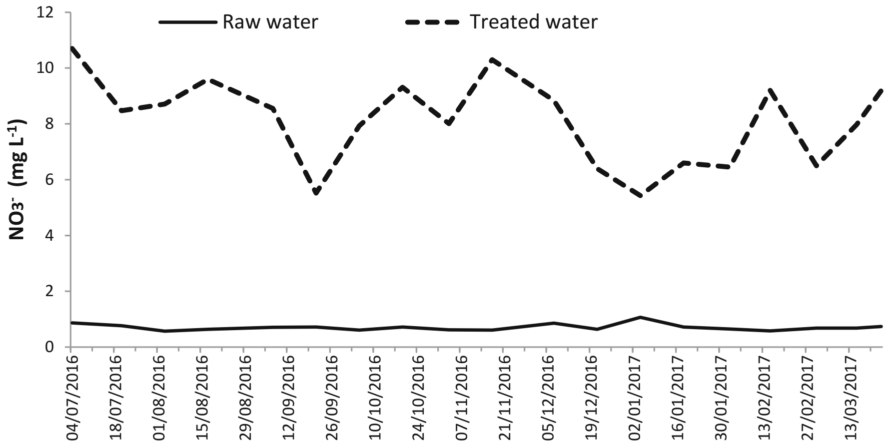

Fig. 13 Temporal NO_3^- variations of wastewater and treated water

0.57 and 1.07 mg L^{-1}, with an average of 0.7 mg L^{-1} and a standard deviation of 0.12 mg L^{-1}.

The nitrate concentrations recorded at the outlet of the WWTP (Table 1 and Fig. 13) vary considerably. They range from 5.43 to 10.7 mg L^{-1}, with an average of 8.1 mg L^{-1} and a standard deviation of 1.5 mg L^{-1}.

The comparison of the nitrate concentrations of the wastewater analyzed with the water quality standard for irrigation shows that they comply with the FAO standard [31] and present a slight to moderate restriction for irrigation water.

3.8.4 Ammonium (NH_4^+)

The ammonium contents in the wastewaters at the WWTP entrance (Table 1 and Fig. 14) range from 19.35 to 64.37 mg L^{-1}, with an average of 39 mg L^{-1} with a standard deviation of 10 mg L^{-1}.These ammonium concentrations decrease after purification (Table 1 and Fig. 14) to values between 0.21 and 2.9 mg L^{-1}, with an average of 1.1 mg L^{-1} and a standard deviation of 0.6 mg L^{-1}.

The variations in the ammonium content recorded in the purified water could be explained by better oxygenation leading to the oxidation of ammonium to nitrate ion.

3.9 Total Phosphorus and Orthophosphates

Total phosphorus is present in a sample in the form of phosphates or organic phosphorus compounds. In wastewater, phosphorus can come from human metabolism, washing and cleaning products, and orthophosphates from the hydrolysis of inorganic phosphate. Phosphorus release from wastewaters into watercourses can

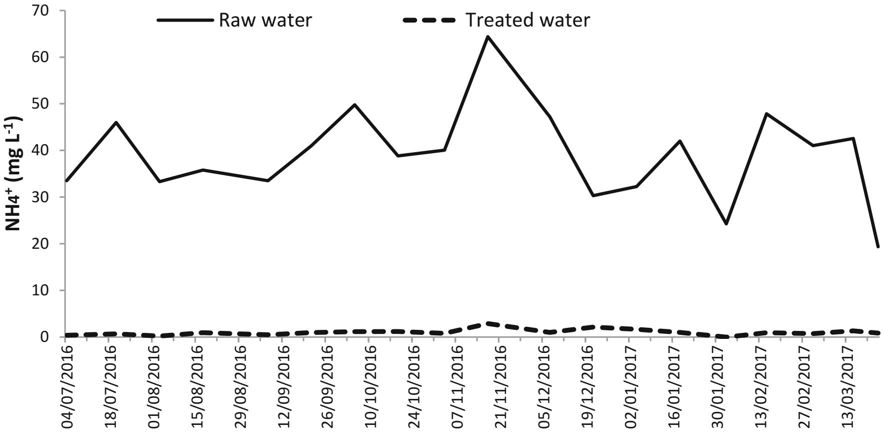

Fig. 14 Temporal NH_4^+ variations of wastewater and treated water

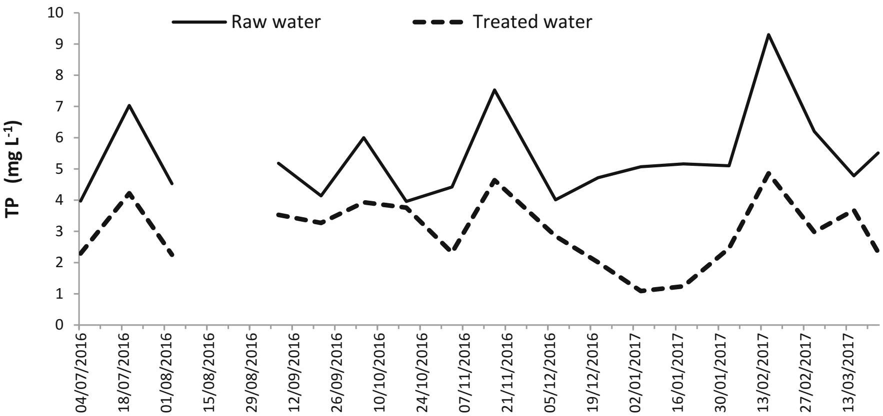

Fig. 15 Temporal TP variations of raw and treated wastewater

cause undesirable effects, such as eutrophication and its related effects [32–35] which leads to profuse algal blooms, excessive growth of aquatic plants, deoxygenation, and water purification problems [36, 37].

The results of raw wastewater analyses (Table 1 and Fig. 15) show that total phosphorus contents vary between 3.96 and 9.3 mg L^{-1} (average, 5.4 mg L^{-1}; SD, 1.4 mg L^{-1}). After purification, the TP values in treated water decreased (Table 1 and Fig. 15) to record contents ranging from 1.09 to 4.86 mg L^{-1} (average, 3.0 mg L^{-1}; SD, 1.1 mg L^{-1}).

These TP concentrations are below 10 mg L^{-1}, the direct release limit value in the natural environment according to JORA, and are generally below the lower limits of

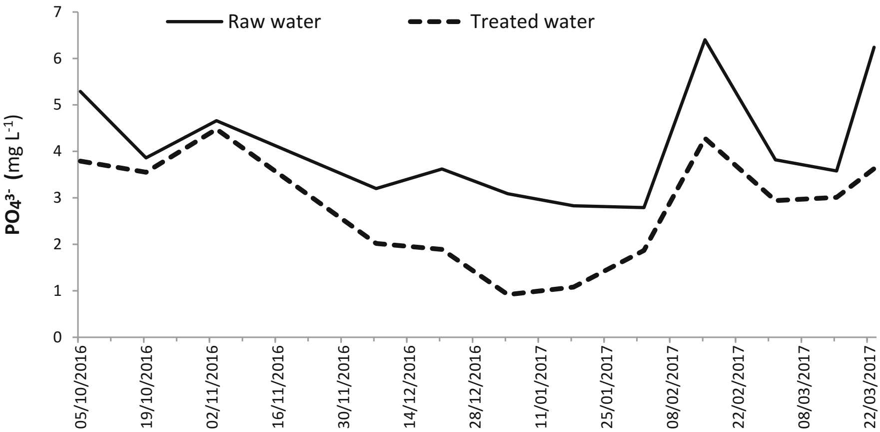

Fig. 16 Temporal PO_4^{3-} variations of wastewater and treated water

the WHO and the FAO [31] standards and can therefore be used for irrigation purposes.

The recorded orthophosphate levels do not vary considerably during the sampling cycle carried out (Table 1 and Fig. 16). Their values vary between 2.79 and 6.4 mg L^{-1} with an average of 4.1 mg $L^{-1}$and a standard deviation of 1.3 mg L^{-1}.

The concentrations of orthophosphate wastewater decreased after treatment (Table 1 and Fig. 16), reaching values of 0.92 and 4.48 mg L^{-1} (average, 2.8 mg L^{-1}; SD, 1.2 mg L^{-1}).

4 Conclusions

Temperatures and pH values at the inlet and outlet of the WWTP show no significant differences and are generally in compliance with wastewater discharge in receiving mediums and reuse standards for irrigation use. Wastewater conductivity values are between 1,240 and 2,730 μS cm^{-1}. They vary after purification to reach values ranging from 1,460 to 2,730 μS cm^{-1} and can therefore be used for crop irrigation according to the standard recommended by WHO.

The values of the COD/BOD_5 ratios for approximating the biodegradability of organic matter in a given effluent indicate that this wastewater is domestically dominant and, in general, easily biodegradable. This biodegradability is well evidenced by the values of the ratios COD/$BOD_5$and which vary between 1.08 and 2.70.

The analyses also revealed significant decreases in BOD_5 and COD. In treating water, they are between 2–8 mg L^{-1} and 18.7–43 mg L^{-1}, respectively, and therefore remain in compliance with JORA discharge standards and those recommended by the WHO for irrigation wastewater reuse. We note, however, an increase in the dissolved oxygen concentration of treated water (6.49–9.63 mg L^{-1}) compared to that of wastewater (0.46–4.46 mg L^{-1}).

Elevated suspended matter content in wastewater (84 to 464 mg L^{-1}) decreases in low concentrations in treating water. The values of the SM concentrations in the latter, between 2 and 17 mg L^{-1}, meet the JORA water discharge standard.

The analyses also revealed significant nitrogen pollution. The high Kjeldahl nitrogen concentrations in raw water (31.81–79.42 mg L^{-1}) decrease after treatment to reach values between 3.01 and 11.6 mg $L^{-1}$and are therefore within the standards of discharge in the environment and that of wastewater reuse in crop irrigation.

Phosphorus is present in treating water with concentrations ranging from 1.09 to 4.86 mg L^{-1}. These values are in line with the JORA effluent discharge standards and the FAO and WHO standards for irrigation use.

5 Recommendations

It is well-known that wastewater should be disposed of in a manner that it should not be harmful to the environment and human health. Currently, although implemented devices allow the elimination of pollutants contained within this effluent, reuse of wastewater from WWTP could cause unhealthy problems. It is necessary to ensure the performance of the treatment techniques used by performing complete physical, chemical, and bacteriological analyses of the treated water.

As for reuse for irrigation, a monitoring and frequent testing of the clean water should be made to ensure the international standards and maximum safety levels. For instance, it was observed that helminth eggs, which constitute a health risk to the human population, might remain in the outlet water, while the separation should be almost total. An increase of awareness at all levels with particular emphasis on WWTPs among farmers is required to mitigate the risks that may be incurred by the population. Farmers should use appropriate crops with treated water and suitable irrigation techniques.

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Protection of Water Resources in Mining Sites in Northeast of Algeria

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Contents

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Abstract Mining is a sector of activity essential in global economic development. These metals and minerals extracted by the mining industry are integrated in several consumer goods. Given the increase in the population and the demand for these goods, the mining industry is growing globally from a few decades.

This type of industry is responsible for several impacts during each phase of the mining process. In particular, it is during the exploitation phase that the natural ecosystems, located above the deposits, are destroyed by the elimination of soil and vegetation and the establishment of storage sites for discharge mining. Thus, the extraction of mineral resources has a definite duration, whereas the associated environmental impacts can be visible indefinitely if no corrective measures are taken. This is why, when extraction is complete, the restoration phase is just as important as it addresses these impacts by rebuilding new ecosystems and giving the site a natural look through revegetation. Responsible catering also ensures that the positive social and economic impacts of mining are sustainable for future generations.

Keywords Mining environment, Natural ecosystems, Restoration of mining sites

1 Introduction

The society is dependent on the mines that supply it with the minerals and metals needed to make things that we use every day, such as trucks, ATVs, boats, and homes. Mineral and metal products can easily be recognized in our daily lives.

Copper cabling in our homes, nickel in our stainless steel sinks, gypsum in our walls, silica in the windows of our windows, and the salt we use in our food, all come from the extraction of minerals and metals from the earth. In addition, various other metals such as zinc, silver, gold, platinum group metals, and rare earth elements are used in the production of many parts of our automobiles and electronic equipment components in our homes, like computers, stereos, and televisions.

Mining has been part of the life and economy of Aboriginal communities for generations. Aboriginal peoples did not just use the rocks as they were; they also extracted materials for a variety of purposes, including making tools, weapons, and decorative items.

Exploration and mining activities can make an important contribution to the prosperity and well-being of Aboriginal communities. For many indigenous communities, the exploitation of natural resources, including mineral resources, is the main driver of socioeconomic development and diversification of the regional economy. Mineral exploration offers employment and skills development opportunities depending on the stage of the project. Well planned, a mine can generate benefits that will survive and strengthen the community's autonomy.

Without forgetting that the mining activities can have significant and long-lasting effects on the environment, there are many examples of good and bad mining operations and rehabilitation. Environmental damage associated with mineral extraction is having an increasing impact on the mining industry and the workforce it employs.

2 History and Current Situation of Mining Sector (According to the Ministry of Industry and Mines)

Before independence (1962), mining activity in Algeria was mainly oriented toward the exploitation of iron and lead-zinc deposits. Between the two world wars, Algeria was a major producer of iron ore in the world; its production contributed to the prosperity of the processing industries of several European countries, in particular France, Great Britain, and Germany.

During the 1950s, particularly during the National Liberation War, foreign mining companies accelerated the process of skimming deposits and limited or even stopped all investment in this sector.

After independence, foreign operators abandoned several mines after making the most of them; only "viable" mines remained in operation, such as phosphate, zinc, iron, barite, coal, and salt mines.

The nationalization of the mines, which took place on May 6, 1966, was followed on May 11, 1967, by the creation of the National Research and Mining Corporation (SONAREM) (http://www.mdipi.gov.dz/?PRESENTATION-DU-SECTEUR-DES-MINES).

It was from that date that the national mining activity was organized for research and exploitation of mineral substances until 1983, when SONAREM's restructuring took place.

During this period, major efforts were made by the state and led to a number of actions, in particular:

- The launch of major research programs to reopen abandoned mines, increase the reserves of active mines, and discover new deposits
- The restoration of the production equipment
- The opening of new mines
- The training of qualified personnel

This plan for the recovery of the mining sector has made it possible to:

- Extend the life of several mines (iron, polymetals, and nonmetallic substances)
- Build several mining complexes (mercury, lead-zinc, and nonmetallic substances)

- Reconvert the activities of mines whose reserves were exhausted
- Conquer new external markets through the placement of a wide range of mining products such as phosphate, mercury, barite, iron ore, bentonite, kieselguhr, zinc, and lead concentrates.
- Establish a high-quality basic national geological infrastructure, accompanied by systematic exploration of the entire national territory, which has made it possible to inventory a large number of deposits and showings, some of which offer real development prospects.

  From 1983 to the present day, the main highlights have been:
- The restructuring of the National Research and Mining Corporation (SONAREM) with the creation of six major mining companies: FERPHOS, EREM, ENOF, ENAMARBRE, ENASEL, and ENG.
- The creation of an industrial mining group MANAL Spa in 2010 bringing together all public companies in the mining sector.

2.1 Partnership in Mining Sector

Algerian mining resources offer significant investment opportunities through multiple partnership operations. Mining legislation now allows access to exploration, development, and exploitation of mining resources by private capital.

The targets of associations may be regions and districts to be explored, deposits to be evaluated for exploitation, or deposits already evaluated for development after feasibility studies have been carried out, as well as deposits currently underexploited such as phosphates, iron, gold, etc.

2.2 Development Axes in Mining Sector

Today, the country has a fairly well-developed geological infrastructure, numerous and high-quality previous works, geological engineers, and qualified miners.

For development, it should be recalled that the mining sector includes all mining activities intended to produce useful minerals or ores: metals and industrial and construction materials.

The main objective is therefore to stimulate a new development momentum in the mining sector so that it contributes substantially to economic recovery and plays a significant role in the national economy.

The development objectives envisaged include, among others, the following:

- The continuation by mining operators of efforts to modernize their production facilities
- The search for foreign partners with technical and financial capacities for the development of mining activities

- The implementation of projects to develop mining products such as phosphates, salt, marble, nonmetallic substances, gold, diamonds, etc.
- Increased export of mining products
- The intensification of mining research
- Partnership development of under- or underexploited mining resources

3 Acid Mining Drainage Training Process

3.1 Acid Mine Drainage

The term "acid mine drainage" (AMD) refers to a complex set of chemical reactions that occur when rocks containing sulfur are exposed to water and oxygen. In many ways, this process is similar to other natural processes such as weathering or rusting.

When oxygen and water come into contact with rocks containing sulfur, acid is produced. This acid can dissolve metals from surrounding rocks that will be released into the soil and surface water. High concentrations of metals and acid can be harmful to fish and other aquatic life.

3.2 Acid Mine Drainage Formation

The natural mineralization of the subsoil is due to the circulations of the fluid that carries metal cations that will be trapped in the reducing horizons. Gold mining has or will abruptly change the oxidation-reduction conditions at the origin of the deposit by denuding the rocks and exposing them to oxygen in the air.

An exploited mine represents several kilometers of tunnels (a few hundred kilometers, sometimes several thousand). These are all conduits likely to bring water and oxygen in contact with the ore. Open pit and quarry materials, by definition, are subject to atmospheric conditions. AMD's are formed, either in the flooded galleries (Fig. 1) or by the percolation of water on the piles of excavated solids containing sulfides.

These materials extracted from the mine are of different types: sometimes containing sulphides (sterile franc) and minerals low in sulphides (halides, sterile selectivity) or reject treatment poor in precious metals but rich in sulfide.

When rocks containing sulfur are present in a rock formation, only small amounts come into contact with oxygen during natural weathering. Oxygen and water in the atmosphere react with exposed rock surfaces, inducing the production of small amounts of acid. The natural environment can often neutralize and/or dilute these small quantities.

During the mining activity, rock fragmentation and crushing exacerbate acid mine drainage as a result of the increased amount of rock surfaces exposed to oxygen and water in the atmosphere. The atmosphere has been observed to react

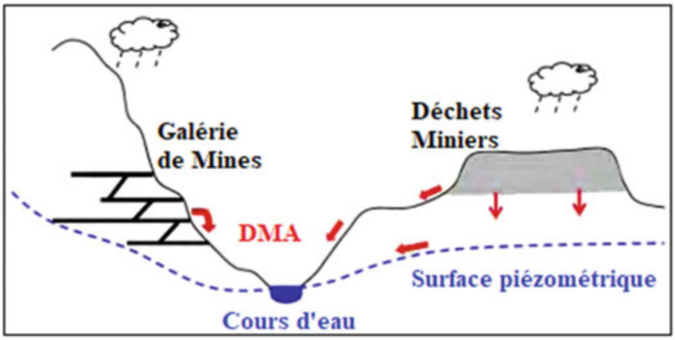

Fig. 1 Acid mine drainage formation [1]

with exposed rock surfaces, inducing the production of small amounts of acid. The natural environment can often neutralize and/or dilute these small quantities.

This phenomenon is accelerated by the presence of the bacterium *Thiobacillus ferrooxidans*, which considerably increases the speed of chemical reactions. *Thiobacillus ferrooxidans* cells grown on ferrous iron oxidized sulfite to sulfate at pH 3, possibly by a free radical mechanism involving iron and cytochrome oxidase.

The bacterium uses the sulfur present in the rocks as a source of energy, and, when the conditions are suitable, it can act as a real catalyst of the chemical reactions present.

The main chemical reactions that give rise to DMA are the oxidation of iron and sulfur in pyrite, the most common sulfide mineral. This reaction takes place in the presence or absence of bacteria according to the equation:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe\,(OH)_3 + 8H_2SO_4$$

This is of course only a balance equation: the oxidation process of the pyrite varies according to the evolution of the ph. The peculiarity of this reaction is to be auto-catalyzed, which allows the phenomenon of DMA production to propagate in a similar way to a fire: just as combustion produces heat that triggers the combustion of other materials, sulfide oxidation produces ferric iron, which causes oxidation of other sulfides.

The mechanism of DMA formation is related to the presence of sulfides (S^{2-} and $S_2{}^{2-}$), sulfur (S^0), or thiosulfate ($S_2O_3{}^{2-}$) with water and oxygen. The most common sulfide mineral present at mine sites is pyrite (FeS_2). The oxidation of pyrite is the main cause of acid mine drainage [2] (Fig. 2).

However, other sulfide minerals also participate in the DMA phenomenon, such as sphalerite (ZnS), galena (PbS), chalcopyrite ($CuFeS_2$), pyrrhotite (Fe_7S_8), and arsenopyrite (FeAsS). The oxidation of pyrite is governed by a set of reactions and takes place in three phases [3].

The first step, oxidation with oxygen, is an initiation step. It occurs in the presence or absence of bacteria. The pH is then greater than 4.5 and progressively acidifies.

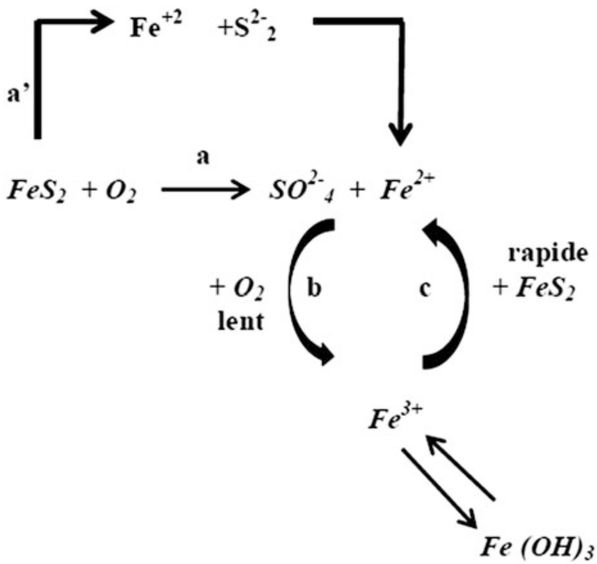

Fig. 2 Model of pyrite oxidation [4]

The reaction is relatively slow, and the kinetics of the reaction decreases as the pH decreases. Both are essentially controlled by the availability of oxygen.

The second step, the oxidation of ferrous ion to ferric ion, is decisive. It becomes preponderant in the reaction with the progressive acidification of the medium: the pH becomes less than 4.5, which allows the ferric iron to remain in solution. The ratio Fe^{3+}/Fe^{2+} is still low and then increases gradually. The importance of this reaction lies in the fact that it produces ferric iron which will be able in turn to react in chain on the pyrite (Fig. 2).

4 Heavy Metals Pollution

The most studied metals in the field of the environment are generally arsenic (As), cadmium (Cd), chromium (Cr), copper (Cu), manganese (Mn), mercury (Hg), nickel (Ni), lead (Pb), and zinc (Zn) due to their abundance and toxic effects.

Naturally present in the geochemical seabed, metal pollutants can also be of anthropogenic origin. The extracted sediments can be compared to a polluting source [5].

The most important chemical processes influencing the fate and mobility of ETM are induced by transfer mechanisms between the solid and liquid phases [6, 7]. The availability of ETM depends considerably on the surface properties of particles, physic-chemical conditions of the environment such as pH and Eh, and salinity and biological processes [8]. The main constituents of soils and sediments likely to bind ETMs are clays.

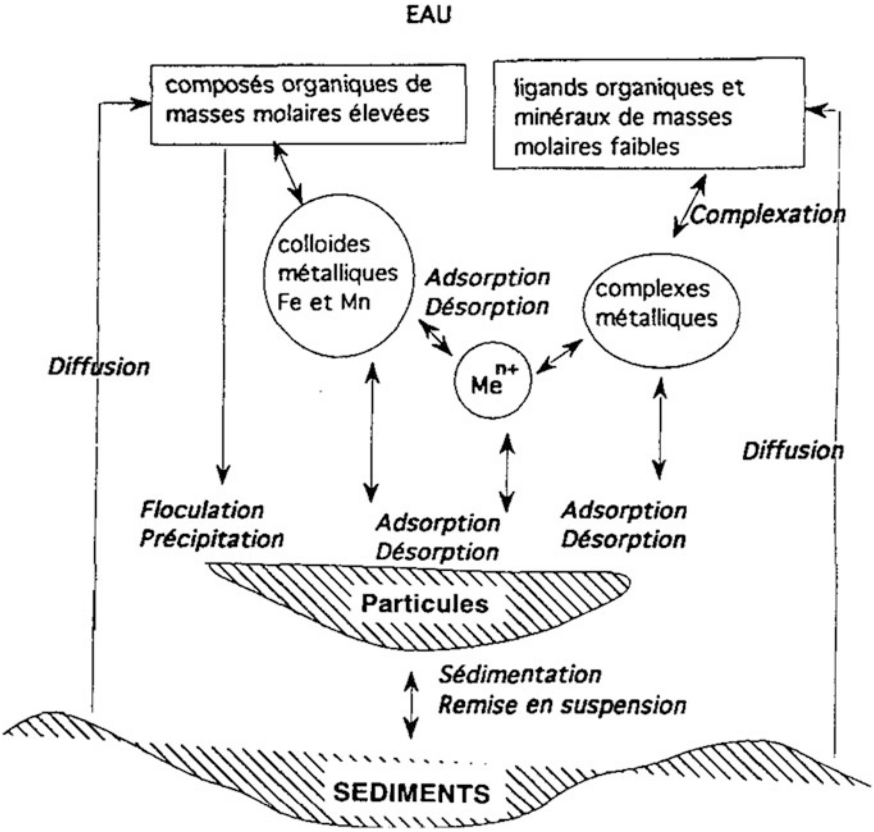

Fig. 3 Schematic representation of a water-sediment exchange system [9]

Indeed, their negative charge makes them suitable for forming electrostatic bonds with any positively charged entity present in the liquid phase, such as metal cations (M^{2+}). Other components of the solid phase also have an important role in the availability of heavy metals, such as carbonates, silicates, iron and manganese oxides, and hydroxides and organic matter.

It is often difficult, in the case of complex media such as soils and sediments, to predict the mechanisms responsible for the fixation and mobility of ETM and to describe these complex media in a "standard" way [8].

Nevertheless, the most important physic-chemical mechanisms involved in these transfers are: ionic exchanges (or nonspecific adsorption), specific adsorption on mineralogical phases (surface complexing), complexing by organic matter, and finally precipitation and coprecipitation phenomena (Fig. 3) [9, 10]. Depending on the physic-chemical conditions of the environment, one of the retention processes will always be predominant in a total interaction between contaminants, mineral species, and organic matter.

Our literature review was limited to these minerals, mercury (Hg), copper (Cu), lead (Pb), zinc (Zn), and iron (Fe).

4.1 Mercury (Hg)

Mercury is the element close to gold in the periodic table of elements and one of the alchemist's favorite. It has the particularity of being the only metal that is liquid at room temperature. It occurs naturally in the form of sulfide cinnabar and is used mainly for physics instruments and gold mining. Known since ancient times, mercury was very quickly used to amalgamate gold. It was referred to as lively silver from the sixteenth to the nineteenth century. Alchemists associated it with the planet Mercury, which explains its current name. The symbol Hg comes from the Greek hydrargyrum for "cash."

Mercury is a compound that can be found naturally in nature, in metallic form, as salts or in organic compounds. Mercury is not naturally present in food, but mercury can be found in food, as it can diffuse into the food chain through smaller organisms that are eaten by humans, such as fish. Mercury is a very toxic element for humans, regardless of the compound and the degree of oxidation. It binds easily in organic matter and metabolic processes. It is then found in methylated form. In addition, it is very mobile, as it is volatile at room temperature. Among its harmful effects on the body, it affects brain function and the kidneys. It could also be an endocrine disruptor and cause cancer. Mercury is also cytotoxic to stem cells in the central nervous system.

It enters the environment when minerals naturally break down in rocks and soil exposed to wind and water. The dispersion of mercury from natural sources has remained about the same over the years. However, the concentration of mercury in the environment is constantly increasing; this is due to human activity.

Most of the mercury released by human activities is released into the air through fossil fuel combustion, mining, smelting, and solid waste combustion. Some activities release mercury directly to land or water, such as the application of agricultural fertilizers and industrial wastewater discharges. All mercury released to the environment eventually ends up in soils or surface waters.

Acidic surface waters can contain a significant amount of mercury. When the pH is between 5 and 7, mercury concentrations in water increase because mercury is mobilized from the soil. Once mercury has reached surface waters or soils, microorganisms can transform it into mercury methyl, a substance that can be rapidly absorbed by most organisms and is known to cause nerve damage.

4.2 Copper (Cu)

Copper is relatively scarce on earth. It is present in 0.007% of the earth's crust (lithosphere) and 0.002% of the soil [7]. It is one of the few metals present in its native state in the environment. However, it is more frequently found in the form of sulfide ores such as chalcocite (Cu_2S) and chalcopyrite ($CuFeS_2$) [11].

The presence of copper in a given environment can be of natural origin, through erosion, volcanism, and vegetation. However, generally, the main contributions to the environment are anthropogenic and linked to the metallurgy industries.

In soils as well as in sediments, ETMs are distributed between the different carrier phases and/or fractions of the matrix according to the physic-chemical conditions governing the environment and the specific retention energies specific to each element. In these matrices, copper can be associated, complexed, precipitated, and adsorbed on six different carrier phases and/or fractions.

World copper production is still increasing. This means that more and more copper is entering the environment. Rivers deposit copper-contaminated sludge on their banks as a result of wastewater discharge. Copper enters the air mainly during the combustion of fossil fuels. It remains in the air for a long enough period before settling when it rains. It is then mainly found in the soil. As a result, soils can contain a large amount of copper after the copper from the air has settled.

Copper can be released into the environment from natural sources and human activities. Examples of natural sources include windblown dust, rotting vegetation, forest fires, and dispersed seawater droplets. Some examples of human activity contributing to copper dispersion have already been given; other examples are mining, metal production, wood production, and phosphate fertilizer production.

Since copper is dispersed by both natural and human processes, it is very widely distributed in the environment. It is often found near mines, industrial facilities, landfills, and garbage crushers. When copper is found in the soil, it binds strongly to organic matter and minerals. As a result, it does not travel very far and rarely enters groundwater. In surface waters, copper can travel long distances, whether suspended on mud particles or as a free ion.

Copper is not destroyed in the environment, and, as a result, it can accumulate in plants and animals when it is present in the soil. On copper-rich soils, only a limited number of plants are likely to survive.

4.3 Lead (Pb)

Lead is a soft metal that has had many applications over the years. It has been widely used since 500 BC in metal products, cables, pipes, but also in paints and pesticides. Lead is one of the four most harmful metals to health. It can enter the human body when ingesting food (65%), water (20%), or air (15%).

Lead is naturally present in the environment. However, most lead concentrations in the environment are the result of human activities. Lead cannot be destroyed; it can only change shape. Lead is a particularly dangerous chemical because it can accumulate in individual organisms but also the entire food chain.

4.4 Iron (Fe)

Since the Iron Age, there have been many iron mines around the world. Iron (Fe) is undoubtedly the most important metal, either because of its abundance in nature or because of the uses made of it. It is found in its native state, especially in the states of magnetite, oligist, limonite, siderite, and pyrite. Iron is rare in its native or pure state. Apart from a few large blocks found in Greenland basalt where iron is mixed with carbon, native iron is only found in meteorites or rocks that have fallen from the sky.

Iron can be found in its natural state in: magnetite (Fe_3O_4), oligist (Fe_2O_3), siderite ($FeCO_3$), and pyrite (FeS_2).

Iron (III)-O-arsenite, pentahydrate can be dangerous for the environment. Particular attention should be paid to plants, air, and water. It is strongly recommended not to allow the chemical to enter the environment because it persists in the environment.

Iron mines played an important role in the Industrial Revolution. Iron deposits in rocks are usually in the form of oxides, such as hematite. Production costs in the iron and steel industry are based on the distance between mines, steel mills, and blast furnaces. The case of the Boukhadra and Ouenza mines in the province of Tebessa and the Mittal Steelworks in Annaba.

4.5 Zinc (Zn)

Zinc is the third most widely produced transition metal (after iron and copper) and is best known for its good corrosion resistance, from industrial steels to roofs. Zinc has been known since ancient times, although it was not used in its pure form. Zinc has a much less chalcophilic character than lead and copper; we will speak of a more lithophilic character.

The most common zinc ores found in nature are however sphalerite (ZnS) and smithsonite ($ZnCO_3$). Sphalerite is fairly uniformly distributed in magmatic rocks (40–120 mg/kg).

Zinc deposits are of magmatic origin, known as primary or sedimentary, known as secondary. Zinc ores are often associated with lead, copper, and iron ores. The main zinc ore deposits are located in China and Australia.

In 1990, the deposits mined were also located in Peru, the United States (including the Red Dog mine in Alaska), Canada, Mexico, Russia (CIS), the Democratic Republic of Congo, Zimbabwe and South Africa, Japan, Morocco, Spain, Ireland, Sweden, Switzerland, Poland, and the Balkans, as well as Bulgaria. Their minimum contents were 40 kg per ton.

Zinc is one of the metallic trace elements that becomes a contaminant and a pollutant beyond the doses that make it ecotoxic (which vary according to the species and the context, e.g., it is more mobile and bioavailable in an acidic environment than in a basic one).

5 Mine Impacts on the Environment and Human Health

The use of metals and rare elements which accompany the development of human societies has led to mining, transformation, and waste elimination all of which are or can be a source of environmental contamination. The use of minerals, materials, and fuels which contain these elements, the intensification of underground water pumping, and other physical or chemical modifications of the soil also induce contaminations through transfers which add to the natural fluxes (alteration, volcanism, erosion) [12].

From the characteristics of use and the risk-related factors particular to each element, four elements stand out as particularly worrisome:

- Mercury is a dangerous contaminant of aquatic environments and even of the atmosphere. Its use is increasingly forbidden. However, the production of waste, the existence of old soil pollution, its considerable capacity for bioconcentration, and the increase in fish consumption are all risk factors. More consideration should be focused on sediments and water.
- Lead has great mobility in non-acid soils. The risk comes from former accumulation of important stocks within the soil surface layers, from which it does not get eliminated rapidly, and from continued deposits which are diminishing. However, some portions of the population remain affected, for example, by latent and irreversible effects on child development which are now well characterized. However, the worst risk is presented by the presence of old paint in older buildings and in old water pipes which distribute acidic water.
- Cadmium is mobile, and its applications are much more dispersive than in the case of lead. Contaminating quantities are much lower, but its toxicity is proportionally much higher. The risk it represents in soils necessitates particular vigilance.
- Arsenic is a naturally occurring and highly ubiquitous mobile element in the soil. Because it is rarely used, the risk mainly comes from water contamination due to circulation in the soil and underground. The recognition of its carcinogenic potential incites increased vigilance.
- The other elements are less problematic, because they remain rare in the soil (this is the case of tin, selenium, and other metals which are sometimes very toxic but have a specific use) or they are found in chemical forms which are only toxic at exceptionally high concentrations (this is the case for copper, zinc, nickel, which are essential trace elements, and even chromium).

5.1 Abandoned Mines

Thousands of abandoned mines are sleeping under the mountains. While they hold wonderful secrets, they also present many dangers, and that is why the government must condemn access and at the same time rehabilitate abandoned sites.

Taking the example of the United States and more precisely the West, an underground world testifies to the turbulent past of the once-promising far west. There are tens of thousands of abandoned mines, created at a time when everyone could take their chances and dig to the grave. However, once the coveted raw materials were extracted, the mines were simply left to fend for themselves without further consideration.

However, neither the closure of a mine nor the surrender of a mining title puts an end to a situation of physical and environmental risks. On the contrary, the risks associated with collapses, groundwater rise, floods, pollution, risks to the groundwater, gas risks (firedamp, CO, CO_2, radon and sometimes H_2S, mercury, sulfur gases, etc.), radiological risks, etc. will often persist over time and may even get worse.

As in the case of the Ismail mine, it ceased all activity in 2005, but unfortunately no rehabilitation operations were undertaken. Already, 12 years of closure and abandonment, but the pollution problem persists to this day. Traces of mercury have been detected on site, in soils and water. The iron mine of El Khanguet closed since 1966, located in Tebessa in northeast Algeria. The waste rock left in the mine site had a negative impact on the soil and water of the area [13].

5.2 Active Mines

Algeria has an interesting geological potential for investment and partnership in mineral exploration, development, and production of certain mineral substances. Despite this, the mining sector has remained very unproductive in relation to the potential of our country, which is particularly significant for nonmetallic useful substances such as phosphates, salt, marble, etc.

The disruptions in the world market for mineral raw materials and metals that have shaken the world economy dictate the implementation of strategies to mitigate the various shocks suffered by all countries, particularly developing countries, which hinder or delay their economic and social development.

Since independence, Algeria has striven to establish a mining sector that can respond to its concerns. In the mining sector, a major prospecting effort has been made over the past 30 years to develop the basic geological infrastructure and to inventory a large number of deposits and showings, some of which offer real investment prospects for their exploitation. It is on this basis that the Algerian state has decided to promote and develop this potential. As such, partnership formulas are offered to foreign investment, combined with incentives for both exploration and mining.

6 Case Study

6.1 History of Ismail Mercury Mine

The mercurial complex “Ismail” is located in Azzaba area; it is the only one in the country and the largest in Africa. This mercurial complex is composed of three deposits “Ismail, Guenicha, Mra sma” with a monometallic mineralization which forms cinnabar HgS. This complex was closed since 2005 without any rehabilitation operation. After 12 years of closure, the formation of mercury droplets in the factory compound has occurred so far due to climate change.

The name of the Ismail deposit is the name of a driver who found mercury in liquid form in northeastern Algeria for the first time in a long time (colonial period). Then, several polymetallic showings were reported in the North-Numidique zone. Others were highlighted during studies on the region’s mercurial potential, carried out by the Soviets in the 1970s.

In 1971, the Ismail mercurial complex was installed and commissioned by ENOF to exploit the deposit. The majority of its production was destined for export to Germany, France, and other Asian countries. It also supplied the electrolysis process of the Skikda petrochemical complex.

Production was stopped in the second half of 2003 for a few months in order to rehabilitate the equipment of the mine and complex, as well as to strengthen work with the installation of a second furnace in order to restart production in January 2005.

Following the drop in production, a mercury pot produced in the 1970s and 1980s 300,000 while it produces 5,000 in recent years and due to its impact on the environment. The mine was closed under ministerial order in 2005 after 35 years of operation without any cleanup operations.

In 2006, following a visit to the site by a team from the Ministry of Environment, a decision was taken to start the cleanup work. As a result, studies have been carried out in collaboration with the French company GenCos in order to carry out rehabilitation work in the coming days. Something that has not been done is what prompted us to conduct this study.

6.2 Physical Setting of Study Area

The Ismail deposit is located 6 km southwest of the town of Azzaba province of Skikda on the left bank of the Fendek wadi valley and the north flank of the numidic chain. The mercurial complex of Ismail was located 2 km from Zaouia (Azzaba – Skikda) (Fig. 4).

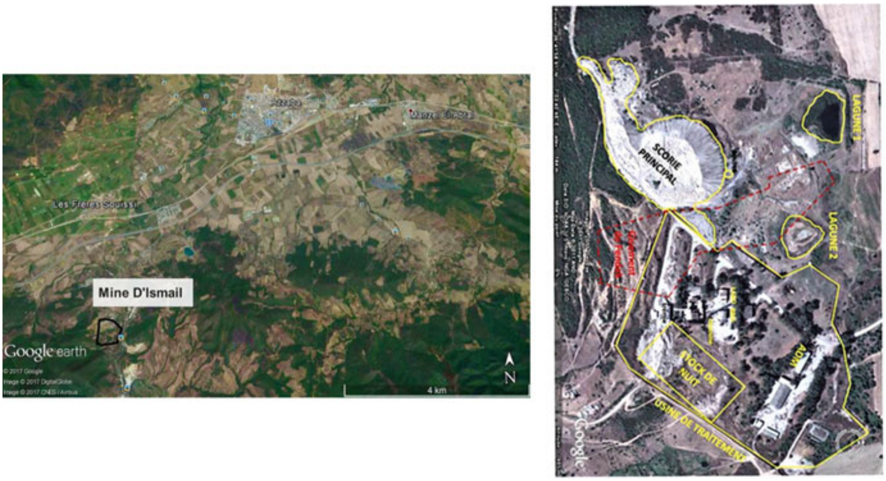

Fig. 4 Geographical location of the Ismail mine and the industrial mining complex [14, 15]

The morphology of our study area, which is part of Azzaba, has two different areas:

– One is an elevated area forming the surrounding mountains.
– The other one corresponds to the Azzaba depression.

The relief of the region is very uneven; the most important orographic elements are part of the numidian chain. The east-west facing massifs extend from Ghedir Mountain in the West to Chbebik Mountain in the East.

The highest ranges, Tengout Mountain and Saiafa Mountain reach 648 m and 496 m, respectively; they are reliefs of quartz sandstone or limestone sandstone covered with cork oak forests. To the east are the limestone and bare mountains, Mazeur mountain 473 m, Moulmdefa mountain 572 m, and Chbebik mountain 447 m, and finally in the center are the gneissic and schistose mountains peaking at 464 at Raout-Lessoued mountain.

The Azzaba low communicates in the West with Ramdane Djamel's at the Ras El Ma meridian and leads to the Fedzara low in the East.

• *Hydro-climatological Overview*, the Azzaba region has a relatively mild Mediterranean to subtropical climate. It is characterized by:

  – A hot and dry season spread over about 5 months, from May to September, characterized by an average monthly temperature of around 23°C. During this season, there are warm winds (sirocco) from the south.
  – A cold and humid season from October to April, characterized by a seasonal average temperature of around 14°C, with an average rainfall of around 82 mm.

As a result of these climatic conditions, typical vegetation has developed in the region. In the plain, there are mainly market gardening, cereals, as well as orangeries and vines. On the mountain slopes, a degraded forest cover develops with some groups of cork oaks and olive trees.

The inhabitants, who are mainly farmers, obtain excellent products in wheat, barley, corn, millet, melons, watermelons, etc.

In addition, this territory is generally wooded; cork oaks, holm oaks, ash trees, elm trees, and poplars are the most numerous species.

- *Hydrographic network* is not very dense; it is mainly composed of temporary wadi, namely:
  - In the mountains delimiting the slopes, thalwegs are ordered and form deep notches that facilitate the drainage of surface runoff.
  - In the plain, the wadi is few in number and shallow. The main wadi is
- Fendek wadi with a south to the north flow of water.
- The Adjoul Wadi is the collector of several small wadis and flows north-east.

These two wadis join the Mchekel Wadi in the northeast of Azzaba. They are characterized during dry periods by thin water drips, while during rainy seasons, the regime becomes turbulent. Mchekel wadi flows toward Kebir wadi, which flows into the sea to the east of Skikda (near iron cap) (Fig. 5).

- *Socioeconomic overview*, Azzaba town is a more or less developed urban center. It currently has a fairly large industrial expansion resulting in the depopulation of isolated areas, thus favoring a concentration majority of the surrounding population.

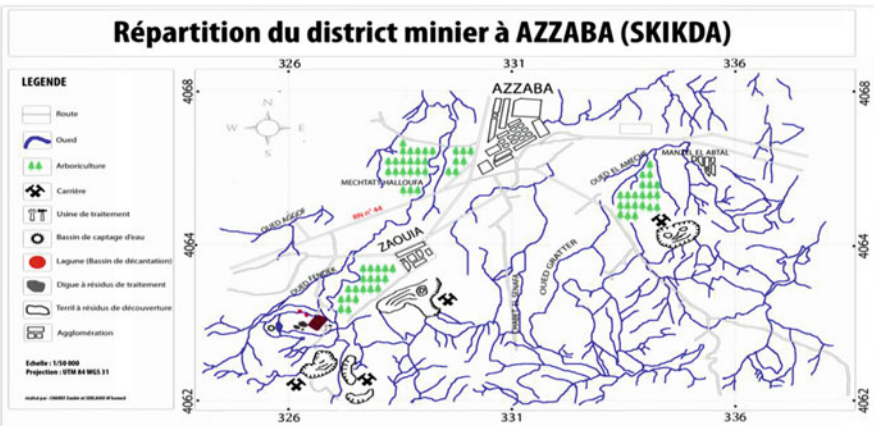

Fig. 5 Hydrographic network of the study area [14]

The Azzaba plain is essentially an agricultural region where market gardening and cereals are widely developed. The main economic resources of the region were mining and agriculture.

6.3 Geological and Mineralogical Study

The Ismail mining field contains three deposits: Ras El Ma, Ismail, and Guenicha. The geological structure of the study area and neighboring territory includes four (4) different units [16]:

1. The sub-Aboriginal unit of the Kabyle Ridge
2. The allochthone Kabyle unit
3. The allochthone flysch unit
4. The numidian unit

The sub-Aboriginal unit of the Kabyle Ridge forms a narrow zone (4–8 km), subdivided according to J.M. Vila into two (2) subzones, namely:

– The inner sub-area that borders the Kabyle unit to the north
– The external sub-area that borders the flysch units to the south [16, 17]

To the north and south of Azzaba [16], the flysch unit is more developed, it occupies an important place in the geological structure of the region, the outcrop of its formations which are limestone, sandstone, and clay breccias is in the form of a cover, and the correlation of some of its parts is difficult to establish (Fig. 6).

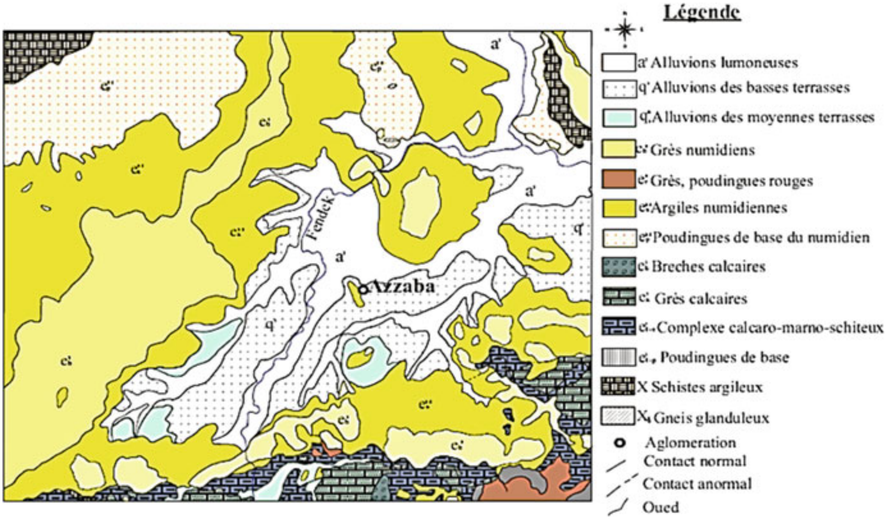

Fig. 6 Geological map of the Azzaba region [18]

So mercurial and polymetallic mineralization are separated over time. The formation of cinnabar is later than polymetallic mineralization, so the major control of mineralization is structural.

All the mercurial deposits exploited in Azzaba are subdivided into two mining fields:

– Ismail mining field (Ismail, Guenicha, and Ras El Ma)
– Mra sma mining field (Mra sma I, Mra sma II, Koudietsma)

Mercurial mineralization is expressed in the form of cinnabar, of which it is associated with another polymetallic mineralization consisting of galena, sphalerite, chalcopyrite, and pyrite. There are many alteration minerals such as malachite, azurite, iron oxide, and hydroxide, gangue is composed of barite, quartz, calcite, dolomite, gypsum, and kaolinite.

This mineralization is hosted in carbonate and sandstone formations, and it generally occurs in clusters; the mining method in all deposits is open-pit. Mercurial mineralization is in the form of cinnabar, of which it is associated with another polymetallic mineralization consisting of galena, sphalerite, chalcopyrite, and pyrite; there are many alteration minerals such as malachite, azurite, oxide, and iron hydroxide; gangue is composed of barite, quartz, calcite, dolomite, gypsum, and kaolinite. This mineralization is hosted in carbonate and sandstone formations; it generally occurs in clusters; the mining method in all deposits is open-pit.

Ismail The mineralized body is stratiform of medium dimensions: length 520 m, width 60 m, power 64 m; it forms two lenticular clusters [19, 20] (Fig. 7, Table 1).

Guenicha Consists of three mineralized bodies, of which bodies two and three are part of a single large cluster measuring 540 m long (Fig. 8, Table 2).

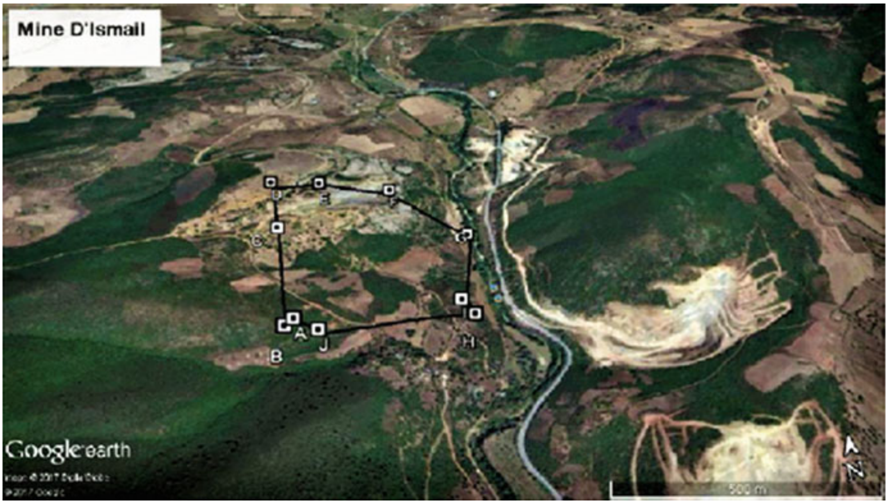

Fig. 7 Ismail's career [15]

Table 1 Perimeter coordinates of the Ismail deposit [21]

Pt	A	B	C	D	E	F	G	H	I	J
X	889,918	889,897	889,880	889,990	889,860	890,181	890,373	890,320	890,310	889,970
Y	385,133	385,110	385,465	385,678	385,678	385,661	385,480	385,380	385,210	385,099

Fig. 8 Guenicha’s career [15]

Mra sma I and II, the body is in the form of irregular pockets, 19 m long and 3–4 m (powerful), and appears in fine spread with a stratoid appearance of 47 m, sometimes in veins of metric length and width centimetric to decametric (Fig. 9, Table 3).

In the study area, the ore textures show two different aspects: friable and compact ore [20]; these two types are distinguished from the rock that holds them:

- Friable (powdery) ore, in the form of debris, isolated angular and rounded grains, it is associated with the following surrounding rocks: clays, clays, and dolomites.
- Compact ore occurs in clusters and disseminations and is associated with the following sedimentary rocks: quartzite sandstone, and detrital limestone (Fig. 10).

- In the study area, the ore textures show two different aspects: friable and compact ore; these two types are different from the rock that holds them.
- Friable (powdery) ore, in the form of debris, isolated angular and rounded grains, it is associated with the following surrounding rocks: clays, clays, and dolomites.
- Compact ore, it occurs in clusters and disseminations, associated with the following sedimentary rocks: sandstone, quartzite, and detrital limestone.
- The macroscopic and microscopic study allowed us to identify the following minerals and establish their paragenetic succession.

Table 2 Coordinates of the perimeter of the Guenicha deposit [21]

Pt	A	B	C	D	E	F	G	H	I	J
X	892,395	892,118	892,118	892,018	891,940	891,758	891,585	891,502	89,137,708	891,169
Y	386,940	386,635	386,445	386,465	386,527	386,540	386,435	386,435	386,407	386,700
Pt	K	L	M	N	O	P	Q	R	S	
X	891,015	891,085	891,285	891,390	891,525	891,638	891,894	892,140	892,195	
Y	387,075	387,365	387,293	387,365	387,385	387,365	387,365	387,352	387,155	

Fig. 9 Mra sma I and II [15]

6.3.1 Primary Minerals

– Cinnabar (HgS, rhombohedral): (Fig. 11a–d) it is the main mineral of the deposit, is distinguished by its earthy red-brown color, and often presents two generations.
– In Ismail, it is found as small granular masses of dark red color, irregular shape (Guenicha), or as veinlets or breach cement, disseminated in Priabonian sandstones (Ismail).
– At Mra sma, it forms plasters and filonites that fill fine cracks in sandstones and quartzites.

Under a microscope, in polarized light, it exhibits a clear anisotropy with massive red internal reflections.

– Metacinnabar (HgS, cubic): is presented in the form of small black isometric grains and forms aggregates and coatings following the walls of the cracks, sometimes impregnated in the surrounding rocks; it is always in association with the cinnabar. Under a microscope, it is grey-white with a lower reflectivity than cinnabar; it is isotropic in polarized light.
– Galena (PbS): characterizes the Mra sma mining field; it occurs in two forms, in small crystals irregularly distributed in mercury ores or impregnation and crystal grouping.

  Microscopically, it has a grey color and is characterized by triangular pullouts.

– Sphalerite (ZnS): occurs in sub-automorphic grains, with dimensions in the millimeter range; it appears as an impregnation of small crystals of greyish color and has internal dark red reflections.
– Pyrite (FeS_2): it is present in the form of small grains of isometric shapes, light yellow; it is also found in fine spread in the silicified gangue.

Table 3 Perimeter coordinates of the Mra sma I and II deposit

Pt	A	B	C	D	E	F	G	H	I	J	K
X	897,110	896,755	896,617	896,865	897,530	897,530	897,682	897,690	897,305	897,237	897,180
Y	389,350	389,410	388,987	388,710	388,157	388,925	389,157	389,417	389,417	389,375	389,242

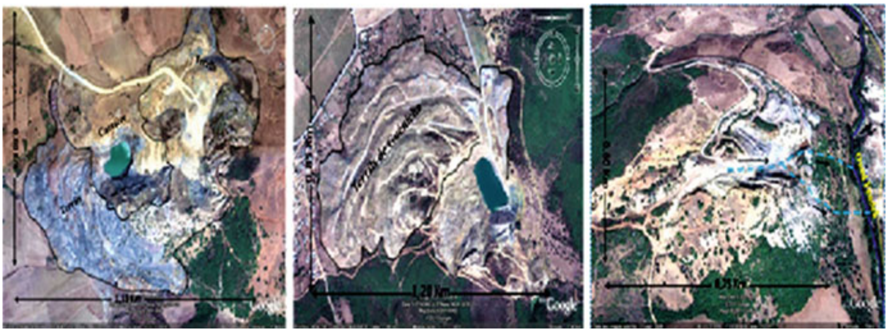

Fig. 10 Flooded Mra sma II and Guenicha quarries, abandoned Ismail quarry [15]

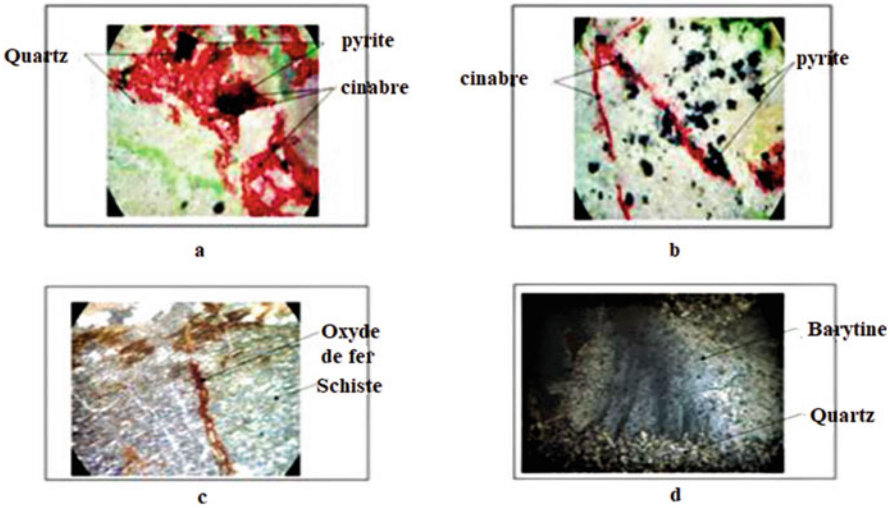

Fig. 11 (**a–d**) Microscopic observation of the extracted ore [18]. (**a**) Cinnabar disseminated in the silicified gangue (ob∗20,LP). (**b**) Cinnabar veinlet intersecting the silicified gangue (b∗20, LP). (**c**) An iron oxide vein intersects the shale (ob∗20, LN). (**d**) Association between barite and quartz (ob∗20,LP)

– Chalcopyrite: it is more rarely found in comparison to other minerals, often disseminated in the gangue.

6.3.2 Secondary Minerals (Fig. C)

– Malachite: a secondary mineral due to the alteration of chalcopyrite, its color is greenish to glassy, often in the form of thin films in the barite veins.
– Azurite: less abundant, occurs in a large xenomorphic range bathed in silicified gangue.

- Iron oxide and hydroxide: represented by hematite, goethite, and limonite, and they are found in impregnation in the surrounding rock or in filling in the dissolution cavities, and the oxides underline the walls of the calcite veins.
- Native sulfur: occurs as yellow-greenish grains in the oxidation zone of mercuro-polymetallic ore.

6.3.3 Gangue Minerals (Fig. D)

- Calcite ($CaCO_3$): it is the most common mineral, it occurs in different forms, and it occurs in the ore body in small veinlets of variable color; sometimes it develops large rhombohedral crystals.
- Quartz: is frequently observed at the surface, easily recognizable to the naked eye, and has several generations and several shapes (geode, veinlet, compact mass, large crystals, well crystallized).
- Dolomite: which is less widespread than other gangue minerals, appears as small losanitary crystals, diffused in carbonate cement, as it can be found in large losanitary crystals in interstitial voids and quartz grain cracks.
- Barite: is widespread in the Mra sma deposit and very rare in the Ismail deposit, is in the form of flattened acicular crystals often grouped into massive lamellar masses in the gangue of the metalliferous vein, and it has a high density of 4.5.
- Kaolinite: a mineral with a cryptocrystalline structure of white to grey color, it is found in vacuoles and intragranular voids, sometimes in small discontinuous veins intersecting cinnabar filonets.
- Gypsum: transparent white, in lamellar and fibrous form, very abundant, and containing cinnabar (Fig. 11).

6.3.4 Textures

Three very common textures are marked in the ore:

- Disseminated texture: predominates over the others, the ore is in the form of small millimeter grains; this texture is often represented by cinnabar and pyrite crystals.
- Brecciated texture: results from the replacement of calcium cement in the breaches by cinnabar, it develops in highly crushed conglomerate breaches.
- Venous texture: observed in fracture zones and calcite and dolomite veins, cinnabar occupies the walls or fills the entire fracture.

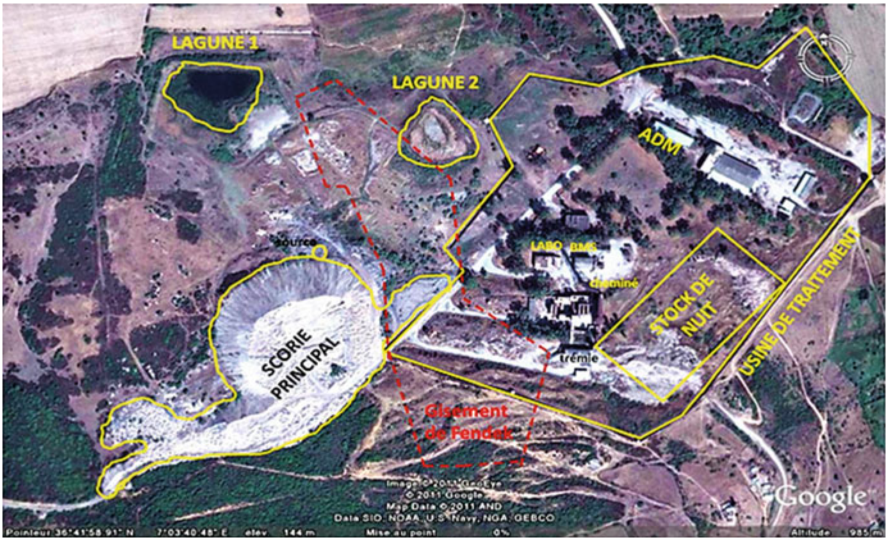

Fig. 12 Ismail industrial mining complex [14]

6.4 Description of Ismail Mercurial Complex

6.4.1 Location

General observations had been made on the location of this complex, which led us to the following description:

- This site is occupied by several buildings and is traversed by several roads, the main one crossing it in an east-west direction.
- From the N coast of the main road, there is:

A huge landfill constitutes the warehouse of solid waste called "slag."
In two small lakes in which liquid waste was settled (called technical waters), the oldest and largest of these lakes is called "settling lake No. 1" or "lake No. 1" of Azzaba).

- On the S side of this road, there is a long cylindrical chimney. (It is 112 m high from the ground and 2 m in diameter.) (Fig. 12)

6.5 Environmental Consequences of Exploitation of Ismail Deposits

A hydrochemical study was carried out on water and soil samples, to determine the impact of mercury on the water and soil of the Azzaba region.

The assessment of surface water quality is based on the measurement of physic-chemical and chemical parameters. These data can be supplemented by soil analysis (leachate) to show the degree of heavy metal pollution.

All these elements together make it possible to assess the degree of contamination of watercourses and their ability to purify themselves.

Our research is based on work that has previously attracted the interest of several authors on the impact of mercury mining in the Azzaba region.

After the closure of the Ismail mercury plant, several studies and research were launched on the area to see the vulnerability of the area to mercury; some works and their results are mentioned:

– Given the observation made on mercurial impregnation in the Azzaba region "Ismail" that the University Hospital research team has finalized a research project within the framework of the Work, Health and Development Research Unit of the University of Annaba. In this project, the hypothesis of this contamination was assumed, and the team developed an approach to verify it by studying the population of schoolchildren in the Azzaba region, comparing it to a control group in Annaba (Nezzal et al. 2004).

The results of this project showed that children attending school in the Azzaba region have an average concentration of mercury (1.32 µg/g creatinine) significantly higher than that of the children in the Annaba region (0.81 µg/g creatinine) showing impregnation chronic mercurial. Some children have reached a concentration of mercury in urine equal to 21 µg/g creatinine. A WHO group report in 1980 indicates that the concentration of mercury in urine appears to be usually, in an unexposed subject, 0.5 µg/L [22].

– The Ismail complex represents an important pollution area for the staff working there as well as for the population and the environment (Megueddem et al.) [23].

The workers in the complex are exposed in various ways. The most exposed group is treatment plant workers with a blood mercury concentration of 89.17 µg/L, due to their direct contact with the mercurial fume [23].

– The high Hg levels in the water analyzes which were 80 µg/L are found in Oligocene formations, while the waters of the Eocene Paleocene groundwater have relatively low levels of Hg (<7 µg/L) (Benhamza 2007) [24].
– The industrial complex of Ismail is an extremely polluted area, and the areas encompassing the quarries are moderately to heavily polluted. By moving away from these areas, the degree of contamination is zero, except for mercury, where in some areas high concentrations are related to geochemical anomalies natural (Seklaoui 2015) [14].

6.5.1 Why Did Our Research Work Focus on Ismail Area?

The selected study area has been the subject of some research before our work in order to show the vulnerability of the Azzaba plain to mercury pollution due to the installation of the Ismail mercury treatment plant in the area.

In the vicinity of this area, there are also three cinnabar quarries that were abandoned after the closure of the plant; these can contribute to the contamination of this area. Following our field visits, water and soil samples were taken for analysis and to see the degree of pollution left by this complex.

6.6 Sampling

The sites where water samples are taken are four stations: settling basin (two samples), lagoon 1 (three samples), lagoon 2 (two samples), and Zebda wadi (three samples).

For the soil, three stations were selected: Stupp waste (two samples), main slag (two samples), and Zebda wadi (one sample).

The physic-chemical parameters such as temperature, pH, and conductivity were determined on the ground during April 2017 in the Azzaba area in the vicinity of the Ismail mercurial site using a Hanna multiparameter (HI 9829) (Fig. 13).

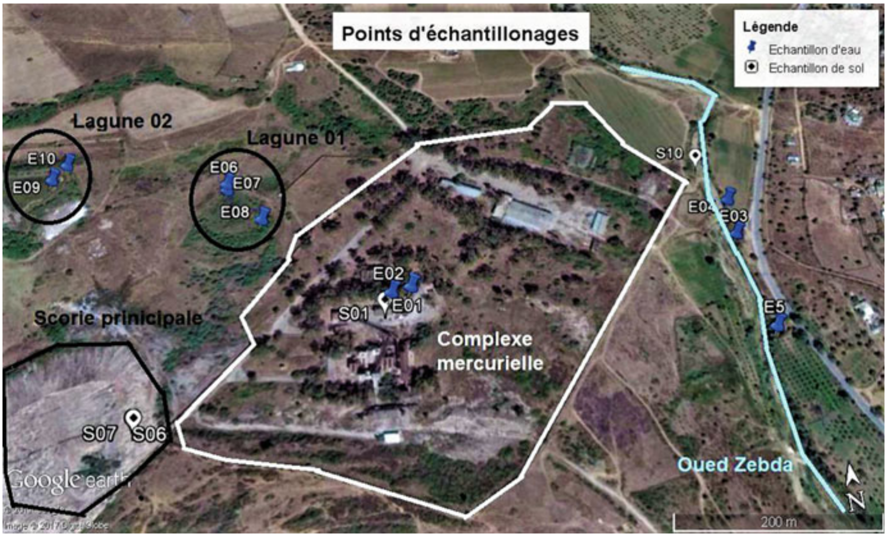

Fig. 13 Sampling plan of the study area [15]

6.7 Discussions of Results Obtained

Water and soil samples were analyzed at the UCEIV laboratory of the Littoral Opal Coast University Dunkirk, France.

The results obtained by ion chromatography show the presence of strong mineralization in our samples. This mineralization has been clearly noticed in the water samples taken from lagoons 1 and 2 with a high concentration of constituent elements (Cl-, So_4^{-2}, Na^+, K^+, Mg^{+2}, Ca^{+2}).

The water samples taken from Zebda wadi show a high concentration of chlorides due to the origin of the water and/or the nature of the ground crossed. For water withdrawn from the settling tank is less loaded with these elements.

To determine the concentrations of mercury, zinc, and copper, atomic absorption with flame was used.

6.7.1 For Waters

The water withdrawn from the settling pond inside the plant has mercury contamination in the order of 20.89 ppb (Sample 1) and 17.41 (Sample 2) ppb. Samples from both lakes contain mercury levels ranging from 0.4597 ppb to 1.29 ppb with a maximum value in the six samples. The waters of Zebda wadi (sample 3, 4, 5) show no evidence of mercury contamination. Zinc is present at low concentrations in all samples with a maximum value of 0.0215 ppm (Sample 8); and for copper, no concentration was found in all stations.

6.7.2 For Soil

Taking soil samples inside the factory shows high mercury contamination, with very high levels of 6,904.15 ppb (sample 1) and 11,749.3 ppb (sample 2). Soil samples which were taken from the main slag also show high mercury contamination also with values of 4,077.57 ppb (sample 6) and 1,252.39 (sample 7), slightly different values compared to samples taken in the factory.

A soil sample which was taken near Zebda wadi shows mercury contamination (5.1823 ppb). Zinc is present with low concentrations with a maximum of 0.0608 ppb (sample 07). Copper was absent in our soil samples.

6.8 Interpretation of Physic-Chemical Results by Statistics Methods

6.8.1 For Water Samples

The distribution of individuals on the F1–F2 plane shows that along the F1 axis, which includes elements with the same chemical facies (Hg, Cu, Zn, Ca2+, Mg2+, Na+, K+, Cl-, Cl-, SO4 2-) at Zebda wadi and the settling basin. Elements with the same chemical facies group along the F2 axis, reflecting a high concentration of elements ($So4^{-2}$, Na^{+}, K^{+}, Mg^{+2}, Ca^{+2}) in the two lagoons (Fig. 14).

To confirm the presence of these high concentrations of the major elements obtained, the diagram software was used to determine the different chemical facies present in the waters of the two lagoons.

According to this diagram, the chemical facies of the waters show the existence of three types of waters:

– Highly calcic chlorinated waters
– High calcium sulfate waters
– Chlorinated and sulfated waters and calcium and magnesium

These chemical compositions obtained reflect the strong mineralization of the waters of the two settling lagoons located near the plant; this mineralization is due to geological formations and the climate that contributes through high precipitation and evapotranspiration.

The dissolution of carbonate rocks (calcite, dolomite, gypsum) reflects the chemical facies obtained in the study area.

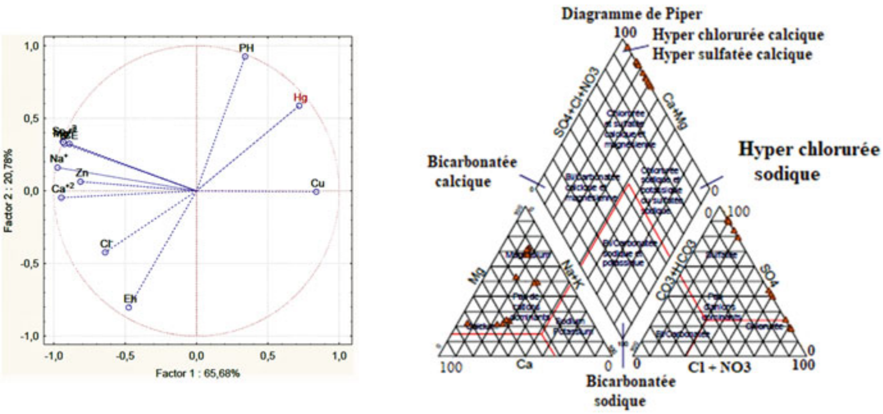

Fig. 14 Piper diagram and correlation circle of the main component analysis for water samples [15]

6.8.2 For Soil Samples

The projection of individuals according to the F1–F2 plane shows that the F1 axis group elements with the same chemical facies S02 and S06 (Hg, Cu, Zn, Ca^{2+}, Mg^{2+}, Na^{+}, K^{+}, Cl^{-}, SO_4^{2-}) and groups in a point cloud the individuals with high Hg contents, despite their samples from different locations. It can be said that the main slag S06 and the stupefied waste S01 have the same chemical composition (Fig. 15).

From the analyses and results obtained, it was found that our samples show strong mineralization with heavy metal contamination. The main source of this contamination is Hg; it comes from the HgS cinnabar, as it is the first ore used for mercury production previously in the plant.

The correlation between mercury and calcium (−0.6281) is explained by the gangue which consists of calcite $CaCO_3$. The strong correlation with Mg is expressed by the presence of dolomite in the gangue also $CaMg(CO_3)$.

Our soil samples show mercury contamination in the order of 11.2 ppm as a maximum value in the plant enclosure (S02) and a maximum value of 6.9 ppm in the

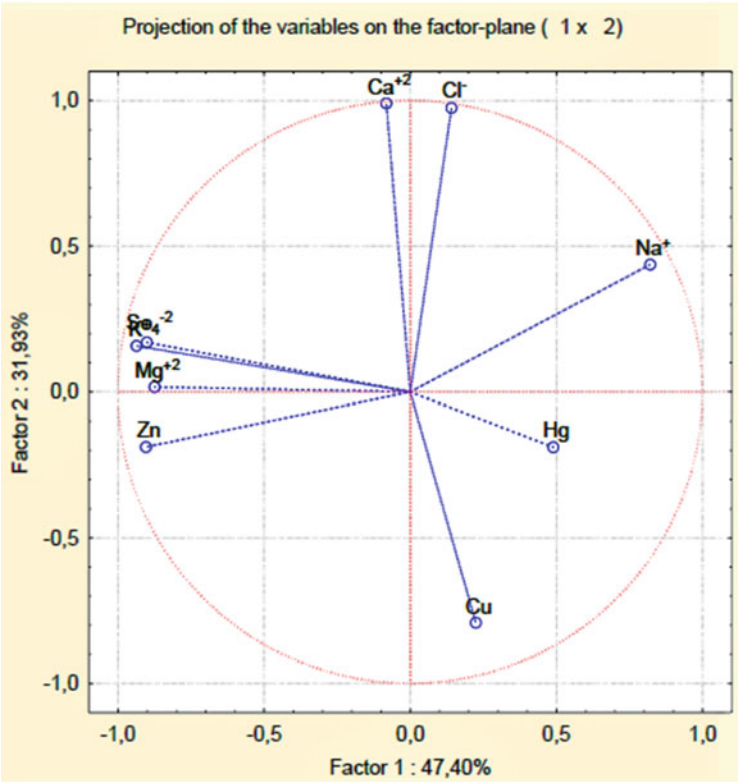

Fig. 15 The correlation circle of the analysis as a main component of soil samples

Fig. 16 The trajectory of mineral-rich waters [15]

main slag. The mercury values in the soil decreasing near the Zebda wadi (0.005 ppm). This decrease in concentration is due to the distance from the plant.

Soil contamination (Stupp waste; main slag) will cause water contamination during periods of heavy rainfall; the water will transport these heavy metals in dissolved form to the settling lakes, as the land has a slope that facilitates the transport of water loaded with these metals. Indeed, the waters of the lakes will be saturated, and the excess will flow once again toward Zebda wadi according to the slope shown in the figure.

Rainwater also generates another very important phenomenon, which is "mercury recycling." The mercury residue in the capacitors will be vaporized under the effect of high temperatures during periods of high temperatures; heavy rains with low temperatures will condense the mercury into small droplets, which is observed on site during the field visit (Fig. 16).

These droplets will be transported by rainwater to Zebda wadi, which is the receiver according to the direction of flow in the region. Zebda wadi is a tributary of Fendek wadi [24], the latter supplies the Oligocene groundwater table, so that this table will be contaminated.

In the metal trace elements (MTE) analyzed according to the different stations and in the vicinity of the site, the following order of abundance or contamination is recorded:

$Hg > Zn > Cu$ [15].

The results obtained are alarming and show that at the plant level the problem of mercury pollution still persists. The rehabilitation operation of the site is strongly requested in order to protect the environment.

7 Suggested Solutions to Clean up the Ismail Site

- As with any therapeutic approach, it is desirable to provide clear and objective information to the public and professionals on the dangers of mercury. To this end, national documents should be produced and widely disseminated.
- The availability of accurate mercury emission inventories is an important first step toward controlling major sources of pollution. Good knowledge of these sources will facilitate the development of cost-effective emission control policies.
- The first phase of depollution involves a waste classification process followed by an assessment of the impact of different disposal methods.
- The decommissioning and dismantling of treatment facilities and equipment are mandatory. These installations must be cleaned and then melted.
- Canals must be empty, equipment cleaned and sold, and buildings must be reused or demolished.

7.1 Solution 01

- Remove the surface layer of the soil (up to 20 cm deep) on which the treatment plant is located.
- Thermal desorption of the removed layers and recovery of mercury in a gaseous state (Fig. 17).
- Tailings and waste rock management techniques include the use of thermally desorbed soils to close pits (Guenicha and Mra-Sma) as backfill.

If the soil is not treated (polluted soil), these pits must be insulated from the outside with a polymer waterproofing geomembrane. The use of a thin layer of topsoil as a growing medium for future vegetation.

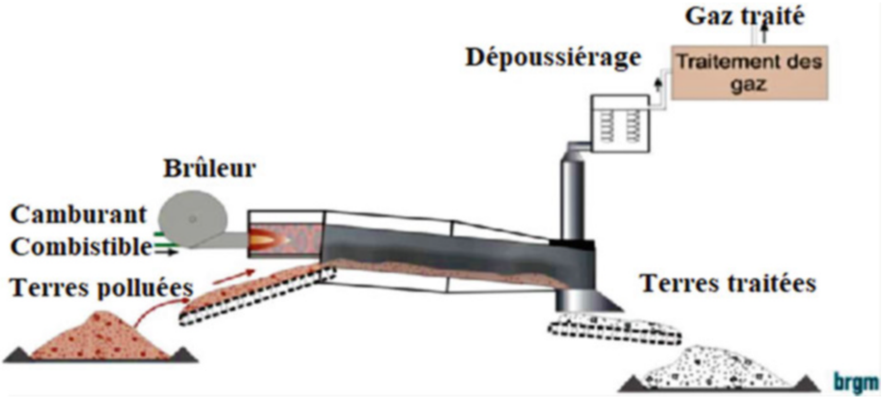

Fig. 17 Schematic diagram of thermal desorption [18]

– Physical stabilization of the soil by reforestation
– The storage of hazardous waste in specialized sites
– Pumping and recycling of water from the settling basin, lakes 1 and 2

7.2 Solution 02

"Venting" is the extraction of volatile pollutants using air injection. Also, preliminary work may be necessary such as lowering the groundwater table (Fig. 18).

Containment (after venting) consists of installing an underground watertight partition to prevent the migration of pollutants to the groundwater table (Fig. 19).

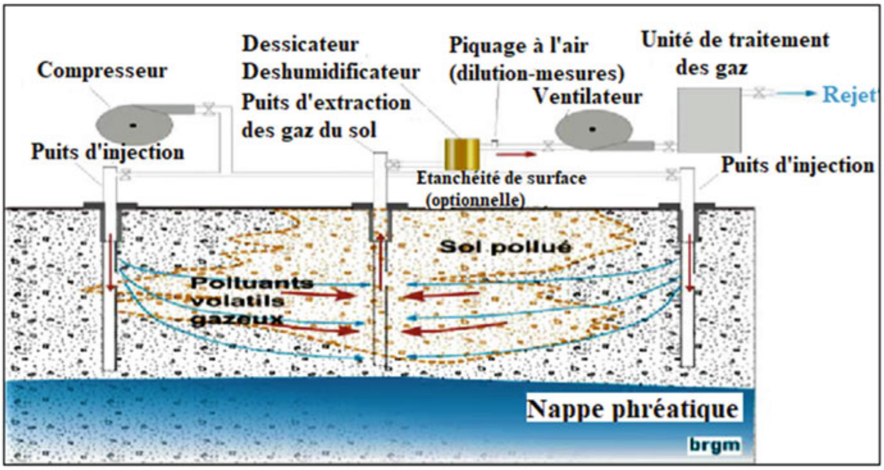

Fig. 18 Schematic diagram of the venting principle [18]

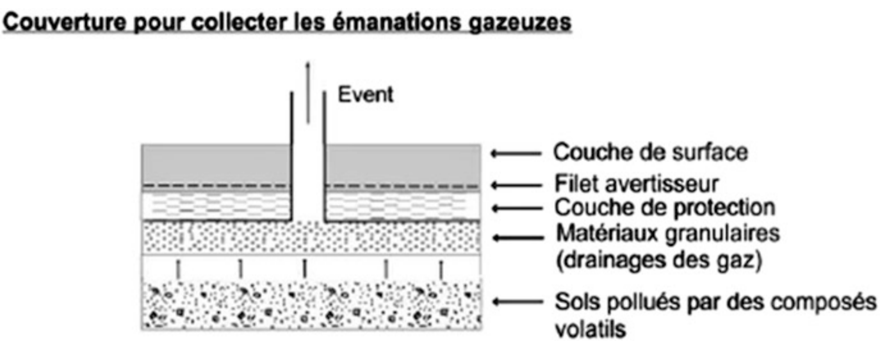

Fig. 19 Surface isolation – containment by covering and sealing [18]

It is a reliable method, but the pollutants are not destroyed and remain in place (heavy metals).

- Physical stabilization of the soil by reforestation
- Storage of hazardous waste in specialized sites
- Pumping and recycling of water from the settling basin, lakes 1 and 2
- Finally, it is recommended that a monitoring program be put in place to assess the effectiveness of the remediation measures and identify any corrective measures that may be required.
- Regular water quality monitoring in wadi and well

8 Conclusions

When an operation is completed, the site must be prepared for future use. The management of waste from mining activities and tailings and waste rock usually represents an undesirable financial burden for operators.

Generally, the mine and ore processing plant are designed to extract as many marketable products as possible, and tailings and environmental management as a whole is then designed as a consequence of the mining stages.

The choice of tailings and/or waste rock management method to be applied depends mainly on an assessment of three factors:

- The cost
- Environmental performance
- The risk of accidents

The aim will therefore be to leave as few traces as possible.

9 Recommendations

Mining operations generate wastes that can be harmful to the environment if they are disposed of without adequate treatment. For example, some of the waste generated by mining contains significant amounts of sulfide minerals that oxidize when exposed to water and air. In the short and long term, metals are known for their effects on human health. In humans, as in other living organisms, the toxicity of metals varies according to the metallic elements, their mode of penetration into the organism, and their chemical form (speciation).

Monitoring of an abandoned or active mine site is mandatory. This monitoring is aimed at preserving the environment and especially natural ecosystems. Therefore, studies must be carried out, whether ad hoc and local or recurrent and national, to measure the levels of metal deposits. These studies measure the deposition either directly (by placing collectors close to the ground) or indirectly (by accumulation in soils, sediments, living organisms).

The implementation of a program allows an estimate, in background situations, of metal deposits (iron, mercury, nickel, lead, arsenic, zinc). This program has the following objectives:

- Monitor the variations of metal deposits in the natural environment.
- Evaluate the extent of contaminated areas by using the ArcMap application.
- Identify the local origin of the sources of emissions.
- Set up a rehabilitation plan for closed or abandoned sites.
- Monitor improvements resulting from the application of rehabilitation plans to reduce the impact of metal emissions.

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Physicochemical and Bacteriological Quality of Surface Water Resources Receiving Common Wastewater Effluents in Drylands of Algeria

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Abstract The assessment of water quality and pollution of surface water resources is crucial to maintain the integrity of aquatic environments. This study aims at characterizing water physicochemical and bacteriological quality of Wadis of Biskra (northeastern Algeria). Water samples were collected monthly from three different Wadis receiving common wastewater effluents from the city of Biskra. Using standard methods, each sample underwent several analyses to determine physicochemical parameters (temperature, pH, electrical conductivity, turbidity, biological and chemical oxygen demand "BOD_5 and COD", and concentrations of suspended solid materials, dissolved oxygen, phosphate, nitrites, nitrates, and ammoniacal nitrogen) and bacterial quality (total coliforms, faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia*). Most of the measured physicochemical parameters reached unsuitable quality limits according to FAO and WHO standards. The water of Wadis of Biskra are characterized by slightly alkaline water pH (7–7.79), electrical conductivity >1,500 μS/cm, turbidity >5 FTU, very low level of suspended solid materials (1–1.33 mg/L), dissolved oxygen <5–8 mg/L, phosphates >2 mg/L, BOD_5 > 5 mg/L, COD >30 mg/L, nitrite >0.1 mg/L, and NH_3–N > 0.5 mg/L. Our findings emphasized the high contamination load of bacterial groups studied that exceeded WHO standards: total coliforms (56,917–76,167 CFU/100 mL), faecal coliforms (457–6,100 CFU/100 mL), faecal streptococci (1,432–5,217 CFU/100 mL), and sulfite-reducing *Clostridia* (886–5,217 CFU/100 mL). These results revealed a significant faecal pollution in the water of study Wadis. The spatiotemporal trend of different physicochemical and bacterial parameters, as well as the relationships between bacteria densities and physicochemical parameters were tested and discussed. The discharge of untreated wastewater into natural Wadis of drylands results in high and potential pollution risk with serious health and environmental issues. Therefore, the appropriate water treatment prior to wastewater discharge is needed urgently to prevent aquatic ecosystem pollution and degradation.

Keywords Algeria, Bacteriological indicators, Drylands, Eutrophication, Faecal pollution, Surface water resources, Urban wastewater effluents, Water physicochemical parameters, Water quality

Abbreviations

ANOVA	Analysis of variance
BOD_5	5-Day biological oxygen demand
CFU	Colony-forming unit
COD	Chemical oxygen demand
DO	Dissolved oxygen
EC	Electrical conductivity
FC	Faecal coliforms
FS	Faecal streptococci

GLM	Generalized linear model
MPN	Most probable number
SD	Standard deviation
SRC	Sulfite-reducing *Clostridia*
SSM	Suspended solid material
TC	Total coliforms
WBK	Wadi of Biskra
WHO	World Health Organization
WRB	Wadi of Chaabet Roba
WZM	Wadi of Zemer

1 Introduction

Water is a rare and precious resource in hot arid regions. In these regions, groundwater plays crucial roles for developing countries as it is often the only source of drinking and irrigation water. This water is therefore vital for the socioeconomic development of these countries [1–3]. However, this water is highly exposed to alteration and seriously threatened by different human activities [4, 5]. Population growth and lack of awareness among people accompanied by rapid urbanization and intensive industrialization and agriculture are causing widespread degradation in natural habitats and disturbances in ecosystem integrity [2, 6], because these activities generate various pollutants that affect the physicochemical and biological quality of water and soil and consequently biota [7–9].

Nature and living beings are increasingly suffering the consequences of pollution generated from industrial development and population growth [10, 11]. Water pollution affecting rivers, seas, groundwater, and lakes is the result of the discharge of wastewater in nature without or with insufficient treatment, thus causing degradation of habitat and disturbance of ecosystem balance [8, 9]. The problem is even more serious in the case of industrial effluents containing toxic pollutants. Generally, effluents require a more or less simple treatment, depending on the degree of water alteration, before their release into the natural environment [3, 8, 12].

Water pollution is one of the serious problems of modern civilization as it continuously concerns people and governments. Increasing pollution is spreading and threatening development efforts and the health of humans and their environment, mainly water resources [5, 6, 12–14]. It is therefore necessary to use wisely these water resources and find the best conditions of their protection. It is also important to delineate the risks of pollution to eliminate or mitigate their harmful effects [6]. One of the negative aspects of the population explosion associated to urban centers and industrial development is the considerable increase in the volume of wastewater (domestic and industrial), which is systematically discharged freely and almost without control in nature [3, 10]. Domestic wastewater generally contains human feces, hospital discharges, and slaughterhouse wastewater. Industrial discharges, in addition to their organic matter load, may also contain toxic substances such as heavy metal salts, arsenic, radioactive particles, etc. [4, 9, 10, 15].

Urbanization, growth of industry, and intensification of agriculture have increased, chronically and/or accidentally, watercourse pollution by affecting its physicochemical and biological quality [11, 15]. Half of the world's rivers are polluted [15]. This chemical, organic, and microbiological pollution comes from, among others, synthetic fertilizers and pesticides used in agriculture and toxic discharges from industrial and mining activities [6]. Rainfall runoff and infiltration into the soil result in pollution of streams and seas/oceans [7, 16]. Microbiological pollutants come mainly from domestic wastewater and landfills [4, 15]. These pollutants are drivers of waterborne diseases that can cause epidemics [13].

Agriculture is currently ranked as the leading source of water pollution in several regions in the developed industrialized world [11], but especially in arid countries where, for adverse climatic reasons, irrigation with sometimes poor quality water is an unavoidable technical imperative [17]. One of the major environmental consequences of the current agriculture intensification is the degradation of water quality. The latter is reflected, for both surface water and groundwater, by pollution linked to the dissemination of agricultural inputs such as phytosanitary products, nitrogenous and phosphate mineral fertilizers, or livestock manure [11]. On the other hand, the reuse of wastewater in crop irrigation [18, 19] and its byproducts such as sewage sludge in land fertilization [20], provided using adequate treatments and pollutant removal [21], may solve partially issues related to water shortage in arid agriculture and food insecurity at drylands [17, 18].

The Wadis of North Africa, Algeria included, have become dumps as they carry all kinds of liquid and solid discharges and trashes [16]. For example, the Wadis of Seybouse, Medjerda, and Kebir receive sewage discharged by the localities and industries located along these rivers [9, 10]. This wastewater contributes to the deterioration of Wadis water quality and the integrity of the ecosystem [7, 8]. It should be noted that this contaminated water is used for irrigation, which leads to the displacement of pollutants toward the soil of crop fields and the surface layers flooded by Wadis [7, 16], but these can also transmit diseases to humans through contaminated agricultural products [22].

Water as a biotope is characterized by its physicochemical and hydrodynamic features [16]. Thus the quality of river water depends on various factors that can be altered and degraded [7, 23]. These factors help to draw up a diagnosis of the watercourse to evaluate the need or not of water resource management. For example, the temperature of water is considered an important abiotic factor since it determines the dissolved oxygen content in the water. Also saturation level of the water in dissolved oxygen is inversely proportional to its temperature [9]. In addition, the most important indicators of water pollution include 5-day biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), nitrogen products (nitrates, nitrites and ammoniacal nitrogen), phosphates, heavy metals concentration, faecal contamination status [4, 7, 15, 23].

Studies on the characterization of surface water in arid regions and the environmental factors that determine the quality of this water are deeply neglected given the scarcity of water and also their ephemeral nature. This study focuses on the physicochemical and biological quality of the surface water of Wadis of Biskra (Algeria's No. 1 agricultural hub [24]). It determines the microbiological quality and investigates how the physicochemical factors of water influence the microbiological characteristics of Wadi water.

2 Materials and Methods

2.1 *Study Area*

The province "Wilaya" of Biskra covers an area of 21.671 km^2 and has a population of 73 k inhabitants with a density of 34 inhabitants/km^2. Located in northeastern of Algeria, it is bounded by the following wilayas: Batna to the north, M'sila to the northwest, Djelfa to the southwest, El-Oued to the south, and El-Oued and Khenchela to the northeast (Fig. 1).

The 41-year climate data (1973–2013), provided from Biskra weather station, and which were retrieved from the TuTiempo.net database (https://en.tutiempo.net/climate/ws-605250.html), indicate an average annual temperature of 21.6°C with a maximum in July of 41.7°C and a minimum of 6.6°C in January. Precipitation is low and irregular reaching 125 mm/year. The wettest month is September with

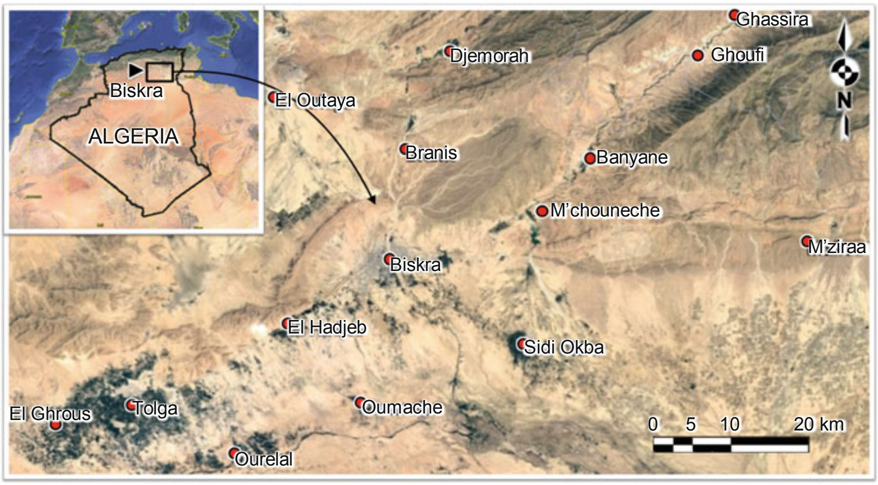


Fig. 1 Location of the region of Biskra "study area" in northeastern Algeria

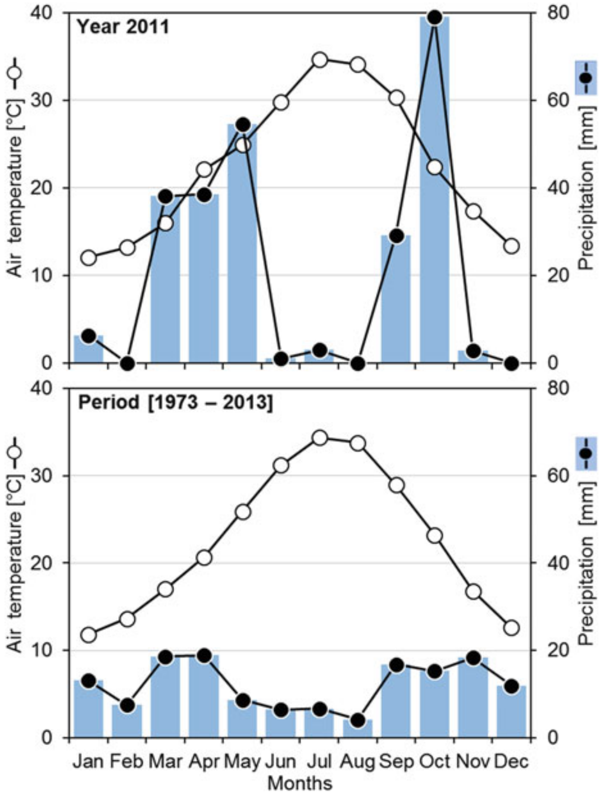


Fig. 2 Ombrothermic diagrams of Gaussen and Bagnouls of the region of Biskra, northeastern Algeria, applied for the study year "2011" (top plot) and the period (1973–2013) (bottom plot)

an average of 20.1 mm, while the least rainy month is July with 2 mm (Fig. 2). According to Köppen classification, the climate is hot desert type "BWh," with an evaporation rate of 99.8% and a runoff of 0.2%. The water deficit is about 1,062 mm/year (Tables 1 and 2). Biskra is classified hyperarid according to De Martonne aridity index ($I_{DM} = 4$). The Gaussen and Bagnouls diagram indicates a dry period that lasts 12 consecutive months (Fig. 2).

2.2 *Study Wadis*

This study was conducted in three sites that represent the main wastewater outfalls from the city of Biskra in the hydrographic network.

Site 1: Wadi of Biskra (WBK). It takes its source at the confluence of Oued El Hai and Djamoura. It is fed upstream by several Wadis, viz., Oued Branis, Oued Lefrahi, Oued El Besbas, and Oued Lakhdar. It is the most important site, characterized by 1.5 m diameter wastewater discharge pipes and a slope of 2.5%, collecting wastewater from the northern zone and the city center of Biskra.

Table 1 Long-term monthly climatic data of the city of Biskra (latitude, 34.85 N; longitude, 5.73 E; altitude, 87 m; WMO station, 60525) in northeastern Algeria

Parameters	January	February	March	April	May	June	July
Mean temperature [°C]	11.6 ± 2.49	13.3 ± 3.04	16.1 ± 3.17	20.2 ± 3.88	24.8 ± 4.56	30.1 ± 5.2	33.4 ± 5.7
Maximum temperature [°C]	16.1 ± 4.39	18.2 ± 4.36	21.7 ± 4.26	26.1 ± 4.02	30.5 ± 4.11	36 ± 4.2	41.7 ± 4.95
Minimum temperature [°C]	6.6 ± 5.35	7.8 ± 5.5	11.1 ± 5.69	14.3 ± 5.9	18.2 ± 5.75	23.8 ± 6.06	26.7 ± 5.88
Precipitation [mm]	9 ± 12.42	8 ± 8.13	12 ± 11.16	10 ± 8.48	13 ± 9.71	6 ± 6.97	2 ± 3.47
Potential evapotranspiration [mm]	33.6 ± 11.5	47 ± 11.31	80.1 ± 16.43	109.3 ± 16.45	138.9 ± 21.54	154.7 ± 21.9	169.1 ± 23.64
Water vapor pressure [hPa]	9.5 ± 1.2	9.2 ± 1.92	10.3 ± 2.62	10.8 ± 3.24	14 ± 4.64	16.1 ± 5.59	16.1 ± 4.15
Wind speed [km/h]	2.16 ± 3.78	2.16 ± 4.58	2.16 ± 4.93	2.16 ± 4.89	2.16 ± 4.61	2.16 ± 4.45	1.8 ± 2.83
Sunshine frequency [%]	60 ± 8.18	67 ± 10.34	69 ± 7.22	70 ± 8.45	70 ± 4.66	69 ± 3.62	76 ± 3.97
Day length [h]	10:04	10:53	11:56	13:01	13:56	14:23	14:10
Sunshine hours [h]	06:02	07:17	08:14	09:06	09:45	09:56	10:46
Ground frost frequency [%]	5	2	0	0	0	0	0
Effective rain [mm]	9	8	12	10	13	6	2
Effective rain ratio [%]	99	99	98	98	98	99	100
Rainy days	2	1	2	1	2	1	0
Solid precipitation ratio [%]	2	1	0	0	0	0	0
Parameters	August	September	October	November	December	Average / sum	
Mean temperature [°C]	32.5 ± 5.12	27.6 ± 4.14	22.1 ± 3.34	16.2 ± 2.63	12.1 ± 2.4	21.67 ± 3.81	
Maximum temperature [°C]	40.5 ± 4.38	34.4 ± 3.7	27.7 ± 4.31	21.1 ± 4.3	16.7 ± 4.44	27.56 ± 4.29	
Minimum temperature [°C]	26.1 ± 5.9	22.7 ± 5.87	17.2 ± 6.26	11.6 ± 5.98	7.1 ± 5.6	16.1 ± 5.81	
Precipitation [mm]	6 ± 5.23	20 ± 7.87	16 ± 10.33	18 ± 9.98	8 ± 12.02	10.67 ± 8.81	
Potential evapotranspiration [mm]	159.6 ± 20.99	126.3 ± 14.65	85.7 ± 13	51.1 ± 14.2	34.8 ± 10.26	99.18 ± 16.32	
Water vapor pressure [hPa]	19 ± 6.02	18.5 ± 3.97	14.5 ± 2.34	11.2 ± 2.39	9.2 ± 1.25	13.2 ± 3.28	
Wind speed [km/h]	1.8 ± 2.62	2.16 ± 2.26	2.16 ± 2.85	2.16 ± 2.71	2.16 ± 3.06	2.1 ± 3.63	
Sunshine frequency [%]	76 ± 5.33	77 ± 5.64	68 ± 5.67	61 ± 6.18	61 ± 11.13	68.67 ± 6.7	
Day length [h]	13:23	12:21	11:16	10:18	09:48	12:07	
Sunshine hours [h]	10:10	09:31	07:40	06:17	05:59	08:24	
Ground frost frequency [%]	0	0	0	0	4	1	
Effective rain [mm]	6	19	16	17	8	125	
Effective rain ratio [%]	99	97	97	97	99	98	
Rainy days	1	2	2	3	1	18	
Solid precipitation ratio [%]	0	0	0	0	2	0	

Table 2 Location and climatic information (classifications and indices) of the province "Wilaya" of Biskra in northeastern Algeria

Climatic information	Value/class
Location	
Latitude (North)	5.733°
Longitude (East)	34.817°
Altitude [m]	240
WMO station code	60,525
Climate characteristics	
Köppen class:	BWh
	B = Arid climate
	D = Desert
	h = hot
Budyko climate	Desert
Radiational index of dryness	10.562
Budyko evaporation [mm/year]	128
Budyko runoff [mm/year]	0
Budyko evaporation [%]	99.8
Budyko runoff [%]	0.2
Aridity	Arid
Aridity index	0.11
Moisture index [%]	−89
De Martonne index	4
Precipitation deficit [mm/year]	1,062
Climatic NPP[a]	244
NPP (Temperature)	2,339
NPP (Precipitation)	244
NPP is precipitation limited	
Gorczynski continentality index	44.5

[a]NPP: Climatic net primary production in g(DM)/m^2/year

Site 2: Wadi of Chaabet Roba (WRB). Located east of Biskra city, it receives all wastewater from the El-Alia area. It is characterized by the presence of domestic wastewater discharge pipes with a diameter of 1.2 m.

Site 3: Wadi of Zemer (WZM). Located west of Biskra city, crosses the El-Corab mountains at a location called Foum Mawya. It is fed along its course by the Wadis of Hammam, Hassi Mabrouk, El Tera, and Leham. It is characterized by discharging ducts with a diameter of 1.5 m and a slope of 1.5%. It collects wastewater from the western sector of Biskra city, which includes the industrial zone, the training center, and the city of 726 housing units.

2.3 Water Sampling

Water samples were collected monthly from January to June 2011. For each site, water sampled from several sampling points was kept in two sterilized glass bottles of 500 mL capacity. Put in isothermal boxes at a temperature of 4°C, samples were immediately transported to the laboratory for carrying out physicochemical and microbiological analyses [19].

2.4 Water Physicochemical Analyses

Water quality was determined by measuring several physicochemical parameters using standard water analysis procedures [19, 23, 25]. Water samples have undergone the following measurements: temperature, pH, electrical conductivity (EC), turbidity, suspended solid material (SSM), dissolved oxygen (DO), 5-day biological oxygen demand (BOD_5), chemical oxygen demand (COD), and concentrations of nitrite (NO_2), nitrate (NO_3), and ammoniacal nitrogen (NH_3–N). Analytical procedures of these physicochemical parameters are summarized in Table 3.

2.5 Bacteriological Analyses

The detection of total coliforms (TC), faecal coliforms (FC), faecal streptococci (FS), and sulfite-reducing *Clostridia* (SRC) was carried out using standard microbiological methods [23]. Bacteriological parameters were determined by the most probable number (MPN) method. This method consists of inoculating, using appropriate decimal dilutions of the sample to be analyzed, a series of tubes containing the nutrient medium for detecting total flora [27]. After incubation at 37°C for 24 h, the turbid tubes were considered positive. Faecal contamination was assessed by counting FC and FS.

FCs were determined and enumerated after culture in a double concentration of lactose bromocresol purple with Durham. Incubation was done at 37°C for 24 h (presumptive test). The detection of FS was carried out on Rothe medium at 37°C for 24 h (presumptive test). From the positive Rothe tubes, a subculture was then performed on Litsky medium at 37°C for 24 h (confirmatory test) (Table 3). For FC and FS, presumptive testing and counting were performed using the MPN method. This number was determined after the culture a certain number of samples and/or dilution of these samples, while the estimate was based on the principle of dilution until extinction [27]. The SRC species were detected on agar medium containing meat, liver, and mineral additives (ammonium iron(III) sulfate dodecahydrate and iron sulfate) [23]. After 24–48 h of incubation, these bacteria give typical colonies and reduce the sodium sulfite (Na_2SO_3) of the medium into sulfide which reacts with Fe^{2+} and gives FeS (iron sulfide) with black color [26].

Table 3 Methods used in water physicochemical and bacteriological analyses of Wadis receiving urban wastewater from the city of Biskra, northeastern Algeria

Water parameter	Method	Reference
Temperature	Electrode V10	CONSORT 535
pH	Electrode storage bottle KK2SP 10 B	CONSORT 535
Electrical conductivity (EC)	Electrode	EC meter
Turbidity	Spectrometry at $\lambda = 450$ nm	ISO 7027\1994 NA 746
Orthophosphate	Spectrometry at $\lambda = 430$ nm	ISO 6378\1983
Dissolved oxygen (DO)	Spectrometry at $\lambda = 535$ nm	NA 1654 ISO 5814\1994
Suspended solid material (SSM)	Spectrometry at $\lambda = 810$ nm	NA 6345
5-day biological oxygen demand (BOD_5)	Dilution and seeding	ISO 5815\1989
Chemical oxygen demand (COD)	Oxidation by excess of $KMNO_4$ in sulfuric acid medium at boiling temperature	ISO 6060\1984
Nitrites (NO_2)	Spectrometry at $\lambda = 420$ nm	ISO 7890\1986
Nitrates (NO_3)	Molecular absorption spectrometry ($\lambda = 640$ nm)	ISO 6777\1984
Ammoniac nitrogen (NH_3–N)	Manual spectrophotometry ($\lambda = 425$ nm)	ISO 7150\1984
Total coliforms	Standard membrane filter colimetry	[23, 26]
Faecal coliforms	Presumptive medium: double concentration of lactose bromocresol purple with Durham; incubation at 37°C for 24 h Confirmative medium: MacKenzie test; peptone water free of indole; incubation at 40°C	[23]
Faecal streptococci	Presumptive medium: Rothe (D/C); Rothe (S/C)	[23]
Sulfite-reducing *Clostridia*	Agar medium containing meat, liver, and mineral additives (ammonium iron(III) sulfate dodecahydrate and iron sulfate)	[23]

2.6 Statistical Analysis

In order to compare values of different variables (water physicochemical parameters and bacterial loads) between study sites, means ± standard deviations (SD) are computed based on monthly raw data that were considered replications per site [10]. The spatiotemporal variation of water physicochemical parameters and bacterial load values of TC, FC, FS, and SRC between study sites and months were tested using two-way ANOVA at a significance level $P \leq 0.05$. When ANOVA test is significant ($P \leq 0.05$), Tukey's post hoc test was applied to distinguish heterogeneous site groups. Interrelationships between water physicochemical parameters were analyzed using Pearson's correlation tests. Using the R package "corrplot" [28], the obtained correlation matrix was visualized in a single plot, in which correlation coefficients (*r*) and *P*-values were included. Because the growth of one bacterial group can either reduce or inhibit the growth of other bacteria as it changes water characteristics [29], interrelationships between densities of bacterial groups (TC, FC, FS, and SRC) were investigated using linear regressions and correlation tests. The effects of measured water parameters on the variation of bacterial loads of each of the four bacteria groups were tested using a generalized linear model (GLM). Bacterial load data “count data” were fitted to a Poisson distribution error and log link function. The statistical software R [30] was used to conduct all statistical analyses of the current study.

3 Results

3.1 Spatial Patterns of Water Physicochemical Parameters

Figure 3 shows the spatial variation of the different physicochemical parameters of the water analyzed. The Wadi of Biskra (WBK) is characterized by surface water with EC of 3,075 ± 1,344 μS/cm (range: 1,200–5,400 μS/cm) at an average temperature of 19.3 ± 4.7°C, turbidity was 150 ± 25.84 FTU (range: 118–180), phosphate content averaged 20.6 ± 8 mg/L (range: 10.5–28.8), and DO concentration was on average 3.2 ± 1.2 mg/L (range: 1.8–4.7 mg/L). SSM recorded 1.3 ± 0.4 mg/L (range: 0.7–1.9). The BOD_5 averaged 139 ± 46.67 mg/L (range: 85–220), and COD was 172.5 ± 46.8 mg/L (range: 120–240). The nitrites averaged 1.6 ± 1.2 mg/L (range: 0.1–3.8). The nitrates averaged 4.7 ± 2.5 mg/L (range: 0.51–7.75), and the ammoniacal nitrogen was 15.5 ± 4.9 mg/L (range: 9.5–22.1) (Fig. 3).

Water of the Wadi of Chaabet Roba (WRB) recorded the following characteristics: the temperature was 19.8 ± 5°C (range: 14–25°C), and pH averaged 7.6 ± 0.3 (range: 7–8). The EC was 2,825 ± 1,300 μS/cm (range: 1,280–5,200). Water turbidity was 192.7 ± 108 FTU (range: 120–401 FTU). Phosphates averaged 18.07 ± 15.07 mg/L (range: 1.8–40). DO was 3.8 ± 1.9 mg/L (range: 1.7–6.3). SSM averaged 1.3 ± 0.5 mg/L (range: 0.7–2.1). BOD_5 was 220.8 ± 152.2 mg/L (range: 40–400). The COD was 281.4 ± 139.1 mg/L (range: 162.8–480). NO_2 concentration averaged 2.7 ± 2.5 mg/L (range: 1.3–7.7), and NO_3 was 4.9 ± 3.1 mg/L (range: 2.3–10.7). NH_3–N was 4.7 ± 5.0 mg/L (range: 8.6–23.8) (Fig. 3).

At the Wadi of Zemer (WZM), water temperature averaged 20.2 ± 5°C (range: 13–26°C). The pH was 7.6 ± 0.4 (range: 7.01–8). Water EC was 3,611 ± 2,220 μS/cm (range: 1,400–7,700). The turbidity was 124.3 ± 36.5 FTU (range: 87–170 FTU). Phosphate concentration was 16.20 ± 15.44 mg/L (range: 1.7–43.5 mg/L). DO averaged 4 ± 2.9 mg/L (range: 1.9–9.8). The SSM was 1 ± 0.7 mg/L (range: 0.3–2.1), BOD_5 was 140 ± 69.5 mg/L (range: 45–250), COD was 160.8 ± 63.9 mg/L (range: 90–270), NO_2 was 1.5 ± 1 mg/L (range: 0.1–4.8), NO_3 was 4.2 ± 3.8 mg/L (range: 0.3–11.1), and NH_3–N averaged 16.2 ± 1.7 mg/L (range: 14–18.6) (Fig. 3).

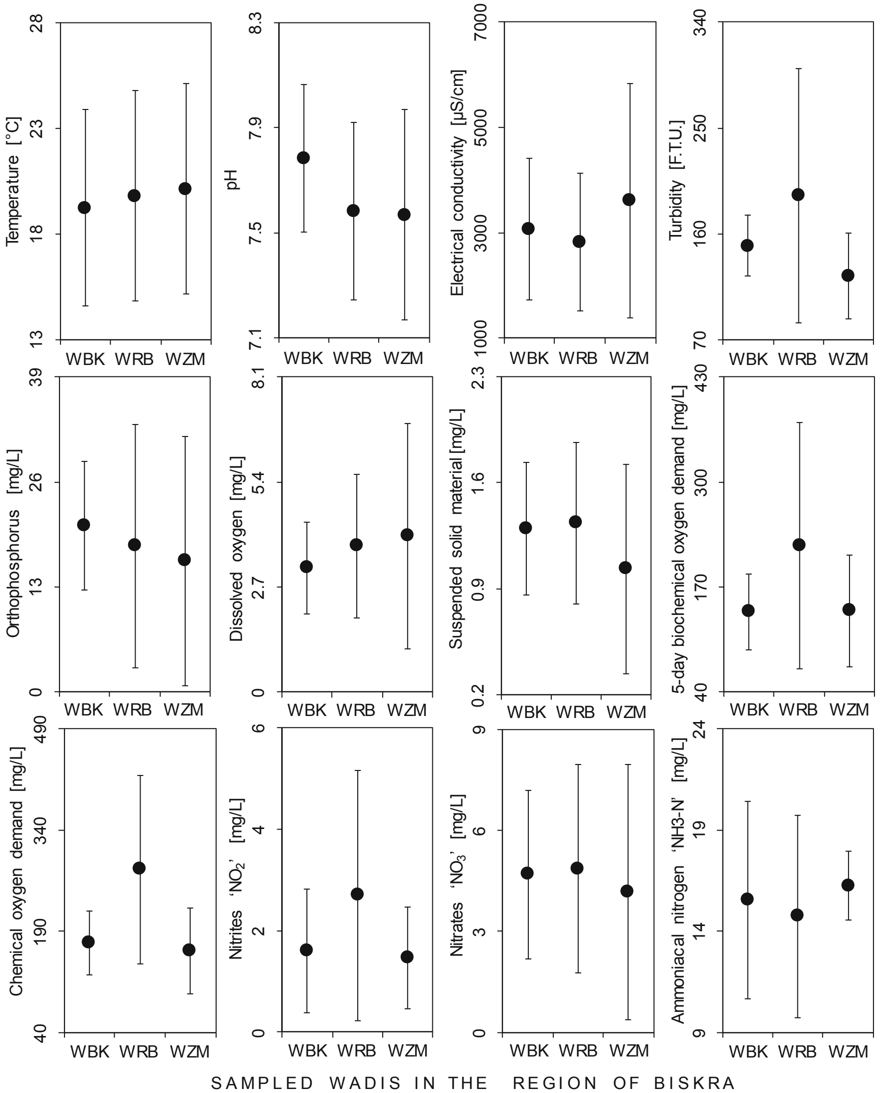
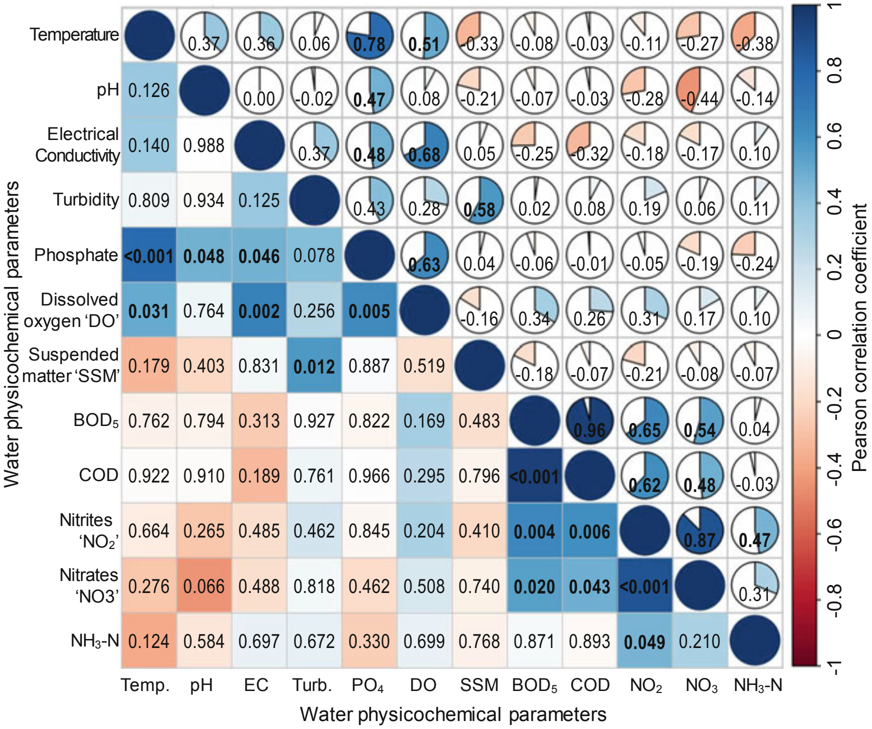


Fig. 3 Spatial variation of the physicochemical parameters of water collected in Wadis receiving wastewater from the city of Biskra, northeastern Algeria. The values displayed are the mean (solid circle) ± standard deviation (vertical bars) (*WBK* Wadi of Biskra, *WRB* Wadi of Chaabet Roba, *WZM* Wadi of Zemer)

3.2 Relationships Between Water Physicochemical Parameters

The pair relationships between water physicochemical parameters revealed many significantly positive correlations at $P < 0.001$ and $P < 0.01$ (Fig. 4). These significant correlations included phosphates–pH ($P = 0.048$), phosphates–EC ($P = 0.046$), temperature–DO ($P = 0.031$), DO–EC ($P = 0.002$), DO–phosphates ($P = 0.005$), turbidity–SSM ($P = 0.012$), COD–BOD_5 ($P < 0.001$), NO_2–BOD_5 ($P = 0.004$), NO_3–BOD_5 ($P = 0.020$), NO_3–COD ($P = 0.043$), NO_2–NO_3 ($P < 0.001$), and NH_3–N–NO_2 ($P = 0.049$).



	Temp.	pH	EC	Turb.	PO_4	DO	SSM	BOD_5	COD	NO_2	NO_3	NH_3-N
Temperature		0.37	0.36	0.06	**0.78**	**0.51**	-0.33	-0.08	-0.03	-0.11	-0.27	-0.38
pH	0.126		0.00	-0.02	**0.47**	0.08	-0.21	-0.07	-0.03	-0.28	-0.44	-0.14
Electrical Conductivity	0.140	0.988		0.37	**0.48**	**0.68**	0.05	-0.25	-0.32	-0.18	-0.17	0.10
Turbidity	0.809	0.934	0.125		0.43	0.28	**0.58**	0.02	0.08	0.19	0.06	0.11
Phosphate	**<0.001**	**0.048**	**0.046**	0.078		**0.63**	0.04	-0.06	-0.01	-0.05	-0.19	-0.24
Dissolved oxygen 'DO'	**0.031**	0.764	**0.002**	0.256	**0.005**		-0.16	0.34	0.26	0.31	0.17	0.10
Suspended matter 'SSM'	0.179	0.403	0.831	**0.012**	0.887	0.519		-0.18	-0.07	-0.21	-0.08	-0.07
BOD_5	0.762	0.794	0.313	0.927	0.822	0.169	0.483		**0.96**	**0.65**	**0.54**	0.04
COD	0.922	0.910	0.189	0.761	0.966	0.295	0.796	**<0.001**		**0.62**	**0.48**	-0.03
Nitrites 'NO_2'	0.664	0.265	0.485	0.462	0.845	0.204	0.410	**0.004**	**0.006**		**0.87**	**0.47**
Nitrates 'NO3'	0.276	0.066	0.488	0.818	0.462	0.508	0.740	**0.020**	**0.043**	**<0.001**		0.31
NH_3-N	0.124	0.584	0.697	0.672	0.330	0.699	0.768	0.871	0.893	**0.049**	0.210	

Fig. 4 Correlation matrix displaying interrelationships between physicochemical parameters of wastewater discharged into Wadis of the region of Biskra, northeastern Algeria. Pearson correlation tests are given as correlation coefficient values (above the diagonal) and the *P*-value (below the diagonal). Significant correlations ($P \leq 0.05$) are indicated in boldface type. Shading and intensity colors in pie charts and squares also visualize Pearson coefficient values

3.3 Spatial Variations of Bacterial Loads

The Wadi of Biskra (WBK) recorded a load of total coliforms of 76,167 ± 14,784 CFU/100 mL (range: 60,000–98,000), faecal coliforms of 457 ± 191.20 CFU/100 mL (range: 225–760), faecal streptococci of 1,492 ± 174.40 CFU/100 mL (range: 1,200–1,700), and sulfite-reducing *Clostridia* of 5,217 ± 3,563 CFU/100 mL (range: 1,600–9,600) (Fig. 5). At Wadi of Chaabet Roba, the density of TC reached 62,767 ± 12,540 CFU/100 mL (range: 48,000–80,500). The FC averaged 628 ± 186 CFU/100 mL (range: 400–860), FS were 7,830 ± 2,026.38 (range: 5,200–9,880), and SRC were 1,702 ± 712.36 CFU/100 mL (range: 760–2,460). The Wadi of Zemer recorded a TC density of 56,917 ± 22,330 CFU/100 mL (range: 21,000–80,000), FC averaged 6,100 ± 2,552 CFU/100 mL (range: 2,800–8,900), FS averaged 4,332 ± 1,807 CFU/100 mL (range: 1,500–6,300), and SRC averaged 886 ± 861 CFU/100 mL (range: 390–2,600).

3.4 Interrelationships Between Bacterial Groups

The growth of TC was correlated negatively with FS (linear regression: TC = −0.5659 × FC + 66,639). The density of FS was positively associated to the increase of TC and FC loads (TC = 0.2611 × FS + 64,100, FC = 0.0783 × FS + 2,039). However, the increase of faecal bacteria (FC and FS) loads in water deemed to be negatively correlated with SRC density (FC = −0.4025 × SRC + 3,442, FS = −0.3906 × SRC + 5,567). A positive relationship was observed between TC and SRC (TC = 3.9230 × SRC + 55,078), where the correlation was statistically significant ($r = 0.61$, $P = 0.007$). The other correlation tests between bacteria densities were nonsignificant (Fig. 6).

3.5 Spatiotemporal Variation of Water Parameters

Regarding the spatial variation of the physicochemical parameters of water, although different values were observed between the sites studied, no significant statistical difference (ANOVA: $P > 0.05$) was detected between the studied Wadis, except for nitrates ($F_{(2,10)} = 4.39$, $P = 0.043$). The temporal variation, i.e., between study months, was significant for water temperature ($F_{(5,10)} = 33.28$, $P < 0.001$), pH ($F_{(5,10)} = 8.40$, $P = 0.002$), EC ($F_{(5,10)} = 17.40$, $P < 0.001$), orthophosphate ($F_{(5,10)} = 7.91$, $P = 0.003$), nitrites ($F_{(5,10)} = 14.58$, $P < 0.001$), and nitrates ($F_{(5,10)} = 6.25$, $P = 0.007$). For these latter six parameters, the general ANOVA model testing spatiotemporal variation "Sites + Months" demonstrated that the

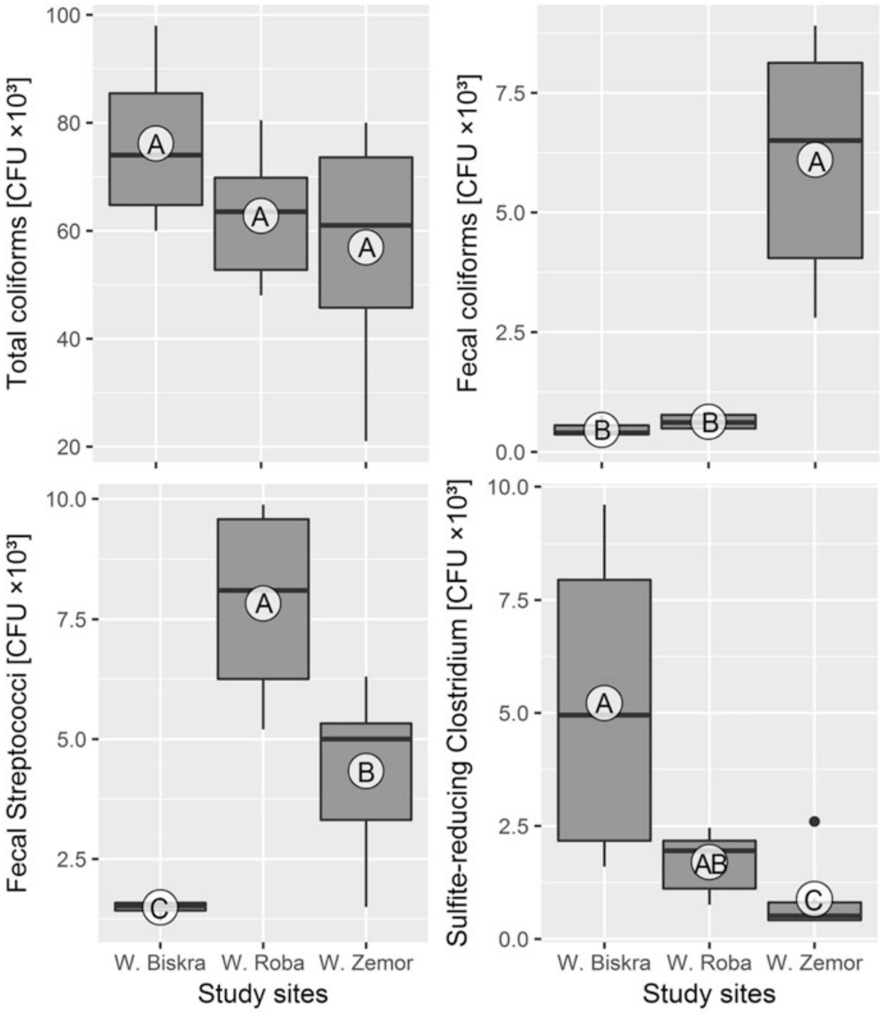


Fig. 5 Boxplots displaying the variation of bacterial loads (in CFU/100 mL) of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving urban wastewater from of the city of Biskra in northeastern Algeria. The same letters associated with average values (white circles) are significantly not different at $P \leq 0.05$ following Tukey's post hoc test

variability of the values recorded monthly in each site was statistically significant (Table 4).

Statistically, ANOVAs revealed a significant difference between the three Wadis for faecal coliform populations ($F_{(2,10)} = 31.92$, $P < 0.001$), faecal streptococci ($F_{(2,10)} = 43.87$, $P < 0.001$), and sulfite-reducing *Clostridia* ($F_{(2,10)} = 5.92$, $P = 0.020$). No difference was observed for spatial variation in total coliforms

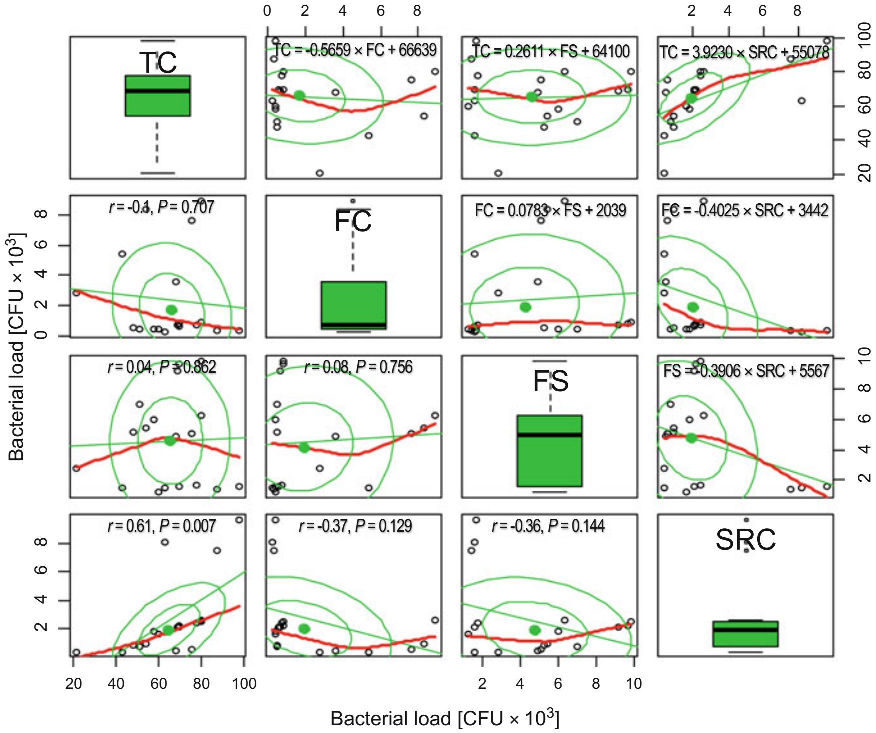


Fig. 6 Scatterplot matrix between all pairs of bacterial groups (TC, total coliforms; FC, faecal coliforms; FS, faecal streptococci; and SRC, sulfite-reducing *Clostridia*) screened in Wadis of Biskra (northeastern Algeria) receiving common wastewater effluents. Red curves are LOWESS smoothers. Green lines represent linear regressions with the equations given at the top of plots above the diagonal. Pearson correlation tests between bacteria density are displayed in plots below the diagonal where r = correlation coefficient value and P = P-value. Green ellipses represent 40 and 80% concentration levels of observations with the center in solid green circle

($F_{(2,10)} = 2.76$, $P = 0.111$) (Table 5). The bacterial load of faecal streptococci varied significantly between the studied months ($F_{(5,10)} = 3.37$, $P = 0.048$). Tukey tests showed significantly higher bacterial loads of FC in WZM, FS in WRB, and SRC in WBK (Table 6).

3.6 *Effects of Water Characteristics on Bacterial Loads*

The GLMs revealed that the bacteria respond differently to water parameters of polluted Wadis (Table 7). While the decrease in temperature, pH, EC, SSM, BOD_5, and NO_2 caused a significant increase ($P < 0.001$) in total coliforms, turbidity, orthophosphate, DO, COD, NO_3, and NH_3–N were deemed correlated positively

Table 4 Two-way analyses of variance (ANOVA) testing the spatiotemporal variations of water physicochemical parameters of Wadis receiving wastewater in the region of Biskra, northeastern Algeria

Variables	Df	SS	MS	*F*	*P*	Sig.	SS	MS	*F*	*P*	Sig.	SS	MS	*F*	*P*	Sig.
		Temperature					pH					Electrical conductivity (EC)				
Sites	2	2.48	1.24	0.61	0.561	NS	0.18	0.09	2.59	0.124	NS	1.9E+06	9.7E+05	2.23	0.158	NS
Months	5	337.02	67.40	33.28	<0.001	***	1.42	0.28	8.40	0.002	**	3.8E+07	7.6E+06	17.40	<0.001	***
Model	7	339.51	48.50	23.94	<0.001	***	1.60	0.23	6.74	0.004	**	4.0E+07	5.7E+06	13.06	<0.001	***
Error	10	20.26	2.03				0.34	0.03				4.3E+06	4.3E+05			
Total	17	359.76					1.94					4.4E+07				
		Turbidity					Orthophosphate					Dissolved oxygen (DO)				
Sites	2	14,297	7,149	1.97	0.190	NS	57.6	28.8	0.54	0.599	NS	2.14	1.07	0.42	0.668	NS
Months	5	32,063	6,413	1.77	0.207	NS	2,111.8	422.4	7.91	0.003	**	40.86	8.17	3.22	0.055	NS
Model	7	46,361	6,623	1.83	0.187	NS	2,169.4	309.9	5.80	0.007	**	43.00	6.14	2.42	0.099	NS
Error	10	36,237	3,624				534.2	53.4				25.38	2.54			
Total	17	82,598					2,703.6					68.38				
		Suspended solid material (SSM)					Biological oxygen demand (BOD_5)					Chemical oxygen demand (COD)				
Sites	2	0.33	0.16	0.50	0.621	NS	26,463	13,232	1.35	0.303	NS	5.3E+04	2.7E+04	3.03	0.093	NS
Months	5	1.48	0.30	0.90	0.516	NS	52,810	10,562	1.08	0.429	NS	4.1E+04	8.2E+03	0.93	0.500	NS
Model	7	1.80	0.26	0.79	0.614	NS	79,274	11,325	1.15	0.405	NS	9.4E+04	1.3E+04	1.53	0.261	NS
Error	10	3.28	0.33				98,151	9,815				8.7E+04	8.7E+03			
Total	17	5.08					177,424					1.8E+05				
		Nitrites (NO_2)					Nitrates (NO_3)					Ammoniacal nitrogen (NH_3–N)				
Sites	2	5.46	2.73	4.39	0.043	*	1.61	0.81	0.22	0.806	NS	6.85	3.43	0.26	0.779	NS
Months	5	45.41	9.08	14.58	<0.001	***	114.25	22.85	6.25	0.007	**	124.22	24.84	1.85	0.190	NS
Model	7	50.88	7.27	11.67	<0.001	***	115.86	16.55	4.53	0.016	*	131.07	18.72	1.40	0.305	NS
Error	10	6.23	0.62				36.56	3.66				134.07	13.41			
Total	17	57.11					152.42					265.14				

Df degrees of freedom, *SS* sum squares, *MS* mean squares, *F* *F*-statistics, *P* *P*-value, *Sig*. statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, NS: $P > 0.05$

Table 5 Two-way ANOVAs testing the effects of sites and months on the variation of water bacterial loads of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving wastewater effluents in the region of Biskra, northeastern Algeria

Variables	Df	SS	MS	*F*	*P*	Sig.	SS	MS	*F*	*P*	Sig.
		Total coliforms					Faecal coliforms				
Sites	2	1.2E+09	5.8E+08	2.76	0.111	NS	1.2E+08	6.2E+07	31.92	<0.001	***
Months	5	2.3E+09	4.5E+08	2.13	0.145	NS	1.4E+07	2.7E+06	1.40	0.304	NS
Model	7	3.4E+09	4.9E+08	2.31	0.112	NS	1.4E+08	2.0E+07	10.12	<0.001	***
Error	10	2.1E+09	2.1E+08				1.9E+07	1.9E+06			
Total	17	5.5E+09					1.6E+08				
		Faecal streptococci					Sulfite-reducing *Clostridia*				
Sites	2	1.2E+08	6.0E+07	43.87	<0.001	***	6.4E+07	3.2E+07	5.92	0.020	*
Months	5	2.3E+07	4.6E+06	3.37	0.048	*	1.6E+07	3.2E+06	0.60	0.704	NS
Model	7	1.4E+08	2.1E+07	14.94	<0.001	***	8.0E+07	1.1E+07	2.12	0.136	NS
Error	10	1.4E+07	1.4E+06				5.4E+07	5.4E+06			
Total	17	1.6E+08					1.3E+08				

Df degrees of freedom, *SS* sum squares, *MS* mean squares, *F* *F*-statistics, *P* *P*-value, *Sig*. statistical significance, ***: $P < 0.001$, *: $P \leq 0.05$, NS: $P > 0.05$

Table 6 Results of Tukey's post hoc tests

Water variables	Study sites			Months					
	WBK	WRB	WZM	January	February	March	April	May	June
Physicochemical parameters									
Temperature	A	A	A	c	c	a	b	ab	a
pH	A	A	A	ab	c	ab	bc	a	ab
Electrical conductivity (EC)	A	A	A	bc	bc	b	bc	c	a
Turbidity	A	A	A	a	a	a	a	a	a
Orthophosphate	A	A	A	b	b	ab	ab	ab	a
Dissolved oxygen (DO)	A	A	A	a	a	a	a	a	a
Suspended solid material (SSM)	A	A	A	a	a	a	a	a	a
Biological oxygen demand (BOD_5)	A	A	A	a	a	a	a	a	a
Chemical oxygen demand (COD)	A	A	A	a	a	a	a	a	a
Nitrites (NO_2)	A	A	A	b	b	b	a	b	b
Nitrates (NO_3)	A	A	A	b	ab	b	a	b	b
Ammoniacal nitrogen (NH_3–N)	A	A	A	a	a	a	a	a	a
Bacteriological group									
Total coliforms	A	A	A	a	a	a	a	a	a
Faecal coliforms	B	B	A	a	a	a	a	a	a
Faecal streptococci	C	A	B	a	a	a	a	a	a
Sulfite-reducing *Clostridia*	A	AB	B	a	a	a	a	a	a

Different letters represent significant differences ($P \leq 0.05$) in parameter values between sites (uppercase) and months (lowercase) in multiple pairwise comparisons of means
WBK Wadi of Biskra, *WRB* Wadi of Chaabet Roba, *WZM* Wadi of Zemer

Table 7 Generalized linear models (Poisson GLMs) testing the effects of water physicochemical parameters on the variation of bacterial loads of total and faecal coliforms, faecal streptococci, and sulfite-reducing *Clostridia* measured in three Wadis receiving wastewater effluents in the region of Biskra, northeastern Algeria

	Total coliforms					Faecal coliforms				
	Goodness of fit: $\chi^2_{17} = 94{,}003$					Goodness of fit: $\chi^2_{17} = 55{,}622$				
Water parameters	Estimate	SE	*Z*	*P*	Sig.	Estimate	SE	*Z*	*P*	Sig.
Intercept	12.940	0.044	293.2	<0.001	***	11.430	0.310	36.9	<0.001	***
Temperature	−0.023	0.001	−40.5	<0.001	***	0.220	0.005	44.4	<0.001	***
pH	−0.236	0.005	−47.6	<0.001	***	−1.436	0.041	−34.7	<0.001	***
Electrical conductivity	−0.000	0.000	−36.3	<0.001	***	−0.001	0.000	−53.4	<0.001	***
Turbidity	0.001	0.000	36.1	<0.001	***	0.001	0.000	2.4	0.016	*
Phosphate	0.025	0.000	95.7	<0.001	***	−0.042	0.002	−21.1	<0.001	***
Dissolved oxygen	0.012	0.002	6.5	<0.001	***	0.797	0.012	66.1	<0.001	***
Suspended materials	−0.608	0.005	−118.7	<0.001	***	−0.428	0.035	−12.3	<0.001	***
BOD_5	−0.005	0.000	−82.5	<0.001	***	−0.001	0.000	−3.2	0.001	**
COD	0.005	0.000	95.1	<0.001	***	−0.002	0.000	−4.6	<0.001	***
Nitrites (NO_2)	−0.215	0.004	−56.1	<0.001	***	−1.559	0.034	−46.4	<0.001	***
Nitrates (NO_3)	0.057	0.002	37.6	<0.001	***	0.477	0.013	38.0	<0.001	***
NH_3–N	0.028	0.001	49.9	<0.001	***	0.307	0.006	53.4	<0.001	***
Φ	0.806					0.892				
AIC	34,567					18,517				
	Faecal streptococci					Sulfite-reducing *Clostridia*				
	Goodness of fit: $\chi^2_{17} = 35{,}586$					Goodness of fit: $\chi^2_{17} = 41{,}289$				
Water parameters	Estimate	SE	*Z*	*P*	Sig.	Estimate	SE	*Z*	*P*	Sig.
Intercept	15.350	0.203	75.6	<0.001	***	6.905	0.231	29.9	<0.001	***
Temperature	−0.025	0.002	−10.8	<0.001	***	−0.048	0.003	−16.3	<0.001	***
pH	−0.897	0.022	−41.0	<0.001	***	−0.085	0.028	−3.1	0.002	**
Electrical conductivity	−0.000	0.000	−2.2	0.027	*	−0.001	0.000	−16.8	<0.001	***

Turbidity	0.007	0.000	32.4	<0.001	***	0.004	0.000	17.4	<0.001	***
Phosphate	−0.001	0.001	−0.6	0.553	ns	0.033	0.001	23.2	<0.001	***
Dissolved oxygen	0.108	0.009	12.3	<0.001	***	0.037	0.009	4.0	<0.001	***
Suspended materials	−1.343	0.026	−51.8	<0.001	***	−0.835	0.030	−27.6	<0.001	***
BOD_5	−0.016	0.000	−57.5	<0.001	***	−0.008	0.000	−28.0	<0.001	***
COD	0.019	0.000	64.1	<0.001	***	0.012	0.000	37.9	<0.001	***
Nitrites (NO_2)	−0.137	0.019	−7.2	<0.001	***	−0.733	0.020	−35.9	<0.001	***
Nitrates (NO_3)	−0.086	0.007	−11.8	<0.001	***	0.130	0.008	15.8	<0.001	***
NH_3–N	−0.002	0.003	−0.6	0.558	ns	0.160	0.003	58.32	<0.001	***
Φ	1.074					0.448				
AIC	9,953.9					27,269				

SE standard error, *Z* *z*-statistics, *P* *P*-value, Φ dispersion (deviance/degree of freedom), *AIC* Akaike information criterion, *Sig*. statistical significance, ***: $P < 0.001$, **: $P < 0.01$, *: $P \leq 0.05$, ns: $P > 0.05$

($P < 0.001$). The faecal coliforms were positively correlated with water turbidity ($P = 0.016$), temperature, DO, NO_2, and NO_3 ($P < 0.001$), but negatively correlated with the rest of water's physicochemical parameters ($P < 0.001$). Faecal streptococci were negatively correlated ($P < 0.001$) with temperature, pH, EC, orthophosphates, SSM, BOD_5, NO_2, NO_3, and NH_3–N and positively correlated with turbidity, DO, and COD. SRC increased significantly ($P < 0.001$) with the increase of water turbidity, orthophosphates, DO, COD, NO_3, and NH_3–N, but load of SRC decreased significantly when water temperature, pH, EC, SSM, BOD_5, and NO_2 increased (Table 7).

4 Discussion

4.1 Physicochemical Proprieties of Wadi Water

Physicochemical parameters of water determine surface water quality, which is also conditioned by the presence and intensity of microbial activities, in particular faecal coliform bacteria (FC) [23, 31]. Values and quality of water parameters are affected by external and internal factors that are interrelated in a very complex way. External factors include meteorological conditions, substrate factors (soil and/or sediment), and pollution sources, while internal factors are generated by biochemical reactions occurring in water [32].

The analyses of water at Wadis of Biskra revealed a temperature that ranges between 19.25 and 20.15°C. Temperature has less importance in pure water due to the wide temperature tolerance range in aquatic life-forms [32, 33]. However, in polluted water, temperature can induce significant effects on dissolved oxygen and biological oxygen demand as well as other physical, chemical, and biological characteristics of water. Temperature influences especially the solubility of salts and gases, density, viscosity, dissociation of dissolved salts, chemical and biochemical reactions, development, growth and behavior of aquatic and amphibiotic living organisms, and particularly the activity of aquatic microorganisms [34–36]. As with all surface water, the temperature depends on seasonal variations [37], varying from 2°C in winter to 30°C in summer [25], geographical location [33], and hot wastewater discharges [23, 38].

Water pH at the Wadis of Biskra fluctuates between 7.57 and 7.79, revealing a neutral to slightly alkaline patterns (6.5–8.5) [38, 39]. This alkalinity is attributed to the presence of carbonates associated mainly with calcium and to a lesser extent with magnesium, sodium, and potassium [40], thus buffering the runoff that flows into the Wadis. Slightly alkaline water inhibits the toxicity of heavy metals in the form of carbonate or bicarbonate precipitates, making these heavy metals unavailable [33]. The water of Wadis of Biskra are characterized by electrical conductivity ranging between 2,825 and 3,611 μS/cm, that is greater than 1,500 μS/cm [39] and 2,000 μS/cm, which represents an abnormal situation [23]. EC values indicate decomposition and mineralization of the organic matter [23, 41, 42], associated with wastewater emanating from the city and neighboring residents. The quality of water is classified poor, when EC > 4,000 μS/cm [43].

The turbidity of water samples averaged between 124 and 192 FTU (range 50–200 FTU). According to the [44], water samples belong to class 4 of turbidity, equivalent to African surface water (extremely colored). Although the standards for this parameter are quite different, it must be less than 5 FTU for drinking water [45]. The recorded values indicate the presence of suspended solids caused by the flow of water or the discharge of wastewater highly loaded with particles [46], although the SSM was very low in this study (1.03–1.33 mg/L). According to Afri-Mehannaoui [47], the SSM level is relatively low except during periods of high watercourses. Natural water is never free from SSM and content of less than 30 mg/L is allowed.

The surface water in the region of Biskra has a dissolved oxygen level of 3.18–4.01 mg/L. These values are below 5–8 mg/L [39], characterizing the water quality as passable (3–5 mg/L) [43]. The low levels of dissolved oxygen observed are due to the high organic load in urban discharges emanating from the city of Biskra without any prior treatment and the consumption of it by biodegradable bacteria. The increase in water and air temperatures promotes microbial activity and thus oxygen consumption [48]. It is well known that hot water contains less dissolved oxygen than cold water [23], but according to [32], the concentration of this element depends on several physical, chemical, and microbiological processes. The low oxygen level observed in the Wadi of Fes (Morocco) [49] was attributed to water pollution by urban discharges from the city of Fes. The high and rapid decomposition of organic matter reduces substantially the solubility of oxygen in water [50], reflecting heavy organic pollution. The DO in water represents a reliable indicator factor of the pollution status in aquatic systems [51]. Oxygen deficiency in water protects anaerobic bacteria and other pathogens, which are harmful to human health [50], by stimulating bioaccumulation and biomagnification process [32].

Phosphate concentration in Wadis of Biskra ranges from 16 to 20 mg/L, exceeding 2 mg/L [39] and the Algerian standards (<4 mg/L). The availability of orthophosphates can be explained by leaching and urban discharges from neighboring agglomerations and the release of phosphorus trapped in large quantities in the sediment [52]. Eutrophication can occur at relatively low concentrations of phosphates (~50 μg/L) [52, 53]. This state initially reduces the biodiversity of the environment by favoring the rapid and important proliferation of eutrophic algae which, at the end of their growth, accumulates in large deposits of organic matter that consume most of the dissolved oxygen of the habitat during their putrefaction. This process transforms the habitat into an anaerobic ecosystem leading consequently to the elimination of plants, animals, and aerobic microorganisms [54].

The BOD_5 recorded in surface water at Wadis of Biskra ranged between 139 and 220 mg/L, which was much higher compared to the standard value of 5 mg/L [39]. Water samples are qualified as very poor as BOD_5 exceeds 25 mg/L [43], which is the result of the discharge of untreated wastewater, rich in organic matter and nutrients (leaching organic fertilizer) from urban agglomerations, resulting in a considerable increase in organic load in surface water [49], affecting even Saharan wetlands such as ephemeral salt lakes "Sabkhas and Chotts" [55]. In conjunction with BOD_5, the COD is an indicator of toxic conditions and the presence of bioresistant organic substances [56]. The obtained values vary between 160 and 281 mg/L, which are 6–9 times higher than the limit of 30 mg/L established by the WHO [39]. The water studied is of very poor quality [43] as it exceeds 80 mg/L and is saturated with less or non-biodegradable pollutants [23, 57]. When the values of BOD_5 and COD are high, it means that wastewater has a high pollution potential and should therefore be treated before releasing into the environment [58]. The use of adequate depollution techniques is necessary to prevent environmental contaminations and preserve aquatic systems safe [21].

In this study, the nitrite content (1.46–2.69 mg/L) far exceeds the WHO standard ($<$0.1 mg/L) [39]. High concentrations of nitrites often reflect the presence of toxic materials [53], indicating pollution above 1 mg/L [38]. On the other hand, nitrates (4.15–4.85 mg/L) are very negligible compared to the reference value of 50 mg/L for drinking water [39]. The values measured in the study area could be attributed to untreated wastewater and agricultural discharges [59]. These values also reflect consumption by bacteria during periods of low oxygenation, thus avoiding anaerobiosis. The pattern of ammonia (NH_3–N) of the analyzed water shows that the concentrations (4.73–16.24 mg/L) are higher than the norm of 0.5 mg/L [39], indicating the absence of dilution and poor oxygenation of water, which leads to the non-oxidation of nitrogen. The presence of this element in water is an indicator of organic pollution by microorganisms, including faecal pollution [49]. Interpretation of nitrogen content is very difficult due to the instability of nitrification/denitrification/ammonification reactions. Knowing that nitrogen is in the organic form of ammonium (NH_4^+) and nitrate (NO_3^-) in wastewater, each of the previous reactions is dependent on the availability of dissolved oxygen. The presence of NH_4^+ with high concentrations leads to a high oxygen consumption due to bacterial nitrification, i.e., transformation of NH_4^+ into NO_2^- and NO_3^- [14, 54].

Nutrient (nitrogen and phosphate) pollution depends on the supply of agricultural land with fertilizers (livestock manures and chemical fertilizer amendments) and the discharge of wastewater. The most commonly used fertilizers are ammonium nitrate, phosphorus and potassium urea, superphosphates, potassium chloride, and to a lesser extent ammonium sulfate, sodium, calcium nitrate, and sulfate of potassium [60].

Regarding the correlations between the different parameters studied, the statistical analysis found positive correlations between many physicochemical parameters (phosphates–pH, P–EC, P–DO, DO–temperature, and DO–EC, SSM–turbidity, BOD_5–COD, NO_2^-–BOD_5, NO_3^-–BOD_5, NO_3^-–COD, NO_2^-–NO_3, NH_4^+–NO_2^-, and NO_3^-–NO_2^-). Generally, the pollution elements are strongly linked: turbidity–SSM, COD–BOD_5, BOD_5–NO_2^-, BOD_5–NO_3^-, NO_3^-–COD, NO_3^-–NO_2^-, and NH_4^+–NO_2^-. The positive correlation between COD and BOD_5 is explained by the setup of the conditions of organic matter degradation by microorganisms whose activity and multiplication require oxygen [61]. The same is true for the significant interrelationships between temperature, phosphates, and the abundance of faecal germs, which are connected to domestic discharges and the availability of nitrogen and phosphate nutrients (i.e., the eutrophication stimulators)

[38]. EC is positively related to temperature, which is a catalyst for chemical reactions that accelerate the dissolution of minerals constituting the geological environment [62]. Water pH and EC are also temperature-dependent, as are carbon biodegradation processes [63].

Positive correlations are reported in the Bizerte lagoon (Tunisia) between temperature, salinity, and coliforms and inversely with dissolved oxygen [64]. Our results are consistent with water analyses of Boufekrane and Ouislane Wadis in Morocco [65], where it has been noted that bacterial loads increased with the increase of water temperature since indigenous bacteria are the dominant component of populations at polluted rivers [66]. A positive correlation was reputed between bacterial loads in water and faecal pollutant loads in the Bizerte lagoon in Tunisia [67], thus explaining the large influx of faecal pollutants by leaching from the center of agglomeration.

It is accepted that cold water is more oxygenated than hot water [9]. However, and contrary to this rule, a positive correlation is established in this study between DO–temperature and DO–EC. These positive correlations may be explained by (1) changes in Wadi water temperature by that of domestic effluents which are independent of climatic conditions. This can be considered as thermal pollution of water; (2) the study period "January–June" coincides with the cold and slightly hot seasons; during this period, the bacterial activity can be qualified as low or moderate to reach the point of significantly reducing the DO level. Indeed, GLMs indicated that water temperature negatively affects the abundance of bacterial groups studied, but "thermotolerant" faecal coliforms were positively affected, and (3) the case of this study is a water receiving heavy pollution load in the form of domestic wastewater, while previous studies reporting the negative correlation between DO and temperature investigated mainly non-polluted or slightly polluted natural surface water. This is the case of the Bizerte lagoon in Tunisia [67], where negative correlation was found between DO and temperature. Similarly, the relationship was negative in the Gulf of Annaba in Algeria [9].

When DO concentration in water is <1 mg/L, it indicates conditions close to anaerobiosis, which occur when the oxidation processes of mineral wastes, organic matter, and nutrients consume more oxygen than is available. Low DO content causes an increase in the solubility of the toxic elements that are released from the sediments [9, 23]. Also, the DO available is limited by the maximum solubility of oxygen (9 mg/L at 20°C), which decreases with the increase of temperature and the presence of pollutants in watercourses [23].

Bacteriologically, the enumeration of total and faecal coliforms is the most widely used bacteriological procedure for assessing water quality [68]. They are good indicators of the microbiological quality of water [32], their abundance reflects organic pollution because they cannot survive in clean water beyond a limited time [29]. Apart from total coliforms, faecal streptococci and faecal coliforms represent signs of recent faecal contamination [50, 69] since their survival in water can be very short, whereas *Clostridium* sulfito-reducers are indicators of old faecal contamination because of their resistance to adverse environmental conditions [46]. This is the case of *Clostridium perfringens* which can survive in water for a longer period compared to other faecal bacteria [68]. The high numbers of total coliforms (56,917–76,167 CFU/100 mL), faecal coliforms (457–6,100 CFU/100 mL), faecal streptococci (1,432–7,830 CFU/100 mL), and sulfite-reducing *Clostridia* (886–5,217 CFU/100 mL) come from the wastewater, rich in nitrogenous nutrients, emanating from the neighboring city ensuring their proliferation. These indicators of faecal contamination have been reported in the surface water of Silver Lake (Delaware, Iowa) [70].

When surface water is constantly contaminated by faecal pollution germs, it is no longer an alarm signal, but an assessment of the importance of faecal pollution, originating from the discharges of urban wastewater with a relatively constant faecal coliform concentration in the order of 106 CFU/100 mL [23]. A similar observation was reported in M'sila in Algeria [71] and in Beni Aza (Blida, northern Algeria) [37].

4.2 Effect of Water Physicochemical Factors on Bacteria Populations

The physicochemical properties of water influence the survival, decomposition, and/or growth rates of coliform bacteria [72, 73]. In the case of Wadis of Biskra TC responded positively to the increase in water temperature, pH, EC, SSM, BOD_5, and NO_2^- and negatively to the increase in turbidity, phosphates, DO, COD, NH_3–N, and NO_3^-. Faecal coliform populations increase when turbidity, temperature, NO_2^-, DO, NO_2^-, and NO_3^- increase, but FC load decreases with the increase of water pH, EC, SSM, BOD_5, phosphates, and NH_3–N. Faecal streptococci increase with the decrease of temperature, pH, EC, phosphates, SSM, BOD_5, NO_2^-, NO_3^-, and NH_3–N, while they are associated negatively to water turbidity, DO, and COD. SRC increases with the increase of turbidity, phosphates, DO, COD, NO_3^-, and NH_3–N, whereas their abundances are deemed negatively related to water temperature, pH, EC, SSM, BOD_5, and NO_2^-.

Water temperature is the most important factor that determines the abundance of coliform bacteria [69]. TC are facultative aerobic-anaerobic bacteria, but they proliferate optimally at 30°C [74]; while FC is thermotolerant, differing from TC in their proliferation temperature that is about 44°C [75]. The temperature was positively correlated with the survival and/or growth of coliforms [76]. However, the mortality rate of coliforms increases with a rise in water temperature [77]. Moreover, low temperatures (~6°C) promote FC survival in seawater [78]. In fact, at low temperature, the bacterial cell limits its energy loss by reducing its metabolic activity, which allows the bacterium to survive much longer compared to high-temperature conditions [79]. Though at 40°C, the survival FC is critically affected than other temperatures [78]. Mancini [80] suggests that temperature is the major factor involved in the disappearance of faecal bacteria in freshwater. Other studies (e.g., [81]) demonstrated that FCs undergo sublethal stress within a week after their introduction into an aquatic environment. The same is true for salinity where high salinity levels reduce the rate of FC in water [78, 82].

As for pH conditions, according to Mayo [83] and Chedad and Assobhei [78], alkaline pHs induce a clear decrease in FC survival, whereas Curtis et al. [84] and Van der Steen et al. [85] argue that TC increases in acidic pHs. Similarly, SSM may facilitate the survival or growth of TC through adsorbing and protecting them from adverse factors such as UV radiations, metal toxicity, and bacteriophage attacks [72]. In all cases, the survival of coliform bacteria can be prolonged, or sometimes even they can grow under certain environmental conditions such as optimum pH, temperature, rich nutrients, and abundant suspended particles [86].

5 Conclusion

This study determined water quality of arid Wadis receiving wastewater in the region of Biskra. The results of water physicochemical and bacteriological analyses revealed that the values of several parameters exceed the standards established by FAO and WHO, which indicate large faecal pollution. In effect, the high level of bacterial loads indicates faecal pollution of all the study Wadis. Our findings show that wastewater effluents pose serious environmental contamination issues and health risks that can affect human communities, agricultural lands, crop products, and aquatic life-forms that rely on water of Wadi system. The main risk is associated with exposure to pathogenic biological agents, including pathogenic bacteria, helminths, protozoa, and enteric viruses. High faecal contamination induces drastic changes and deterioration in water characteristics that causes the collapse of aquatic ecosystems.

6 Recommendation

In perspective, in order to limit the risks of Wadi water pollution, it is recommended to (1) install wastewater treatment plants before releasing it into the environment in order to preserve water quality in the natural environment and thus sustain life-forms and ecosystem integrity; (2) divert sewage collectors and discharges sites away from agricultural lands to reduce the risk of soil contamination and thus produce healthy agricultural products; and (3) periodically monitor water quality to prevent events of high contamination of hydrosystems receiving polluted water. Under conditions of water scarcity in drylands, a wise water management policy needs to promote the increase agricultural production with less water. This can be achieved through the rationalization of irrigation and drinking water use and improvement of irrigation systems with cutting-edge techniques of water saving. The reuse of adequately treated wastewater in agriculture irrigation is a promoting practice to save natural water resources for other healthy uses. Since arid agriculture is often associated with land degradation and soil salinization, biosolids produced by wastewater treatment plants are indicated to increase soil fertility with organic matter and improve several soil proprieties and also alleviate the negative effects of soil salinity and water stresses on the crop plant.

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Valorization of Oily Sludge in Arzew Refinery

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Abstract The sludge treatment is a difficult phase in the fight against pollution. Indeed the scrubber with a difficult problem was solved for many reasons: scarcity of land available for application and filing need sets requirements of the environment and public hygiene. Moreover the economic importance of this problem is illustrated by the importance of the cost both in investment and operating it can represent. Oily sludge with a significant calorific value which represents 90% of methane (CH_4) can be considered as an interesting fuel. The impact related to its combustion in poor conditions can be important. The main objective of this study is to thermally treat oily sludge from the oil industry at the level of the RA1/Z refinery and then make a characterization of sludge by: X-ray fluorescence (XRF) to determine the mineralogical composition mass in the form of oxides, e.g., percentages (% SiO_2, % CaO, % Fe_2O_3, % K_2O, etc.). X-ray diffraction (XRD) for sentencing phases, for example, silica, crystalline, or amorphous. Fourier-transform infrared spectroscopy in attenuated total reflection (FTIR-ATR) to determine functional groups, for example, O–H, C–H, C–Cl, Br–C, C–I, C–N, N–H, etc., and finally detection of heavy metals by atomic absorption spectroscopy (AAS). This study is to determine the sources of heavy metals in industrial wastewater which predictably sludge quality. Several origins can be identified such as industrial activities. In a second part, we're interested in studying the operating constraints due to the presence of the sludge contaminated as well as health and environmental risks. One is interested in identifying different Condit's other than spreading agricultural.

Keywords Agricultural, Environmental, Metal heavy, Mineralogical, Oily sludge, Wastewater

1 Introduction

Water was always synonymous with life and growth. This "blue gold" is first of all essential with the survival of the human being. Water is also essential to agriculture and breeding independent sources of food for any company. The natural and drinkable fresh water is mainly contained in the icebergs and the glaciers. The remainder being in the lakes, rivers, and underground reserves. These sources of cumulated fresh water account for hardly only 2.5% of terrestrial water. For a long time, no one was hardly concerned with the manner of supplying itself out of water of quality. Nature has always been enough to provide this invaluable resource [1]. Following the industrial revolution and with the intensification of agriculture answers the needs of an increasing population. The fresh water worldwide consumption did not cease increasing since the beginning of the twentieth century. In the one century space, the world population has tripled, whereas the fresh water consumption was multiplied by six. The high standard of the population living conducts more water consumption for domestic and industrial uses, as a consequence more discharge of wastewater, which has an impact on the quantity and water quality. This phenomenon is worsened by the reduction in the capacity car purifier of the rivers (clearing out dredging's artificial drains of the rivers). Moreover, following the increasing urbanization with the erosion of the grounds and the deforestation, water infiltrates less and less deeply in the ground and more quickly joins the rivers and the seas. Also everywhere in the world, the fresh and drinkable water is an increasingly expensive and increasingly rare good. The first structured sewerage systems appeared about 1,850 primarily with the aim of cleansing of the cities. As for the precursory centers of purification of our modern stations, they developed in Europe at the beginning of the twentieth century [2]. If the man wanted to continue to enjoy this natural good. it was indeed necessary to reduce the polluting load of wastewater, as well domestic as industrial. In Algeria, there exists more than one hundred of wastewater treatment plant (WWTP) of which about 60 "known as urban" devoted to domestic wastewater. Others were installed in the production facilities. The need to purify wastewater will be increasing in Algeria and in other countries because of the demography and the increased consumption of the urban and industrial areas. Who says purification of water also says production of muds. However, the main objective of these stations is to reduce the environmental risk coming from wastewater discharge and to guarantee the rejection of treated water with defined quality by paying attention to the sludge generated by the purification processes. The current trend is different in the direction where muds as well as purified water are regarded as an element which contributes to the environmental impact of a purification plant. The activities listed in the industrial park of Arzew are at the origin of several pollution. Most important are industrial water of rejections coming from the processing centers of oil, the modules of treatment of gas and water services (industrial water for the desalting of the crude water of washing and water fire protection). Refinery is provided with a purification plant which will treat all; in particular, the effluents will split waste oil and muds [3]. Sludge treatment is a difficult phase for the fight against pollution. Indeed, the scrubber has a difficult problem to solve for multiple reasons: scarcity of land available for spreading and depositing, necessities and requirements of the environment, and public hygiene [4]. The purpose of this study is to characterize and investigate the feasibility of converting oily sludge to clean fuel that meets energy and environmental requirements [5].

2 RA1/Z Complex Presentation

The Algerian economy is dominated by industries generated by gas of Hassi R' mel and the oil of Hassi Messaoud. In the northeast of Oran, the industrial center of Arzew, allows the liquefaction of gas and the refining of oil. In 1970 it was realized with the refinery of Arzew by Japan Gasoline Company(JGC) and inaugurated in 1973 and managed by NAFTEC after the reorganization of SONATRACH [3].

It was conceived to:

- Treat the crude oil of Hassi Messaoud
- Treat imported reduced crude (production of bitumen)
- Satisfy the needs for consumption out of fuels, lubricants, and bitumen of the national market
- Export the surplus products (naphtha, kerosene, fuel, and gas oil)

The refinery extends on a surface from 170 ha including/understanding production units of the fuel, lubricant, and bitumen. In 1978 following the needs important for lubricant, the construction of another unit integrated of production of 120,000 T per annum of basic oil was launched [3].

2.1 Production Capacity

The milked refinery:

1. 2.5 million tons per year of Saharan crude oil
2. 280,000 tons of reduced crude imported for the production of the bitumen [3]

2.2 Geographical Location

The refinery of Arzew is established in the industrial park to 2 km of Arzew; it is located on the plate of the locality of El Mohgoun at the crossroads of the trunk road N° 11 (Oran–Arzew) and the trunk road N° 13 (Arzew–Sidi Bel Abbes) and at approximately 40 km of Oran as shown in Fig. 1.

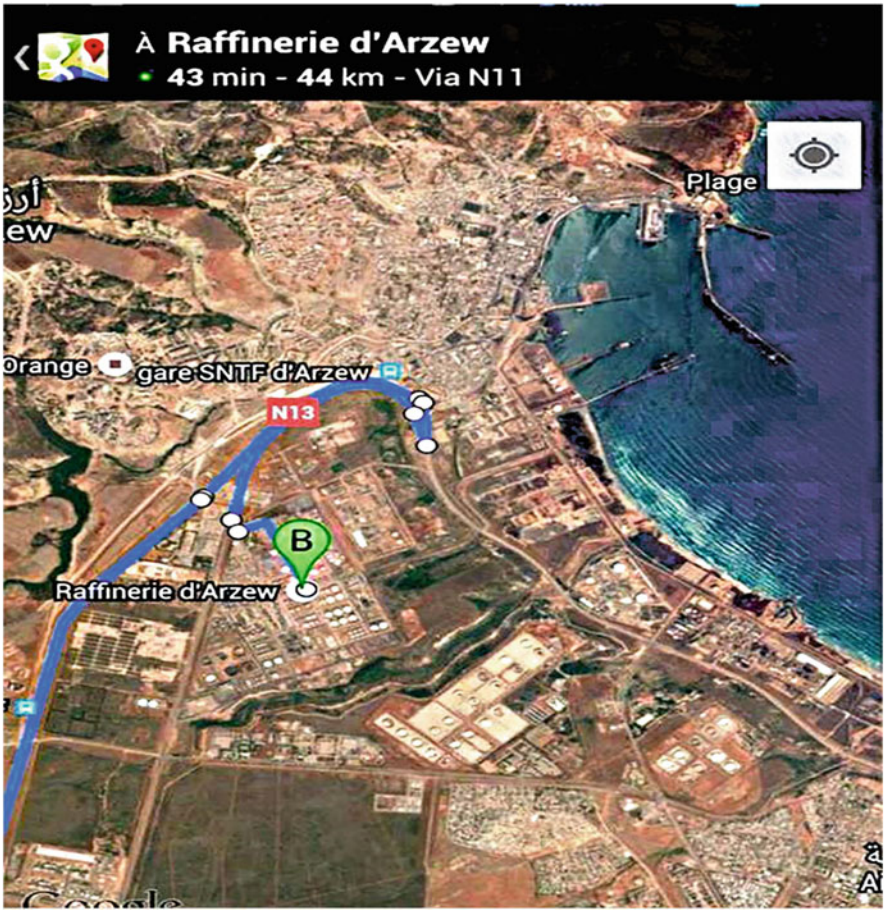

Fig. 1 Geographical location of the refinery of Arzew [3]

2.3 Description of the Production Areas of the Arzew Refinery

- Zone 1: Parking
- Zone 2: Standby station
- Zones 3 and 19: Utilities

Utilities are an important area within the Arzew Refinery producing steam, electricity, air service and instrument, and distilled water.

– Zone 4: Fuels

The Algerian crude from Hassi Messaoud is used as main load in zone 4. It consists of three (03) following units:

- Unit 11: atmospheric distillation (topping)

- Unit 12: platforming or catalytic reforming with three (03) reactors
- Unit 13: plant gas production (butane and propane)

  – Zone 07 and 05: Lubricants

- Unit 21/100 (vacuum distillation)
- Unit 22/200 (propane deasphalting)
- Unit 23/300 (furfural extraction)
- Unit 24/400 (MEP/toluene dewaxing)
- Unit 25/500 (hydrofinishing)

  – Zone 06/unit 3,000

- Unit 51/3,100: Finished oil mixing and conditioning unit
- Unit 52/3,200: paraffin treatment and conditioning unit
- Source treatment of acidic waters (acidic water depletion)
- Primary treatment in API separators
- Intermediate processing to complete the H&G removal
- Biological secondary treatment
- Clarification of the effluent

Other sources contribute to the pollution of the natural environment. It is the sanitary and domestic waters conveyed in underground networks separating toward sea [6].

3 Industrial Sludge Generalities

The environment is one of the pillars of sustainable development. For a long time, it was forsaken with the profit of economic and the social one. It is obvious today that the company and the economic activities will have to be built on a better balance of these three realities closely dependent. It is about a new and considerable challenge, which is carrying opportunities and innovations [7]. Industrial waste is a type of waste produced by the activity of industries. These industrial discharges are opposed to domestic waste coming from daily household activity, which originates mainly from the industry, construction, services, and agricultural activities. Within the framework of the responsibility widened for the producer who is responsible for the management of his waste until their elimination or their final valorization [8].

3.1 Principle and Objectives of the Regulation

- To reduce
- To reuse
- To recycle [6]

3.2 Effect of the Industrial Pollutant on Health

Industrial pollution has very serious effects on the health of man. One distinguishes several types of pollution corresponding to several types of diseases [9].

3.3 Air Pollution

Industrial pollution is due to the presence of toxic particles in the air; it is caused by industrial smoke (refineries or exhaust fumes of the cars – CO_2), manures or pesticides, methane, and ozone. This pollution increases the disease risks to man:

– Respiratory diseases: asthma, bronchiolitis, angina, respiratory insufficiency, and allergies
– Cardiovascular diseases: myocardial infarction, angina pectoris, and accident vascular cerebral
– Risk on the reproduction of the man
– Cancers
– Skin diseases [10]

3.4 Pollution of Soil

The pollution of soil is due to the artificial fertilizers or pesticides which are widespread on the arable lands to improve the output. Their use causes:

– Food poisonings
– Cancers
– Endocrine disturbances (glands) [11]

3.5 Pollution of Water

Pollution of water is related to that of the grounds because water infiltrates in the ground and will contaminate the groundwater. The risks on health are:

– The allergen's effects (causing allergies): rhinitides, conjunctivitis, asthmas
– Viruses and microbes, which make non-drinking water and cause many diseases [12]

3.6 Muds Definitions

- Muds: liquid-solid matter effluents strongly charged (with concentrations in solid of about 1–10% correspond 10–100 g/L)
- muds: inert chemically or ferment target (odors)

The treatment of muds is an additional problem with that of the water treatment. Various mud classes:

- Absorbent organic mud
- Absorbent oily mud
- Hydrophobic oily mud
- Absorbent mineral mud
- Hydrophobic mineral mud
- Fibrous mud

Mud indicates a residue organic or mineral, solid, liqui, or pasty.

A mud is characterized by its aspect, but specifically its origin supplemented by its chemical characterization, which will determine its die of treatment.

Broadly a mud is characterized by the following parameters:

- Concentration in polluting elements
- pH

Dry matter concentration (DM) is expressed, either in g/L for the slurries or in dryness (% in weight of DM):

- 6–10% of DM: liquid muds
- 10–20% of DM: pasty muds
- >20% of DM: solid muds [13, 14]

3.7 Different Types of Muds

One distinguishes here:

- Muds of industrial wastewater treatment plant WWTP by physicochemical treatment.
- Hydrocarbon muds and bottom of tanks resulting from the clearing out of unutilized fuel tanks.
- Muds of clearing out the hydrocarbon separators, sluices, grease removers located in particular in pretreatment before rejection at the natural environment and/or in the networks of rainwater.
- Muds of urban purification plant or agribusiness industry exits of the biological treatment of the effluents nonconformity to be épandues.

- Muds of clearing out and matters of drainings not spreadable are resulting from the maintenance of the urban and industrial networks of cleansing (clearing out of the networks) or installations of autonomous cleansing (septic tank).
- Muds of machining [13, 14].

3.8 Management of Muds

The evacuation of muds is the last link of the purification of wastewater. In order to preserve the aquatic environments, the placement of lawful and perennial dies of evacuation of muds is essential. These dies indeed condition the good quality of the rejection of the purification plants (regular extraction of muds of the basins of purification) and guarantee a respectful destination of muds of the environment.

Muds come from the purification of domestic wastewater in the purification plants. The wastewater is brewed there in basins where one supports the development of the microorganisms which will degrade and absorb the organic matter. One then separates by decantation of muds of purified water which is rejected in the medium. Muds are primarily made up of water, rock salt, and organic matter. They contain nitrogen and phosphorus, which are fertilizing elements for the plants. Each one among us produces approximately 3 L of muds per day.

3.9 Industrials Muds

The stages of industrial processing liquid waste generate by-products and waste which is recovered and forms industrial muds. These muds of nature specific to industries must undergo treatments or pretreatments so to reduce their quantity, to improve the public health and quality of muds, and to develop them if possible.

Muds can come from several sources:

- Industrial purification plant
- Hydrocarbons resulting from the basic clearing out of tank
- Machining
- Clearing out various and matters not spreadable whitebaits

One also distinguishes three types of muds according to the dry matter contained:

- slurries: 5–10%;
- pasty muds: 10–20%;
- solid muds: + of 20%.

The principal treatments of industrial muds are done with the upstream of the industrial process. Indeed. the control of the productions and the optimization of the processes often make it possible to reduce the volume of muds significantly to be treated.

The treatment of muds obtained is made to share several techniques. Their use depends on chemical and physical nature of muds thus obtained:

- Thickening
- Dehydration
- Anaerobic digestion
- Treatment of lubricating muds
- Oxidation by the wet process
- Drying
- Incineration
- Chemical conditioning and treatment of the odors
- Storage

The valorization of industrial muds is an important outlet. The muds obtained after treatment (mainly muds resulting from agribusiness industry) can indeed be used for agriculture thanks to their physicochemical properties.

3.10 Technical of Reduction and Water Elimination of Muds Waste of Machining

To reduce the volume of proceeded, different muds are implemented including/understanding by order ascending of effectiveness and cost, thickening, dehydration, and drying.

3.11 Wastewater Treatment Plant WWTP

Each day the man consumes large quantities of water as well for his personal use as professional. This wastewater is collected in order to be purified. The collected wastewater has two origins: an origin domesticates (Urban Wastewater: UWW) and an industrial origin (Industrial Wastewater: IWW). In the case of zones little or fairly industrialized, this wastewater is mixed and treated together in a wastewater treatment plant (WWTP) which aims to reduce the polluting load that they convey in order to return in the aquatic environment water of good quality [15]. Muds come from the purification of wastewater. They result from the biological activity of the microorganisms living in these stations which transforms the matters transported by wastewater so that they can be extracted about it [16].

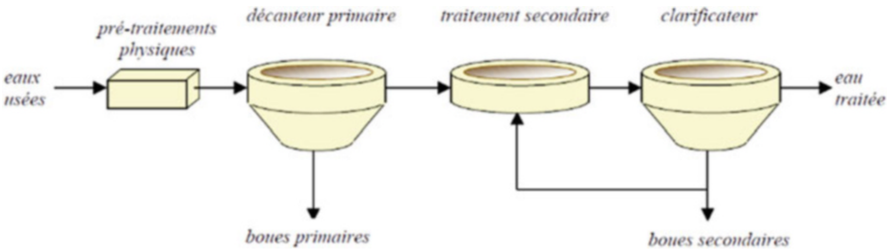

Fig. 2 Diagram of wastewater treatment plant WWTP Degrémont [17]

3.11.1 Fonctionnement of Wastewater Treatment Plant WWTP

Wastewater treatment plant WWTP consists in reducing the load out of organic matters and mineral. At the time of this stage, it occurs a transfer of pollution of the liquid phase (water) toward more concentrated phase (muds), and a gas phase (CO_2, N_2, . . .). The production of waste muds is thus completely dependent on the die of water treatment Degrémont [17] in Fig. 2.

3.11.2 Various Types of Muds of Wastewater Treatment Plant WWTP

Muds are mainly made up of solid particles not retained by the pretreatments upstream of the purification plant of not degraded organic matters, mineral suspended matte, and microorganisms (degradative bacteria essentially). They are presented in the form of a "thick soup." which undergoes then treatments aiming in particular at reducing their water content Champiat [16].

Muds of purification plants are classified into four great groups Degrémont [17].

Primary Muds

They result from the primary education treatment and are produced by simple decantation at the head of the purification plant. These muds are fresh, i.e., not stabilized (strong content of organic matter), and strongly fermentable. From the nature of the new installations, they tend to disappear Degrémont [17].

Muds Secondary or Activated

These muds are stabilized biologically results from biological treatment by means of the properties épuratoires of the microorganisms consequently the mineral matter, and the refractory organic matter are accumulated while the biodegradable organic matter is used as a substrate with the purifying microorganisms. These microorganisms mainly of the bacteria, use biodegradable pollution for their maintenance and their growth. The formed products are cells, carbon dioxide, and water [18, 19] as shown in Figs. 3 and 4 [18, 19].

Mixed Muds

The mixture of primary muds and secondaries leads to obtaining mixed muds. Their composition is dependent on the quantity of primary and secondary muds produced. Very fermentable, these muds undergo then the stabilizing treatment Degrémont [19].

Physicochemical Muds

These muds result from a using treatment of the mineral flocculating agents (aluminum or iron salts). The physicochemical treatment is mainly used on industrial muds or for stage with under dimensioning of certain purification plants (for example, stations located in tourist areas) Degrémont [19].

3.11.3 Different Dies Treatment from Muds

Waste muds arise in a liquid form and with a highly fermentable organic matter load. These two characteristics are awkward and pose many engineering problems for their evacuation “whatever the destination among which them transport and their storage, which often lead to problems of handling and smell pollutions. This imposes the choice of a die of treatment as of the installation of the WWTP**.**

Generally, sludge treatment has two objectives:

Stabilization

To prevent or reduce the problems of fermentation and to avoid smell pollutions thus. Stabilization can be biological by aerobic or anaerobic way (methanization) or chemical (liming or other treatments)[22]. Biological stabilization has the advantage of limiting the later evolution of the composition of muds.

Dehydrations

The concentration of muds which aims to reduce their volume (more than water 97%) by thickening and/or dehydration to facilitate thereafter their transport and their storage. Conditioning is often used upstream to support separation liquid-solid using organic flocculating agents of synthesis or minerals and pressure-sealing.

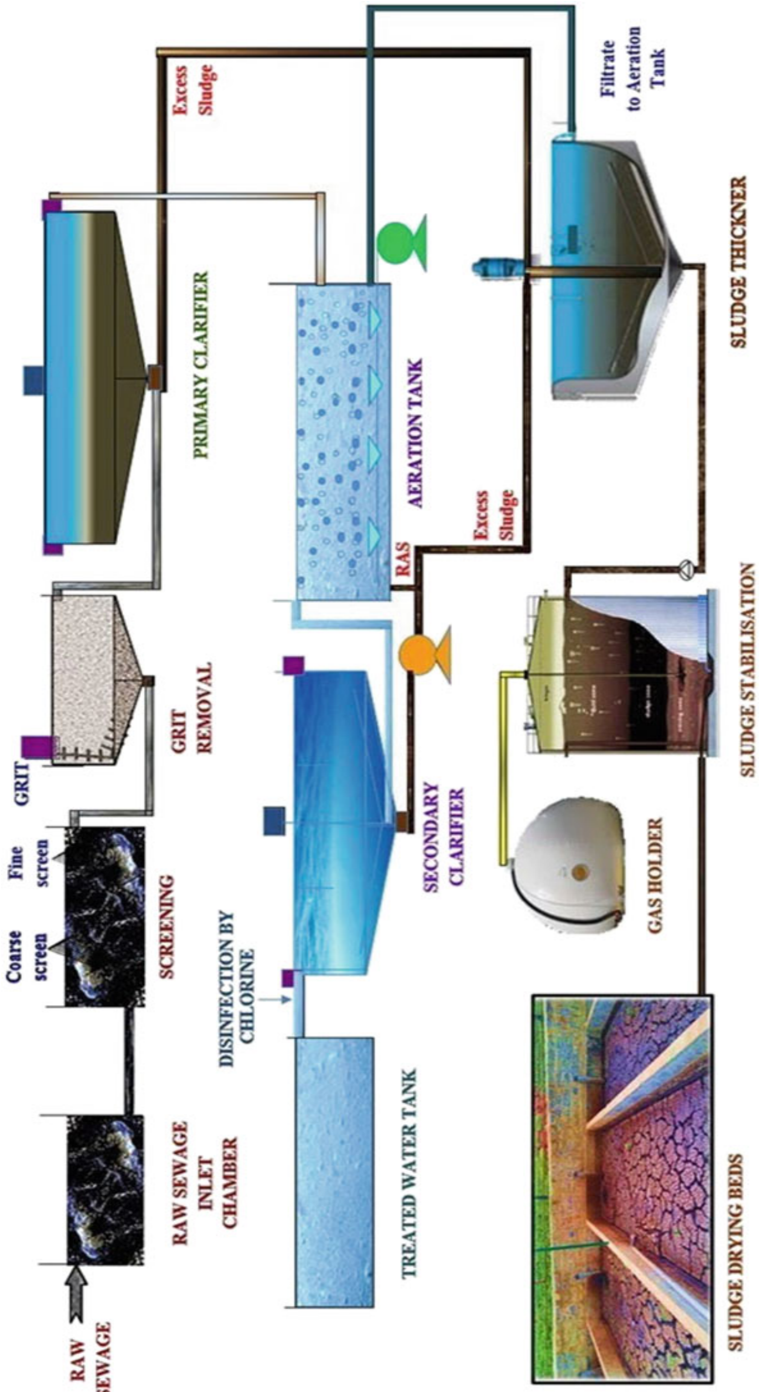

Fig. 3 Diagram of the wastewater treatment process and of production of muds [20]

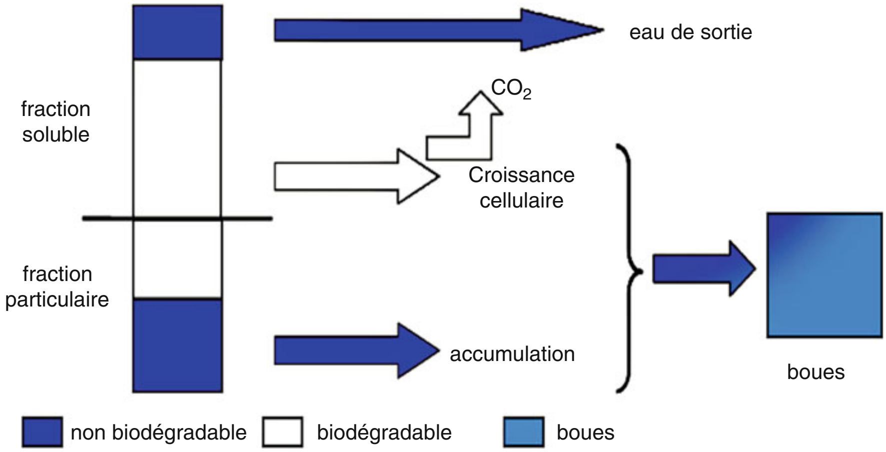

Fig. 4 Diagram of treatment biological of wastewater [21]

According to the power of the process of drying, it used thickening, dehydration, or thermal drying. One obtains muds with various percentages of dryness: slurries (4–10%), pasty muds (10–25%), and solid muds (25–50%) and granulated muds or powders some for a dryness higher than 85% [23].

Spinneret of Elimination of Muds

If there exist many treatments to reduce volume upstream of the harmful effects and the harmfulness of muds, currently three dies are used to evacuate muds, according to whether one privileges a digestion mode based on elimination or recycling. It acts:

– Setting in controlled discharge
– Incineration
– Return on the ground by spreading [24]

Put in Controlled Discharge

The setting in pure mud discharge or mixture corresponds to a maximum concentration of all waste. Carbon leaves in the atmosphere in the form of methane. Remain the nitrogen and phosphorus (no recoverable). The stock room must be confined, and one is unaware of which can be to become to it in a long term nor duration of containment despite everything the precautions [25, 26]. Muds must be stabilized beforehand and dehydrated (maximum moisture of 70%). This solution has gradually lost its interest and is currently prohibited for financial reasons (closure procedure, etc.) and for environmental problems such as foul-smelling, breeding of mosquitoes, entrainment of fertilizing elements (nitrates, phosphates) and toxic products, which have an influence on the surface and groundwater [27–31].

Incineration

It carries out the destruction of the organic matter of waste by combustion at high temperature (+ of 500°C) producing named smoke and residual mineral matter ashes. In the objective of an energy valorization of waste, produced heat is recovered in the form of vapor or of electricity for the operation of the furnace itself for the district heating or industrial [32]. The residues of the incineration (blast furnace slag) are usable for public works [33]. In France, 14–16% of urban muds are incinerated. In Europe, the percentage varies from 0% to 55% according to the countries. In Morocco, a treatment by incineration was not carried out yet. However, in spite of the interest of this process for an important reduction of volumes of waste, it has constraints mainly related to a very expensive investment. Muds alone are not car fuels. They require special furnaces and a mixture with other waste such as household waste. The elimination of ashes and the blast furnace slags require a controlled discharge of class 1 or one unit of inerting. This technique also remains harmful from ecological and environmental point of view since it contributes in addition to the organic matter wasting useful for the ground for the very toxic gas diffusion (NO, CO, SO, dioxane, etc.) which was covered by specific regulations [30, 31, 34].

Direct Spreading on the Soil

In the current hour, the agricultural spreading of muds remains in Europe the principal die of elimination. This last is practiced that if those respect the principle "of agronomic interest" and are free from great contents of inorganic or organic pollutants.

This mode of recycling has adapted the most to rebalance the cycles biogeochemical (C, N, P) for environmental protection and of a very great economic interest. It aims to spare the natural resources and at avoiding any organic matter wasting due to the incineration or the hiding in discharges. Waste muds can thus replace or reduce the excessive use of expensive manure [34].

4 Sludge Problematic

The treatment of muds is a difficult phase for the fight against pollution. Indeed the purifier with a difficult problem has to solve for multiple reasons: rarefaction of the grounds available for spreading and the deposit need set requirements of the environment and the public health. In addition the economic importance of this problem is illustrated by the importance of the cost as well in investment as in exploitation as it can represent. Oily muds with an important calorific value, which represents 90% of methane (CH_4) that can be regarded as an interesting fuel. The impact related to its combustion under bad conditions can also be important. The main aim of this study is to thermically treat oily muds of oil industry with the level of refinery RA1/Z and then to make a characterization of these muds by X-ray fluorescence (XRF) to determine the mineralogical composition in mass percentages in the form of oxides, for example (% SiO_2, % CaO, % Fe_2O_3, % K_2O, . . .). X-ray diffraction (XRD) for the determination phases, for example, crystalline or amorphous silica. Fourier-transform infrared spectroscopy in total mode of reflection attenuated (FTIR-ATR) to determine the functional groupings, for example, O-H, CH, C-Cl, C-Br, Ci, CN, N-H, etc. and finally detection of heavy metals by of atomic absorption spectroscopy (AAS). This study is to determine the sources of emission of heavy metals in the industrial wastewater which downgrades the quality of muds. Several origins can be identified such as industrial activities. In a second part, one is interested in studying constraints of exploitation due to the presence of the muds contaminated as well as the health hazard and environmental. We are interested in identifying the various dies of valorization other than agricultural spreading.

5 Material and Experimental Methods

One studied oily mud resulting from the purification plant of the refinery of Arzew RA1/Z as shown in Fig. 5. Thus for an oily comparison between two muds in the furnace with two different temperatures with 200°C during 4 h and with 600°C during 1 h (as shown in Figs. 6 and 7).

Fig. 5 Local of taking away of oily mud [3]

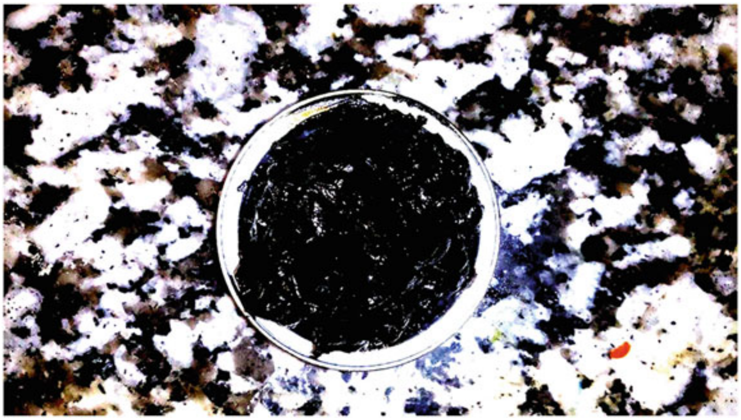

Fig. 6 Oily mud before putting it in the furnace

Fig. 7 To put mud in the furnace

5.1 Objective and Analyses

The knowledge of the chemical compounds of oily mud helps to characterize this waste. In this work, we have dried the mud in two different high temperatures by using blast furnace gas and the cement plants.

5.2 Sampling and Analyses

5.2.1 Material and Taking Away

- A shovel of collecting
- Bottle

5.2.2 Mode of Taking Away

- A manual taking away

5.3 Point Intake

Oily mud at summer taken on the level of the bed of final drying of the phase of the treatment of the mud of complex RA1/Z of Arzew as shown in Fig. 5.

5.4 Muds Analysis Methods

5.4.1 Preparation of the Mud Powder for Various Analyses

The level of the laboratory of GL2/Z carried out the drying of this oily mud.

One put oily mud in a furnace at 200°C during 4 h (as shown in Figs. 6 and 7) and another oily mud with 600°C during 1 h (as shown in Figs. 8 and 9).

Fig. 8 Oily mud dries with 200°C

Fig. 9 Oily mud dries with 600°C

Fig. 10 Crusher mortar has agate

Once they are dried, using a mortar one crushed the mud to prepare it in various analyses for oily mud at 200°C and at 600°C (Figs. 8, 9, 10, 11, and 12). This operation makes it possible to homogenize the taken matter.

This powder will be used:

- Analyses by Fourier-transform infrared spectroscopy(FTIR) and X-ray diffraction (XRD)
- The chemical composition by Energy of Dispersive of X-ray (EDX)
- For the chemical analysis by atomic absorption spectroscopy (AAS)
- Oily mud has 200°C
- Oily mud has 600°C

Fig. 11 Crushed oily mud

Fig. 12 Crusher with agate mortar and rammer oil

5.4.2 Test Performed on the Mud

Determination of the Rate of Waste Oils in Oily Mud

This method is used to determine the existing oil concentration in mud by extraction with a solvent (toluene). We take $M = 5$ g muds in a beaker, then we add a toluene excess, and we carry out the agitation of the mixture. After the separation of the phases, we balance the quantity of mud collected after filtration as shown in Figs. 14 and 15.

Fig. 13 Crushed mud at 600°C

Fig. 14 Oily mud rate of 200°C

- Calculate of the oil concentration in mud with:

$$\text{Oil rate } (\%) = M - M_1/M_2 \quad (1)$$

M: mass of mud powders
M_1: mass of mud after drying
M_2: mass of oil to extract
$M_2 = M - M_1$

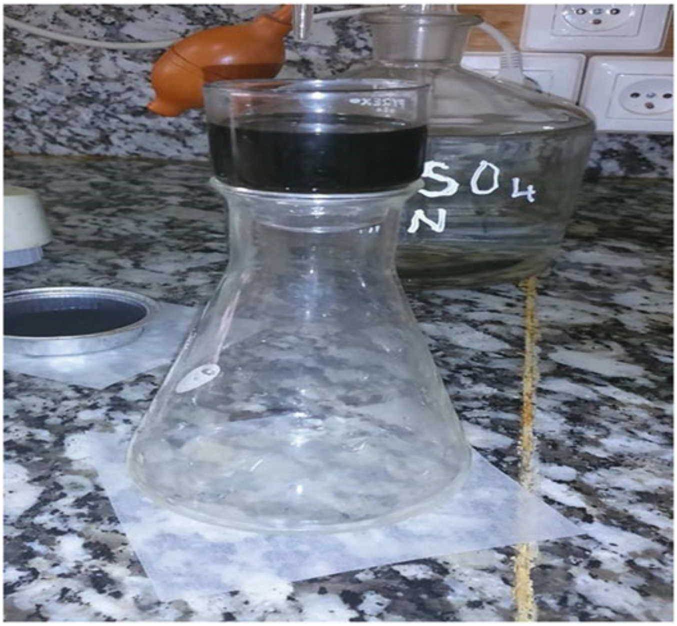

Fig. 15 Oily mud oil rate of 600°C

5.5 Determination of Heavy Metals in Oily Mud by Atomic Absorption Spectroscopy (AAS)

(AAS) is a technique described for the first time by Walsh (1955). AAS studies absorptions of light by the free atom. It is one of the principal techniques bringing into play the atomic spectroscopy in the UV-visible field used in chemical analysis. It makes it possible to proportion about 60 chemical elements (metals and non-metals). The applications are numerous since one usually reaches concentrations lower than the mg/L (ppm). In its principle AAS spectroscopy consists in vaporizing the liquid sample and heating it using a flame or of a furnace. In flame mode the equipment can be used in the spectrometry of absorption and emission. The flame is directed toward a light emitted by a suitable lamp emitting the wavelengths characteristic of the required element. While crossing the flame, the light waves – of which the wavelengths correspond to the proportioned element – are absorbed by the excited ions present in the flame. Absorption is measured using a dispersive prism and of an electric eye; it is directly proportional to the concentration of the element. When the atoms of an element were excited, their return at the fundamental state is accompanied by the emission of light of a frequency F well defined and specific to this element. The same element dispersed in a flame has the property to absorb any of the same radiation frequency F. It results in an absorption from it from the incidental radiation related to the concentration of the element considered. In flame mode the

Fig. 16 Preparation of water levels [Step 1]

limit of detection is about the ppm. The sensitivity of proportionings in flame mode is limited by secondary reactions (evaporation) and by time every court of passage in the flame. To increase the sensitivity of proportion, it is necessary to reduce or eliminate these two factors by atomization. This one is carried out in furnace graphite of a volume reduced under inert atmosphere. The limit of detection is then about Pb.

The developed applications in our laboratory allow us to determine the following elements: Na, K, Ca, Mg, Mn, Fe, Cd, Cr, Cu, Ni, Pb, Co, Zn, and As, by using the flame mode and the graphite furnace. These proportionings supported several studies on the operation of the grounds: the characterization of liquid samples (solution of the ground water of river and navy) and the behavior of metal elements traces in the grounds and the estuaries [35].

Before passing the two samples in the apparatus of atomic absorption spectroscopy (AAS), one prepared the water treatment which will be used for this analysis and which is prepared in the following way:

There is prenait 1 gram sample that we add hydrochloric acid 21mL to him (HCl) 6N and 7 mL of nitric acid (HNO_3) 3N, then we heat until complete drying. We take the operation again, but this time by using 10 mL HCl (5N) and demineralized water 50 mL (see Figs. 16 and 17).

Fig. 17 Preparation of water levels [Step 2]

5.5.1 Preparation of Water

One has taken 1 g sample that we add hydrochloric acid 21 mL to him (HCl) 6N and 7 mL of nitric acid (HNO_3) 3N, then we heat until complete drying. We take the operation again, but this time by using 10 mL HCl (5N) and demineralized water 50 mL (see Figs. 18 and 19).

Rough I let boil the whole then I filtered the filtrate once collected. We add 10 mL to him HCl, then we measure until 100 mL with demineralized water. I would obtain a yellowish mud solution then (see Figs. 20 and 21).

One diluted the solution 2 mL to the solution of 100 mL.

The factor of dilution (Fd) = 50

Thus the result to calculate the concentration of this solution:

Concentration of the solution in ppm (mg/L) = la value obtained ∗factor of dilution (Fd)

6 Results and Discussions

6.1 Determination of the Rate of Waste Oils in Oily Mud

Calculation of the oil concentration in mud with: Eq. (1).

The oily mud at 200°C (OMX200):

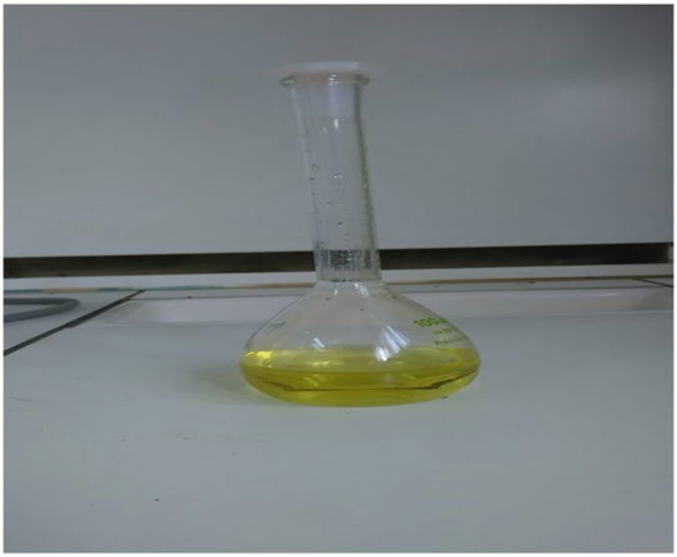

Fig. 18 Preparation of water levels [Step 3]

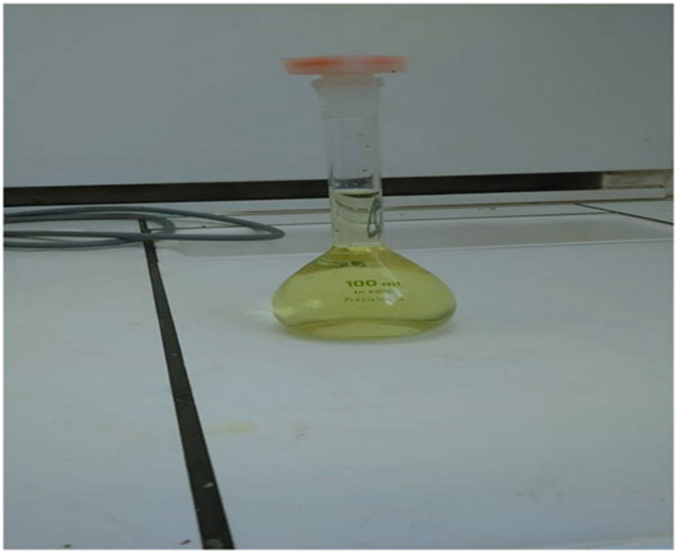

Fig. 19 Preparation of water levels [Step 4]

Oil rate (%) $= ((5 - 4.5) \div 5) \times 100 = 10\%$
Oil rate (%) $= 10\%$
The oily mud at 600°C
Oil rate (%) $= ((5 - 4.8) \div 5) \times 100 = 4\%$
Oil rate (%) $= 4\%$

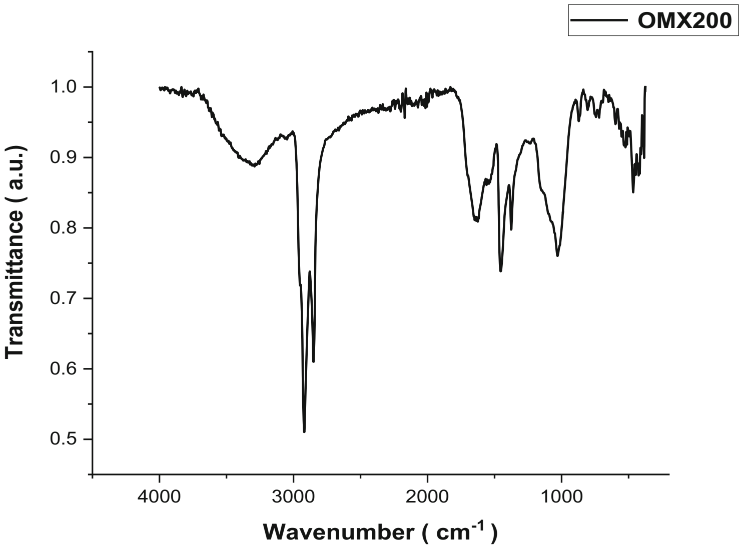

Fig. 20 Spectrum of oily mud dries with 200°C (OMX200)

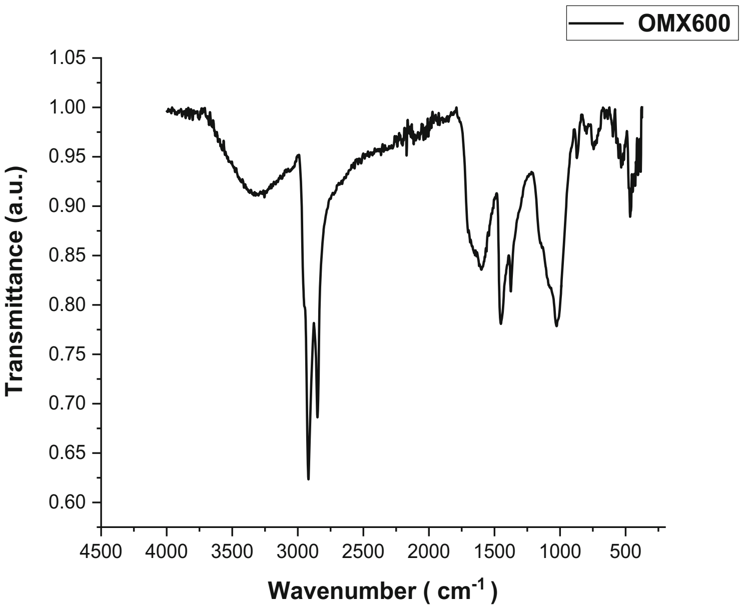

Fig. 21 Spectrum of oily mud dries with 600°C (OMX600)

6.2 X-Ray Fluorescence (XRF)

Quantitative mineralogical analysis by X-ray fluorescence (XRF) of oily mud dries at temperature $T = 200°C$. The mineralogical composition of dry oily mud at temperature 200°C (OMX200) studied refinery RA1/Z was determined by fluorescence of X-rays quantified in the form of oxides and is deferred in Table 1.

The mineralogical analysis of oily mud dries at $T =$ temperature 200°C; watch the prevalence of silica (SiO_2) with the value of 16.16% and the presence of oxides of small mass percentages which are iron oxide (III) (Fe_2O_3) 4.46%, alumina (Al_2O_3) 4.22%, calcium oxide (CaO) 3.70% , potassium oxide (K_2O) 0.70%, magnesium oxide (MgO) 0.35%, sulfur trioxide (SO_3) 0.19%, and finally sodium oxide (Na_2O) 0.02%. The loss of ignition of dry oily mud at temperature $T = 200°C$ is of 63.09%.

6.3 Analysis by Fourier-Transform Infrared Spectroscopy (FTIR)

In oily mud dries with 200°C (OMX200) as shown in Fig. 20.

According to this result, one obtains a spectrum which contains various bands to be explained: The absorption band to 3,290.59 cm^{-1} indicates the presence of a O-H of the carboxylic acid because of the various chemicals used [36]. The absorption band to (2,919.18 cm^{-1}; 2,850.87 cm^{-1}) correspond to the vibration of elongations C-H; generally they are hydrocarbons of language chains carbonaceous of C_{11} to the C_{30} [36].

The absorption band to 1,625.34 cm^{-1} corresponds to the vibration of carbons of double connections C=C [36]. The absorption band to 1,560.07 cm^{-1} indicates the radicals of amines N-H [36]. The absorption band to 1,455.03 cm^{-1} corresponds to the C-H vibration [36]. The absorption band to 1,375.83 cm^{-1} corresponds to the vibration of radicals CH_2 and CH_3 [36]. The absorption band to 1,030.60 cm^{-1} corresponds to the vibration of C-F [36]. Five absorption bands to (871.94 cm^{-1}; 806.23 cm^{-1}; 778.21 cm^{-1}; 743.14 cm^{-1}; 719.82 cm^{-1}) correspond to the C-Cl

Table 1 Chemical composition of oily mud dries for $T = 200°C$ (OMX200) by XRF

Composants	(%) mass
SiO_2	16.16
Fe_2O_3	4.46
Al_2O_3	4.22
CaO	3.7
K_2O	0.70
MgO	0.35
SO_3	0.19
Na_2O	0.02
LOI	63.09

vibrations [36]. Five absorption bands to (597.91 cm^{-1}; 570.11 cm^{-1}; 552.50 cm^{-1}; 523.19 cm^{-1}; 512.22 cm^{-1}; 512.22 cm^{-1}) correspond to the C-Br vibrations [36].

The set's absorption bands to (494.58 cm^{-1}; 465.79 cm^{-1}; 447.47 cm^{-1}; 425.90 cm^{-1}; 418 cm^{-1}; 406.35 cm^{-1}; 384.48 cm^{-1}) correspond to the vibrations of Cl [36].

In oily mud dries at 600°C that the absorption band to 3,254.15 cm^{-1} indicates the presence of a O-H of absorption to carboxylic acid R-COOH. The formation of carboxylic with the cause of different chemicals used. Two absorption bands (2,918.15 cm^{-1}; 2,849.91 cm^{-1}) generally corresponds to the vibrations of CH elongation; they are the hydrocarbons of the language chains carbonaceous of C_{11}–C_{30}.

The new absorption bands (2,566.95 cm^{-1}; 1,600.30 cm^{-1}) corresponds to the vibrations of carbons doubles connections C=C. A new absorption band with (1,451.43 cm^{-1}) corresponds to the vibration of C-H. The absorption band with (1,025.70 cm^{-1}) corresponds to the CH vibration. The absorption band with (871.88 cm^{-1}) corresponds to the C-Cl vibration. A new absorption band with (797.72 cm^{-1}) corresponds to the C-Cl vibration. Absorption band with (743.55 cm^{-1}) corresponds to the C-Cl vibration. Two absorption bands (597.11 cm^{-1}; 570.36 cm^{-1}) correspond to the C-Br vibrations. A new absorption band with (533.64 cm^{-1}) corresponds to the C-Br vibration. An absorption band with (512.80 cm^{-1}) corresponds to the C-Br vibration. An absorption band with (465.34 cm^{-1}) corresponds to vibration Cl. Two new absorption bands (445.49 cm^{-1}; 426.54 cm^{-1}) correspond to the vibration of Cl. An absorption band with (418.33 cm^{-1}) corresponds to the vibration of Cl. Two new bands correspond to the vibration of Cl as shown in Fig. 21.

The comparison between two oily muds dry with 200°C and the other has 600°C According to what this superposition sees, some of the difference between the two spectra of oily mud at 200°C (OMX200) and at 600°C (OMX600); which shows us that there are disappeared bands during heating, and we obtain new bands at 600°C which is explained by the effect of heat on the oily mud as shown in Fig. 22.

6.4 X-Ray Diffraction (XRD)

Figures 23 and 24 correspond the diffractograms of two oily muds present and their superposition as shown in Fig. 25.

Tables 1 and 2 represent the characteristics of the two diffractograms.

X-ray diffraction is a method of nondestructive analysis of solids in powder form based on Bragg's law (Eq. 2):

$$2d_{\mathrm{hkl}}\ \sin\ \theta = n\lambda\ (1).\big(N = 1.\lambda = 1.54\ \text{Å}\big). \tag{2}$$

d_{hkl}: outdistance between 2 plans of index of d_{hkl} in Å.

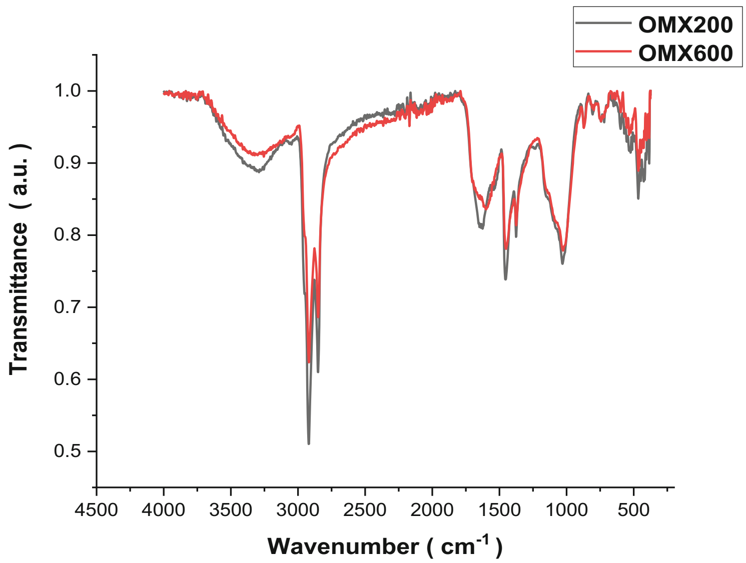

Fig. 22 Spectrum of oily mud dries at 200°C (OMX200) and at 600°C (OMX600)

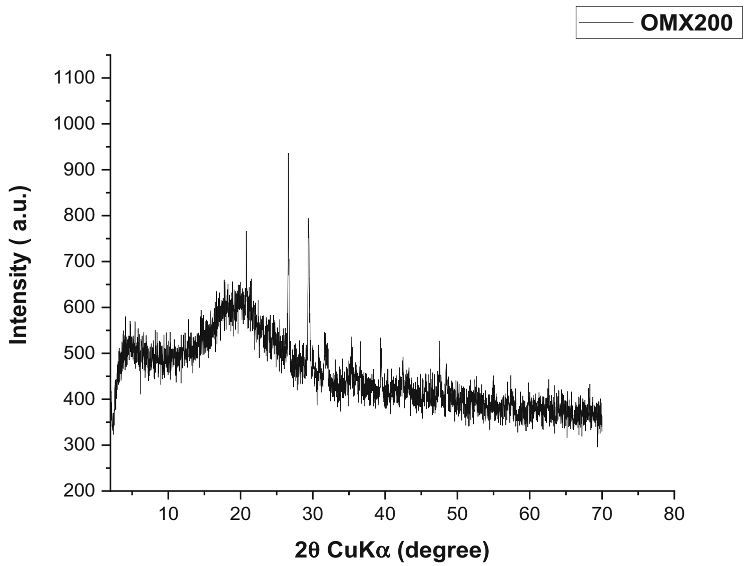

Fig. 23 Diffractogram of oily mud dries with 200°C (OMX200)

θ: Bragg angle.
λ: Wavelength of the radiation in Å.
Sin $\theta = \lambda/2d$.
$\theta = \text{arc sin } (\lambda/2d)$.

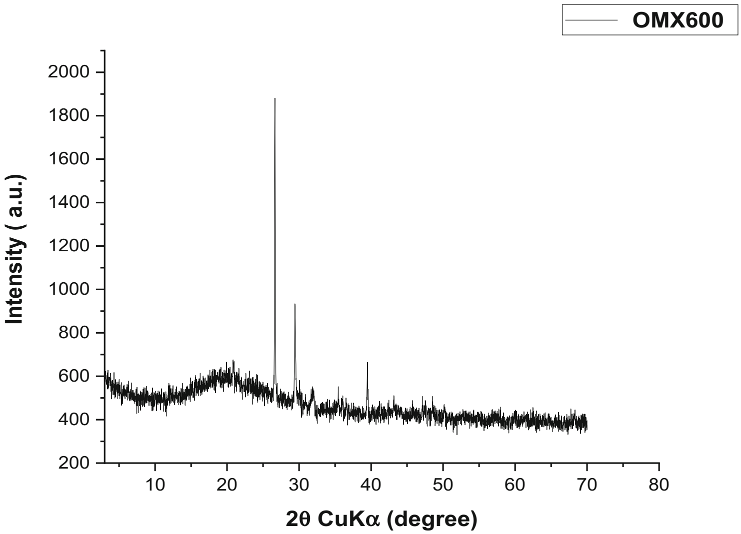

Fig. 24 Diffractogram of oily mud dries with 600°C (OMX600)

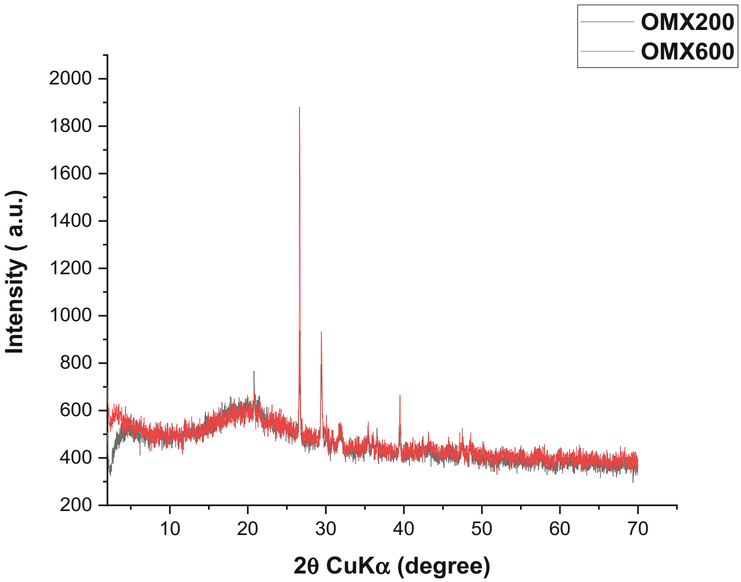

Fig. 25 Diffractogram of two oily mud dries with 200°C (OMX200) and at 600°C (OMX600)

For dry oily mud that has 200°C (*OMX200*), according to this result, one obtained a diffractogram which contains different distances interarticular to explain: the peak with $2\theta° = 2°$ with the interarticular distance $d = 50.95$ corresponds for the smectite ((K. H_3O) (Al. Mg. Fe)$_2O_{10}$ [$(OH)_2$. H_2O)]) [37]. The peak with $2\theta° = 2.5°$

Table 2 Elements analyses (Cu, Zn, Fe, Ni, Pb, Cd) in the oily mud at 200°C (OMX200) of RA1/Z by atomic absorption spectroscopy (AAS) in mg/L

Elements	Oily mud at 200°C (OMX200) [RA1/Z] (mg/L)
Cu	1.0575
Zn	0.8765
Fe	1.04
Ni	0.37
Pb	0.243
Cd	0.0075
Cr	0.05642

with the interarticular distance $d = 33.18242$ corresponds for the smectite ((K. H_3O) (Al. Mg. Fe)$_2$ O_{10} [(OH)$_2$. H_2O)]) [37]. The peak with $2\theta° = 3.3°$ with the interarticular distance $d = 26.41$ corresponds for the smectite ((K. H_3O) (Al. Mg. Fe)$_2$ O_{10} [(OH)$_2$. H_2O)]) [37]. The peak with $2\theta° = 18°$ with the interarticular distance $d = 4.97$ corresponds for kaolinite Al_2Si_2 $O_5(OH)_4$ [38–41]. The peak with $2\theta° = 21.2°$ with the interarticular distance $d = 4.26$ corresponds for the illite (K_2. H_3O) (Al. Mg. Fe)$_2O_{10}$ [(OH)$_2$. (H_2O)]) (ASTM N° = 9–343). The peak with $2\theta° = 21.1°$ with the interarticular distance $d = 4.26$ corresponds for quartz (SiO_2) (ASTM N°=5-490). The peak with $2\theta° = 21.1°$ with the interarticular distance $d = 4.26$ corresponds for the opal has (SiO_2n H_2O) [40]. The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.340$ corresponds for the rutile (TiO_2) (ASTM N° = 8–98). The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.340$ corresponds for the lepidocrocite (γ-FeOOH) (ASTM N° = 4–55). The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.340$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.340$ corresponds for the akaganeite (β-FeOOH) [41]. The peak with $2\theta° = 29.4$ with the interarticular distance $d = 3.03$ corresponds for diopside (Ca $MgSi_2O_6$). The peak with $2\theta° = 29.4$ with the interarticular distance $d = 3.03$ corresponds for calcite ($CaCO_3$) (ASTM N° = 5–490) [42].

The peak with $2\theta° = 29.4$ with the interarticular distance $d = 3.03$ corresponds for opal-A ($SiO_2 \cdot nH_2O$) [40]. The peak with $2\theta° = 30.1°$ with the interarticular distance $d = 2.97$ corresponds for the opal-A [40]. the peak with $2\theta° = 30.\ 1°$ with the interarticular distance $d = 2.97$ corresponds for calcite ($CaCO_3$) (ASTM N° = 5–490) [42]. The peak with $2\theta° = 30.1°$ with the interarticular distance $d = 2.97$ corresponds for diopside (Ca $MgSi_2O_6$) (ASTM N° = 11–654). The peak with $2\theta° = 31.1°$ with the interarticular distance $d = 2.89$ corresponds for diopside (Ca $MgSi_2O_6$) (ASTM N° = 11–654). The peak with $2\theta° = 31.1°$ with the interarticular distance $d = 2.89$ corresponds for the Opal-A (SiO_2.n H_2O) [40]. The peak with $2\theta° = 31.1°$ with the interarticular distance $d = 2.89$ corresponds for calcite ($CaCO_3$) (ASTM N° = 5–490) [43]. The peak with $2\theta° = 31.9°$ with the interarticular distance $d = 2.82$ corresponds for the Opal-A (SiO_2.n H_2O) [40]. The peak with $2\theta° = 31.9°$ with the interarticular distance $d = 2.82$ corresponds for calcite ($CaCO_3$) (ASTM N° = 5–490) [43]. The peak with $2\theta° = 35.6°$ the interarticular distance $d = 2.53$ corresponds for kaolinite (Al_2 SiO_5 $(OH)_4$) [54].

The peak with $2\theta° = 35.6°$ with the interarticular distance $d = 2.53$ corresponds for hematite (α- Fe_2O_3) [37].

The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for the rutile (TiO_2) (ASTM N° = 4–55). The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for lepidocrocite (γ- FeOOH) (ASTM N° = 8–98). The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for the goethite (α – FeOOH).

The peak with $2\theta° = 39.5°$ with the interarticular distance $d = 2.28$ corresponds for the aragonite $CaCO_3$) [46,60]. The peak with $2\theta° = 39.5°$ with the interarticular distance d = 2.28 corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 39.5°$ with the interarticular distance $d = 2.12$ corresponds for the opal-A (SiO_2 n H_2O) [40].

The peak with $2\theta° = 47.1°$ with the interarticular distance $d = 1.91$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 47.1°$ with the interarticular distance $d = 1.91$ corresponds for illite (K_2. H_3O) (Al. Mg. $Fe)_2O_{10}$ $[(OH)_2$. $(H_2O)]$) (ASTM N° = 9–343). The peak with $2\theta° = 48.1°$ with the interarticular distance $d = 1.91$ corresponds for calcite ($CaCO_3$) [33].

The peak with $2\theta° = 48.1°$ with the interarticular distance $d = 1.87$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 50.5°$ the interarticular distance $d = 1.87$ corresponds for kaolinite $Al_2Si_2O_5(OH)_4$) (ASTM N° = 9–343).

The peak with $2\theta° = 54.5°$ with the interarticular distance $d = 1.66$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 57.5°$ with the interarticular distance $d = 1.60$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 62.6°$ with the interarticular distance $d = 1.48$ corresponds for quartz (SiO_2) (ASTM N° = 5–490).

For dry oily mud that has $600°C$ (*OMX600*), according to this result, one obtained a diffractogram which contains different distances interarticular to explain:

The peak with $2\theta° = 1.8°$ with the interarticular distance $d = 49.07$ corresponds for the smectite ((K. H_3O) (Al. Mg. $Fe)_2$ O_{10} $[(OH)_2$. $H_2O)]$) [37]. A new peak with $2\theta° = 11.8°$ with the interarticular distance $d = 7.43$ corresponds for quartz (SiO_2). The peak with $2\theta° = 20.8°$ with the interarticular distance $d = 4.25$ corresponds for quartz (ASTM N° = 5–490) [41].

The peak with $2\theta° = 20.8°$ with the interarticular distance $d = 4.25$ corresponds for the opal-A (SiO_2 nH_2O) [40]. The peak with $2\theta° = 26.8°$ with the interarticular distance $d = 3.34$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.34$ corresponds for rutile (TiO_2) (ASTM N° = 8–98). The peak with $2\theta° = 26.5°$ with the interarticular distance $d = 3.34$ corresponds for the akaganeite (β-FeOOH) [41].

The peak with $2\theta° = 29.5°$ with the interarticular distance $d = 3.03$ corresponds for diopside (Ca $MgSi_2O_6$) (ASTM N° = 11–654). The peak with $2\theta° = 29.5°$ with the interarticular distance $d = 3.03$ corresponds for the opal has (SiO_2nH_2O) [40]. The peak with $2\theta° = 35.4°$ with the interarticular distance $d = 2.52$ corresponds for hematite (α-Fe_2O_3) [43]. The new peak with $2\theta° = 35.9°$ with the interarticular distance $d = 2.48$ corresponds for rutile (TiO_2) (ASTM N° = 8–98).

The new peak with $2\theta° = 35.9°$ with the interarticular distance $d = 2.48$ corresponds for lepidocrocite (γ-FeOOH) [66]. The new peak with $2\theta° = 35.9°$ with the interarticular distance $d = 2.48$ corresponds for goethite (α-FeOOH) [58]. The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for the rutile (TiO_2) (ASTM N° = 8–98). The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for lepidocrocite (γ- FeOOH) [66]. The peak with $2\theta° = 36.8°$ with the interarticular distance $d = 2.45$ corresponds for goethite (α-FeOOH) [58]. The peak with $2\theta° = 39.4°$ with the interarticular distance $d = 2.27$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 39.4°$ with the interarticular distance $d = 2.27$ corresponds for aragonite ($CaCO_3$) [58, 60]. A new peak with $2\theta° = 41.2°$ with the interarticular distance $d = 2.19$ corresponds for Opal-A (SiO_2. nH_2O) [40]. A new peak with $2\theta° = 43.3°$ with the interarticular distance $d = 2.19$ corresponds for the opal-A [40]. The peak with $2\theta° = 47.1°$ with the interarticular distance $d = 1.92$ corresponds for quartz (SiO_2) (ASTM N°=5-490). The peak with $2\theta° = 47.6°$ with the interarticular distance $d = 1.91$ corresponds for quartz (SiO_2) (ASTM N° = 5–490).

The peak with $2\theta° = 47.6°$ with the interarticular distance $d = 1.91$ corresponds for illite (K_2. H_3O) (Al. Mg. Fe)O_{10} [$(OH)_2$. (H_2O)]) (ASTM N° = 5–490). The peak with $2\theta° = 47.6°$ with the interarticular distance $d = 1.91$corresponds for calcite ($CaCO_3$) [33]. The peak with $2\theta° = 48.6°$ with the interarticular distance $d = 1.87$ corresponds for quartz (SiO_2) (ASTM N° = 5–490). The peak with $2\theta° = 48.6°$ with the interarticular distance $d = 1.87$ corresponds for kaolinite ($Al_2Si_2O_5$ $(OH)_4$) (ASTM N° = 9–343). The new peak with $2\theta° = 50.1°$ with the interarticular distance $d = 1.81$ corresponds for quartz (SiO_2) (ASTM N° = 5–490).

6.4.1 The Superposition Enters Both Diffractogram

According to this superposition, being able to see the diffractogram of mud that has 200°C (OMX200) and amorphous on the other hand the diffractogram at 600°C (OMX600) and crystalline, however, perhaps explains by the effect of heat on mud what one has understood of it that there has organic phases disappeared during heating of mud as shown in Fig. 25.

6.5 Determination of the Metal Elements in Oily Mud

(Cu, Zn, Fe, Ni, Pb, and Cd) atomic absorption spectrometry analyses in the oily mud of RA1/Z.

The masses of heavy metals in oily mud are summarized in the table of the results.

6.6 *Quantification Table of the Metal Elements in the Oily Mud of 200°C (OMX200)*

These values are represented in (mg/L), but standard Afnor gives us values in matter mg/kg dries; this is why we must convert them into mg/kg DM in the following way:

To prepare water treat, we have dissolve 1 g of mud in 100 final ml of solution in 1 L of solution of ms, and we calculate the quantity of these elements in dry mud 1 kg with the following formula as shown in (see Tables 3, 4, and 5), respectively:

$$\text{Valor in mg/kg of DM} = \text{X} \times 100/1{,}000 \tag{3}$$

Table 3 Quantification of the metal elements in the oily mud of 200°C (OMX200) in mg/kg

Elements	Oily mud at 200°C (OMX200) [RA1/Z] in (mg/kg)	Norm in agriculture in (mg/kg)
Cu	105.75	1,000
Zn	87.65	3,000
Fe	104	/
Ni	37	200
Pb	243	243
Cd	0.75	0.75
Cr	5.642	1,000

Table 4 Elements analyses (Cu, Zn, Fe, Ni, Pb, Cd) in the oily mud of RA1/Z at 600°C (OMX600) by atomic absorption spectroscopy (AAS) in mg/L

Elements	Oily mud at 600°C [RA1/Z] in (mg/L)
Cu	1.3691
Zn	1.09
Fe	2.3
Ni	0.40
Pb	0.347
Cd	0.065
Cr	00.0431

Table 5 Quantification of the metal elements in the oily mud of 600°C (OMX600) in mg/kg

Elements	Oily mud at 600°C [RA1/Z] in (mg/kg)	Norm in agriculture in (mg/kg)
Cu	136.91	1,000
Zn	109	3,000
Fe	230	/
Ni	40	200
Pb	34.7	800
Cd	6.5	20
Cr	4.31	1,000

7 Conclusions

At the time of the realization of our memory of end of study, we became aware of the importance of the purification plant which with for objective to purify oily water so that they are not directly rejected in the natural environment, because they can generate serious environmental problems and handles public. On the other hand, this stations generate another waste (mud) rich in oily age of nature toxic and carcinogenic and can be neither stored nor put in discharge. The exact composition of muds varies according to the origin of oily water of the period of the year and the type of purification plant. Muds are very rich in organic matter (between 50% and 70% of matter dries) which supports the proliferation of micro the organizations which multiply and break up the organic matter. In the absence of sufficient ventilation, the decomposition releases from the organic compounds malodorous has jumps as well as gases with greenhouse effect (carbonic gas, methane, etc.). This situation illustrates clearly that an action plan became necessary fine to rehabilitate a system allowing an adequate exploitation for muds by respecting the standards of environmental protection. The contribution to the valorization of oily muds of the refinery of Arzew-like fuel of substitution in the furnaces of the cement factories or the blast furnaces of the foundries as a principle to develop the energy capacity of the organic matter of dried mud because its calorific value is very high of that of methane. The use of alternative fuels makes it possible to diversify the energy resources and to reduce these costs. On the one hand, in the furnaces, the organic components will be exposed by heat treatment with different temperature with 200°C, and 600°C will be burned completely, while the mineral components will undergo a chemical conversion which will integrate into the clinker without deteriorating the excellent quality of this one. The use of ashes of muds like an addition to the clinker in the manufacture of cement in goal to minimize the increasing quantity of waste of coordination with existing industries with the national territory by using the least expensive processes devoted of the very satisfactory results with the various studied percentages.

8 Recommendations

As an example the substitution of 13% of the raw material by ashes enables us to eliminate a quantity from 65,000 tonnes/year knowing that annual production of cement in a cement factory (e.g., cement factory of Saida) is estimated at 500,000 tonnes/year cements with ashes as addition obtained at 900°C and will be used preferably in the nonexposed works, for example, highways. Finally we can completely say that our study of valorization of muds eliminates this waste in an exemplary industrial process on the ecological and economic level. It is the most suitable way, ecologically and economically, in order to respond to the problem of removing heavy metals and sewage sludge ashes.

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Part III
Water Resources Modeling and Forecasting

Kalman Filter for Spatio-temporal Modeling and Prediction of Algerian Water Resources Variability: Case Study of Precipitation and Stream Flows at Monthly and Annual Scales

Khadidja Boukharouba and Samra Harkat

Contents

Abstract The present chapter is an overview of our recent works in the area of water resources modeling for ends of prediction in Algeria. It focuses on a particularly interesting type of models that can support not only the stochastic nature of the hydrological processes but also their temporal variability as well as the nonlinear character of the hydrological system. Such models are mostly required in water resources design and management because they provide a helpful tool for decision

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and policy makers in Algeria. The objective here is to showcase some of our recent results regarding the extent of applicability of discrete Kalman filter (KF) to the modeling and prediction of water resources in Algeria. For this end, two important hydrological variables have been investigated: rainfalls in the Cheliff watershed and stream flows in the northern Algeria. The corresponding time series data in the annual and monthly scales have been utilized to build some mathematical models based on the discrete KF structure. For each of the two hydrological variables, annual and monthly models have been set for prediction. In all cases, the obtained model is an online prediction operation where the variable predictor is not bound to time or space, but rather adapts itself recursively to evolving conditions related to any climatic and physiographic factors in the study area. The obtained models provide with predictions that respect the variables stochastic character and undertake also the nonlinear nature of the hydrological system. Moreover, the obtained results are optimum in more ways than one: (1) To be initiated, calculations need only a minimum objective information. (2) Recursivity in the time domain gives to the model an adaptive character that can be used in real-time forecasting. (3) The prediction covariance error is provided exactly at each iteration calculations. The obtained results for either the spatial or the temporal variability of the considered variables are satisfactory, and the associated errors are quite acceptable.

Keywords Algeria, Kalman filter, Precipitation, Prediction, Stochastic, Stream flows

1 Introduction

The hydrological time series variability in time and space has always been a big challenge facing any action plan or investigation in water resources in Algeria. This was due to either the randomness hypothesis of this variability, which makes impossible the prediction of such variables, or the deterministic character of the adopted models, which are very far from the reality of the hydrological system and, hence, provide with some inacceptable predictions.

Actually, the hydrological variables such as rainfalls and stream flows occur in nature as the result of a very complex climatic and physiographic factors interaction [1] that cannot be simplified in practice, by adopting purely deterministic or purely random models. For a better prediction of these variables, one needs to adopt a mathematical model that depicts not only the stochastic and non-stationary nature of the hydrological process itself but also the nonlinear feature of the hydrological system in general. Such understanding of nature in a model type selection will certainly enable a good description of the underlying generating mechanism which is a fundamental requirement in water resources modeling.

Such models in hydrology are numerous and diverse, and the literature offers a wide range of them, but in this study our attention is focused on a particular type: the state-space models. The latter include the distinction between the observed variables (signal) and hidden variables (internal state), and they generally consist of an equation of state, showing the dynamic of the hidden variables, and a measurement equation, describing the way how observations are generated by hidden variables and residuals [2].

In the present chapter, we opted for the discrete Kalman filter (KF) type of models to the modeling and prediction of rainfall and stream flow records in northern part of Algeria.

The term "filter" comes from electronic language and means the extraction of a signal from a noisy environment [3]. In such way, the filtering operation is defined as the operation of estimating the state of a dynamic system from partial and noisy observations. In other words, it means any mathematical operation that uses past data or measurements of a dynamical system to obtain better estimations in the past (interpolation), in the present (filtering), or in the future (forecast).

KF is one of the most popular filters in this area. It relies on the recursive least squares concept, and it is well-known in so many other fields than hydrology by its optimality provided the assumptions of linearity and white Gaussian noise [4, 5]. It processes by combining two independent estimations to get a better weighted one: the first estimation is an estimate (prediction) based on a prior knowledge, while the second estimation is an estimate based on new information (measurement). The major advantage of KF is to provide with the prediction error covariance which is an indicator of the filter accuracy. In addition, its calculation algorithm works in the temporal domain with a recursive nature and has an optimal estimator in the least squares concept. Another aspect of its optimality is the incorporation of all the available information on the system, measurements and errors in an adaptive operator which is reset each time a new measurement becomes available.

The objective of this chapter is to showcase some of our recent works in water resources modeling and prediction in Algeria. Two case studies are reviewed here, each one of them is about the applicability of KF technique to the modeling and prediction of annual and monthly hydrological records. The first case study concerns stream flow records [6], whereas the second deals with rainfalls in the Cheliff watershed [7], both of them in northern Algeria.

2 Development of the Discrete Kalman Filter Equations

The discrete Kalman filter (KF) is considered to be one of the most well-known and often-used significant mathematical tools that can be used for stochastic estimation from noisy measurements [8]. It is as an optimal recursive data processing algorithm which is constituted essentially by a set of five mathematical equations that implement a predictor-corrector type estimator that is optimal in the sense that it minimizes the estimated error covariance, when some presumed conditions are met [9]. It combines all available measurement data, plus prior knowledge about the system and measuring devices, to produce an estimate of the desired variables in such a manner that the error is minimized statistically.

The fundamental multidimensional KF recursive equations can be expressed as follows:

$$X_k = \phi_{k/k-1} X_{k-1} + W_{k-1} \tag{1}$$

where X_{k-1}, X_k: $(n \times 1)$ state vectors at times $t_{k-1}$and t_{k-1}, t_k respectively, $\phi_{k/k-1}$: $(n \times n)$ transition matrix relating X_{k-1} to X_k, and W_{k-1}: $(n \times 1)$ white noise sequence vector with known covariance structure.

The discrete measurement of the process is supposed to be linearly related to the state according to the following relationship:

$$Z_k = H_k X_k + V_k \tag{2}$$

where:Z_k: $(m \times 1)$ vector measurement at time t_k

H_k: $(m \times n)$ matrix giving the ideal (noiseless) connection between the measurement and the state vectors at time t_k

V_k: $(m \times 1)$ measurement error assumed to be a white noise sequence with known covariance structure and zero cross-correlation with the W_{k-1} sequence

The covariance matrices for W_{k-1} and V_k vectors are given by the following equations, where subscript T denotes transpose of the vector.

$$\mathrm{E}\left[W_k\, W_i^T\right] = \begin{cases} Q_k, i = k \\ 0, i \neq k \end{cases} \tag{3}$$

$$\mathrm{E}\left[V_k\, V_i^T\right] = \begin{cases} R_k, i = k \\ 0, i \neq k \end{cases} \tag{4}$$

$$\mathrm{E}\left[W_k\, V_i^T\right] = 0, \forall i \text{ et } k \tag{5}$$

Equation (1) is the state model; it allows the transition of the state X_{k-1} at time t_{k-1} to the state X_k at time t_k via the transition matrix $\phi_{k/k-1}$. Equation (2) provides the value of the variable Z_k at time t_k, obtained by a measurement process; it supposes a linear relationship between the measurement and the state vector. In the same time, W_{k-1} et V_k are supposed to be white noises of zero mean and known covariance Q and R, respectively. The problem, in this case, can be stated as follows:

1. Is it possible to find an estimate of the state X_k by linear combination of the measurement Z_k and the state X_{k-1}? Of course this estimation must be optimal in the sense of the least squares concept.
2. Is it possible to obtain an optimal prediction of the state and the measurement? In the same sense.

Under certain hypothesis, the response to the previous questions can be affirmative. This can be materialized by the implementation of the discrete KF recursive equations.

In the presence of some available measurement information until time t_{k-1} (initial time), the initial (a priori) estimate of the concerned process based on the available information at time t_{k-1} might be available and can be denoted as $\widehat{X}_{k/k-1}$. The prior estimation error and the error covariance matrix associated to the initial estimation are given by the following expressions:

$$e_{k/k-1} = X_k - \widehat{X}_{k/k-1} \tag{6}$$

$$P_{k/k-1} = \mathrm{E}\left[e_{k/k-1} e_{k/k-1}^T \right] \tag{7}$$

$$P_{k/k-1} = \mathrm{E}\left[\left(X_k - \widehat{X}_{k/k-1} \right) \left(X_k - \widehat{X}_{k/k-1} \right)^T \right] \tag{8}$$

The updated (a posteriori) state estimate $\widehat{X}_{k/k}$ at time t_k incorporates the coming measurement $Z_k$for the improvement of the a priori estimate $\widehat{X}_{k/k-1}$. This task is achieved by adding a correction term constituted by the difference $\left(Z_k - H_k \widehat{X}_{k/k-1} \right)$, which is ponderated by a blending factor K_k, so as to obtain:

$$\widehat{X}_{k/k} = \widehat{X}_{k/k-1} + K_k \left(Z_k - H_k \widehat{X}_{k/k-1} \right) \tag{9}$$

The blending factor K_k is supposed to yield an optimum estimate $\widehat{X}_{k/k}$ as far as the the least squares concept is concerned. To find this particular K_k, we have to combinate together the following error $e_{k/k-1}$ and the associated updated error covariance matrix $P_{k/k}$, in the following equations:

$$e_{k/k} = X_k - \widehat{X}_{k/k} \tag{10}$$

$$P_{k/k} = \mathrm{E}\left[e_{k/k} e_{k/k}^T \right]$$

$$P_{k/k} = \mathrm{E}\left[\left(X_k - \widehat{X}_{k/k} \right) \left(X_k - \widehat{X}_{k/k} \right)^T \right] \tag{11}$$

By substitution one can obtain the following expression:

$$\widehat{X}_{k/k} = \widehat{X}_{k/k-1} + K_k \left(H_k X_k + V_k - H_k \widehat{X}_{k/k-1} \right) \tag{12}$$

Then, by substituting Eq. (12) into Eq. (11), it becomes possible to get a general expression for the updated error covariance matrix:

$$P_{k/k} = (\mathrm{I} - K_k H_k)\, P_{k/k-1}(\mathrm{I} - K_k H_k)^T + K_k R_k {K_k}^T \tag{13}$$

In order to find the particular K_k, we have to minimize the individual terms on the main diagonal of the matrix $P_{k/k}$. After some mathematical manipulations, one can obtain the following expression:

$$K_k = P_{k/k-1}{H_k}^T \left(H_k\, P_{k/k-1}{H_k}^T + R_k\right)^{-1} \tag{14}$$

This particular vector K_k which minimizes the mean square estimation error is called Kalman gain. This later is utilized in the calculation of the updated estimate $\widehat{X}_{k/k}$ as well as the updated associated error covariance matrix $P_{k/k}$. Once again, after some mathematical manipulations, one might come to the given expression:

$$P_{k/k} = (\mathrm{I} - K_k H_k)\, P_{k/k-1} \tag{15}$$

In the same above-described way, one can project ahead the updated estimation $\widehat{X}_{k+1/k}$ using the transition matrix as follows:

$$\widehat{X}_{k+1/k} = \phi_{k+1/k}\widehat{X}_{k/k} \tag{16}$$

Of course the contribution of W_k term in Eq. (1) is reduced to zero because it has zero mean and it is not correlated with the previous $W's$. In this way, the associated error is given by the following expression:

$$e_{k+1/k} = X_{k+1} - \widehat{X}_{k+1/k} \tag{17}$$

By substitution of Eqs. (1) and (15) into Eq. (17):

$$e_{k+1/k} = \phi_{k+1/k}\, e_{k/k} + W_k \tag{18}$$

where e_k et W_k have zero cross-correlations. The error covariance matrix is then expressed as follows:

$$P_{k+1/k} = \phi_{k+1/k} P_{k/k} \phi^T_{k+1/k} + Q_k \tag{19}$$

These are the necessary equations for prediction at time t_{k+1}.

For the next step, estimations $\widehat{X}_{k+1/k}$ and $P_{k+1/k}$ are considered as initial conditions.

Definitively, Eqs. (9), (14–16), and (19) are the five required equations for the multi-site KF algorithm development. For more details on the theoretical development of the KF algorithm and relating equations, refer to Şen and Latif [1]. Those equations are recursive and present the main advantage to provide the prediction error accurately at each step. In addition, KF can be initiated with minimum available objective information, and it is adaptable as soon as a new observation arrives. It has been the subject of extensive research and application, in many areas [10–17] among others. This is not only due to the great developments in digital computing that made practical use of the filter but also to the simplicity and the robustness of the filter itself.

3 Application to Water Resources in Algeria

KF technique is achieved by combining two independent estimations: the first one is a prediction operation which relies on a deterministic model, and the second one is an update which is based on the innovation (the difference between the observed and the predicted values). It is important to notice that the recurrent type of the formulas is an advantage because predictions are required in discrete time points.

After the state-space model formulation, the calculations need to be initiated with the following information:

1. The state variable vector X_k
2. The transition matrix $\phi_{k/k-1}$ of the state variable from time t_{k-1} to t_k
3. The initial state X_0 and the associated error covariance matrix P_0
4. The joint and mutual statistics of all the concerned random variables

Then, the proper calculations are lunched accordingly with the KF recursive algorithm. This procedure remains the same whatever is the hydrological variable of concern; what will differ from one case study to another in the following sections is the dimension of vectors and matrices which is a natural consequence of the available data used in calculations.

3.1 Modeling and Prediction of Annual Stream Flows

In this case study, KF methodology has been applied using data of annual stream flow records of ten gauging stations in northern Algeria. The observed time series, provided by the National Agency of Hydraulic Resources (ANRH), have a common observation period of 25 years (1968–1992).

3.1.1 State-Space Model Formulation

State-space model formulation is one of the most important steps in KF technique application. This means the formulation of the system state and measurement equations with respect to the KF structure. The system state here is the vector of annual stream flows observed simultaneously at the ten gauging stations. In this case, for $n = 10$ the dimensions of the state and measurement vectors are (10×1), while the dimensions of the transition matrix as well as the measurement and covariance matrices are (10×10).

Hence, the state and measurement equations are respectively formulated as follows:

- State equation:

$$\begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_{10} \end{bmatrix}_k = \begin{bmatrix} \phi_{1,1} & \phi_{1,2} & \cdot\cdot\cdot & \phi_{1,10} \\ \phi_{2,1} & \phi_{2,2} & \cdot\cdot\cdot & \phi_{2,10} \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \phi_{10,1} & \phi_{2,10} & \cdot\cdot\cdot & \phi_{10,10} \end{bmatrix}_{k/k-1} \begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_{10} \end{bmatrix}_{k-1} + \begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ \cdot \\ W_{10} \end{bmatrix}_{k-1} \tag{20}$$

where:

– $\begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_{10} \end{bmatrix}_k$: the state vector at time k

– $\begin{bmatrix} \phi_{1,1} & \phi_{1,2} & \cdot\cdot\cdot & \phi_{1,10} \\ \phi_{2,1} & \phi_{2,2} & \cdot\cdot\cdot & \phi_{2,10} \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \cdot & \cdot & \cdot\cdot\cdot\cdot & \cdot \\ \phi_{10,1} & \phi_{2,10} & \cdot\cdot\cdot & \phi_{10,10} \end{bmatrix}_{k/k-1}$: state transition matrix from time $k-1$ to time k

– $\begin{bmatrix} W_1 \\ W_2 \\ \cdot \\ \cdot \\ \cdot \\ W_{10} \end{bmatrix}_{k-1}$: system noise vector

- Measurement equation:

$$\begin{bmatrix} Z_1 \\ Z_2 \\ . \\ . \\ . \\ Z_{10} \end{bmatrix}_k = \begin{bmatrix} H_{1,1} & H_{1,2} & . & . & . & H_{1,10} \\ H_{2,1} & H_{2,2} & . & . & . & H_{2,10} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ H_{10,1} & H_{2,10} & . & . & . & H_{10,10} \end{bmatrix}_k \begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_{10} \end{bmatrix}_k + \begin{bmatrix} V_1 \\ V_2 \\ . \\ . \\ . \\ V_{10} \end{bmatrix}_k \tag{21}$$

where:

- $\begin{bmatrix} Z_1 \\ Z_2 \\ . \\ . \\ . \\ Z_{10} \end{bmatrix}_k$: measurement vector at time k
- $\begin{bmatrix} H_{1,1} & H_{1,2} & . & . & . & H_{1,10} \\ H_{2,1} & H_{2,2} & . & . & . & H_{2,10} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ H_{10,1} & H_{2,10} & . & . & . & H_{10,10} \end{bmatrix}_k$: measurement matrix at time k
- $\begin{bmatrix} X_1 \\ X_2 \\ . \\ . \\ . \\ X_{10} \end{bmatrix}_k$: state vector at time k
- $\begin{bmatrix} V_1 \\ V_2 \\ . \\ . \\ . \\ V_{10} \end{bmatrix}_k$: measurement noise vector at time k

3.1.2 Initial Conditions

Once the state-space model formulation is set, the execution of KF algorithm requires specification of some initial conditions, as previously mentioned. This has been set according to the following steps:

Initial State Vector and Associated Error Covariance Matrix

The initial calculation begins at time $k = 1$; the initial state vector estimate $\widehat{\boldsymbol{X}}_{k/k-1}$ is constituted by the mean annual stream flows at the ten concerned gauging stations $\left(\overline{X}_1, \overline{X}_2, \ldots, \overline{X}_{10}\right)$ as follows:

$$\hat{\boldsymbol{X}}_{1/0} = \begin{bmatrix} \bar{X}_1 \\ \bar{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \bar{X}_{10} \end{bmatrix} \tag{22}$$

The associated error covariance matrix $\boldsymbol{P}_{k/k-1}$ is a (10×10) matrix that is not known. In order to get an initial estimation of it, one can start with large values of 1,000 or more in the main diagonal elements and zero elsewhere; this has the advantage of giving more flexibility to the algorithm in order to fit the sensitive values in a relatively short time.

$$\boldsymbol{P}_{1/0} = \begin{bmatrix} 1,000 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1,000 \end{bmatrix} \tag{23}$$

This choice will lead to an increase in both of the covariance matrix ***Pk/k*-1** and the filter gain, allowing as such the filter to weigh more heavily the new coming measure. As such, the trace (sum of the diagonal elements) of the initial covariance matrix is expected to decrease continuously with calculations to reach a constant positive value near zero. This behavior is indicative of the KF convergence which means the good performance of the filter.

System and Measurement Noise Covariance Matrices

For the initial system and measurement noise covariance matrices ($\boldsymbol{Q}$) and ($\boldsymbol{R}$) respectively, one can start with a (10×10) matrix with the value of 100 on the main diagonal and zero elsewhere for ($\boldsymbol{Q}$) and the value of 50 on the main diagonal and zero elsewhere for ($\boldsymbol{R}$). Such choice was adopted since we hope the measures to be less noisy than the dynamic of the system.

$$\boldsymbol{Q} = \begin{bmatrix} 100 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 100 \end{bmatrix} \tag{24}$$

$$\boldsymbol{R} = \begin{bmatrix} 50 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 50 \end{bmatrix} \tag{25}$$

Transition Matrix

The transition matrix $\boldsymbol{\phi}_{k\ k-1}$ has been considered as the cross-correlations between all the ten considered gauging stations records. As such it is a (10×10) matrix. Harrison and Stevens [18] showed that the initial value of such a matrix does not substantially affect the results of the Kalman filter.

The Measurement Matrix

Regarding the measurement matrix $\boldsymbol{H}_k$, it has been considered as a (10×10) unity matrix because all of the ten gauging stations provide their observations.

$$\boldsymbol{H}_k = \begin{bmatrix} 1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1 \end{bmatrix} \tag{26}$$

3.1.3 Kalman Filter Algorithm and Calculations

Once the initial conditions are set, the KF calculations can be launched using the five recursive fundamental equations and their loops in the following order. The software utilized for calculations has been developed and provided by Şen and Latif [1].

Kalman Filter Gain

This is the first step of calculations for $k = 1$. The (10×10) Kalman gain matrix K_k can be calculated according to Eq. (14):

$$\boldsymbol{K}_1 = \begin{bmatrix} 1000 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1000 \end{bmatrix} \left[\begin{bmatrix} 1000 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1000 \end{bmatrix} + \begin{bmatrix} 50 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 50 \end{bmatrix} \right]^{-1} \quad (27)$$

Updated Estimate Vector Using Coming Measurement

This is the second step of calculations for $k = 1$. In order to improve the initial estimate $\widehat{\boldsymbol{X}}_{1/0}$, the new measurement $\boldsymbol{Z}_k$is incorporated by considering the difference $\left(\boldsymbol{Z}_k - \boldsymbol{H}_k\,\widehat{\boldsymbol{X}}_{k/k-1}\right)$ which is weighted by the factor $\boldsymbol{K}_1$, according to Eq. (9), so as to obtain:

$$\hat{\boldsymbol{X}}_{1/1} = \begin{bmatrix} \bar{X}_1 \\ \bar{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \bar{X}_{10} \end{bmatrix}_{1/0} + \begin{bmatrix} k_{1,1} & k_{1,2} & \cdot & \cdot & k_{1,10} \\ k_{2,1} & k_{2,2} & \cdot & \cdot & k_{2,10} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ k_{10,1} & k_{10,2} & \cdot & \cdot & k_{10,10} \end{bmatrix}_1 \left(\begin{bmatrix} Z_1 \\ Z_2 \\ \cdot \\ \cdot \\ \cdot \\ Z_{10} \end{bmatrix}_1 - \begin{bmatrix} \bar{X}_1 \\ \bar{X}_2 \\ \cdot \\ \cdot \\ \cdot \\ \bar{X}_{10} \end{bmatrix}_{1/0} \right) \quad (28)$$

Error Covariance Matrix Associated to the Updated Estimate

The error covariance matrix associated to the updated estimate vector can be obtained by substituting the initial error covariance $\boldsymbol{P}_{1/0}$ associated to the initial state vector $\widehat{\boldsymbol{X}}_{1/0}$, Kalman gain matrix $\boldsymbol{K}_1$, as well as the measurement matrix $\boldsymbol{H}_k$ in Eq. (15).

$$\begin{aligned} \boldsymbol{P}_{1/1} = & \begin{bmatrix} 1000 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1000 \end{bmatrix}_{1/0} \\ & - \begin{bmatrix} k_{1,1} & k_{1,2} & \cdot & \cdot & k_{1,10} \\ k_{2,1} & k_{2,2} & \cdot & \cdot & k_{2,10} \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ \cdot & \cdot & \cdot & \cdot & \cdot \\ k_{10,1} & k_{10,2} & \cdot & \cdot & k_{10,10} \end{bmatrix}_1 \begin{bmatrix} 1000 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 1000 \end{bmatrix}_{1/0} \end{aligned} \quad (29)$$

Prediction One Step Ahead of the Updated State Estimate

The updated estimation $\widehat{\boldsymbol{X}}_{1/1}$ is projected one step ahead using Eq. (16). Here, the term $\boldsymbol{W}_{k-1}$ is not considered because it has zero mean and not correlated with the previous $\boldsymbol{W}'\boldsymbol{s}$. This step is considered as one step ahead prediction of the state vector in order to obtain the estimate $\widehat{\boldsymbol{X}}_{2/1}$ such as:

$$\begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_{10} \end{bmatrix}_{2/1} = \begin{bmatrix} \phi_{1,1} & \phi_{1,2} & \cdot\ \cdot\ \cdot & \phi_{1,10} \\ \phi_{2,1} & \phi_{2,2} & \cdot\ \cdot\ \cdot & \phi_{2,10} \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot\ \cdot & \cdot \\ \phi_{10,1} & \phi_{2,10} & \cdot\ \cdot\ \cdot & \phi_{10,10} \end{bmatrix}_{2/1} \begin{bmatrix} X_1 \\ X_2 \\ \cdot \\ \cdot \\ \cdot \\ X_{10} \end{bmatrix}_{1/1} \tag{30}$$

One Step Ahead Prediction Error Covariance Matrix

The one step ahead prediction error covariance matrix $\boldsymbol{P}_{2/1}$, which is associated to the previous $\widehat{\boldsymbol{X}}_{2/1}$, can also be obtained by substitution of the state transition matrix $\boldsymbol{\phi}_{\mathbf{2,1}}$, $\boldsymbol{P}_{1/1}$, and the system covariance noise matrix $\boldsymbol{Q}$ in Eq. (19).

$$\boldsymbol{P}_{2/1} = \begin{bmatrix} \phi_{1,1} & \phi_{1,2} & \cdot\ \cdot & \phi_{1,10} \\ \phi_{2,1} & \phi_{2,2} & \cdot\ \cdot & \phi_{2,10} \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \phi_{10,1} & \phi_{2,10} & \cdot\ \cdot & \phi_{10,10} \end{bmatrix}_{2/1} \begin{bmatrix} p_{1,1} & p_{1,2} & \cdot\ \cdot & p_{1,10} \\ p_{2,1} & p_{2,2} & \cdot\ \cdot & p_{2,10} \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ p_{10,1} & p_{10,2} & \cdot\ \cdot & p_{10,10} \end{bmatrix}_{1/1} \begin{bmatrix} \phi_{1,1} & \phi_{1,2} & \cdot\ \cdot & \phi_{1,10} \\ \phi_{2,1} & \phi_{2,2} & \cdot\ \cdot & \phi_{2,10} \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \cdot & \cdot & \cdot\ \cdot & \cdot \\ \phi_{10,1} & \phi_{2,10} & \cdot\ \cdot & \phi_{10,10} \end{bmatrix}_{2/1}^{T} + \begin{bmatrix} 100 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & 100 \end{bmatrix} \tag{31}$$

As such, in the next iteration, $\widehat{\boldsymbol{X}}_{2/1}$ and $\boldsymbol{P}_{2/1}$ are considered as initial conditions to the next iteration calculations and so on, until the end of the iterations that depends on the data length which is 25, for the annual stream flow records considered here. During this period, the first 15 years period has been used for model parameters estimation, while the remaining 10 years period has been considered for model validation.

3.1.4 Obtained Results and Discussion

Kalman filter technique has been applied to generate multi-site annual predictions for the ten considered gauging stations with a common observation period of 25 years (1968–1992). The obtained results can be appreciated in both temporal and spatial points of view, but only some of them are presented here for illustration because of space limitation.

Figure 1 is an example of the obtained results in the temporal point of view. It provides the annual observed and predicted stream flow values at Bouhnifia gauging station during 25 years time period. From a spatial point of view, Fig. 2 is a first example that provides the annual observed and predicted stream flow values at the ten gauging stations during 1969, which corresponds to the beginning of calculations, while Fig. 3 is a second example that gives the same information for 1991, which corresponds to the end of calculations, when the model is well set. The relative error in percent between observations and predictions is also illustrated in the same figures.

It is obvious from these figures that the observed and predicted values follow each other closely. This is indicative of the KF efficiency for modeling of annual stream flow values.

There are some differences between the observed records and their estimations by KF technique, particularly at the beginning of calculations, so some of the predicted

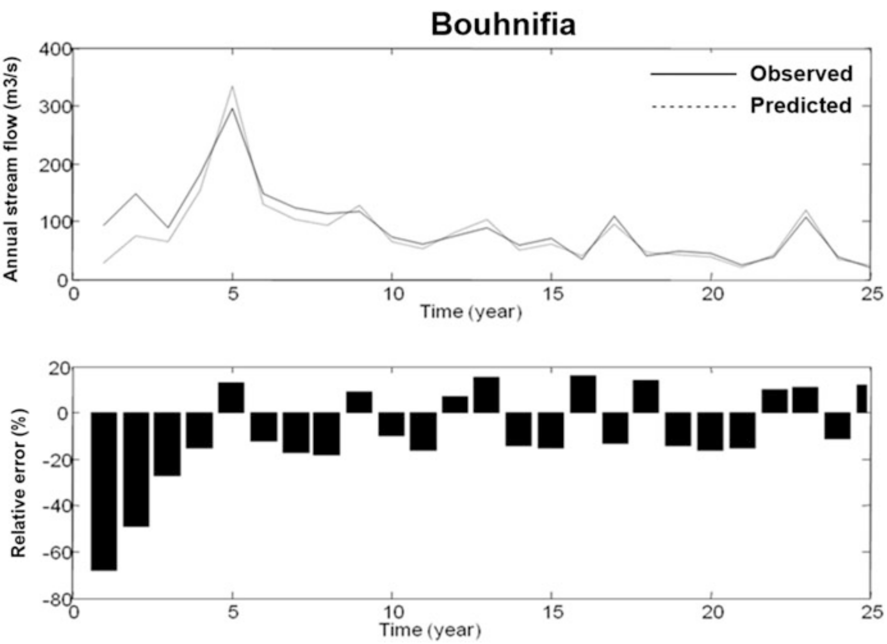

Fig. 1 Kalman filter annual predictions and prediction errors at Bouhnifia hydrometric station for 25 years period (1968–1992)

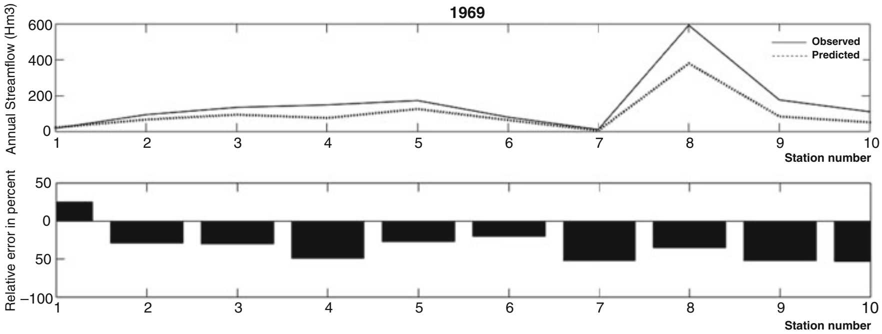

Fig. 2 Multi-site Kalman filter annual estimations and relative error for 1969

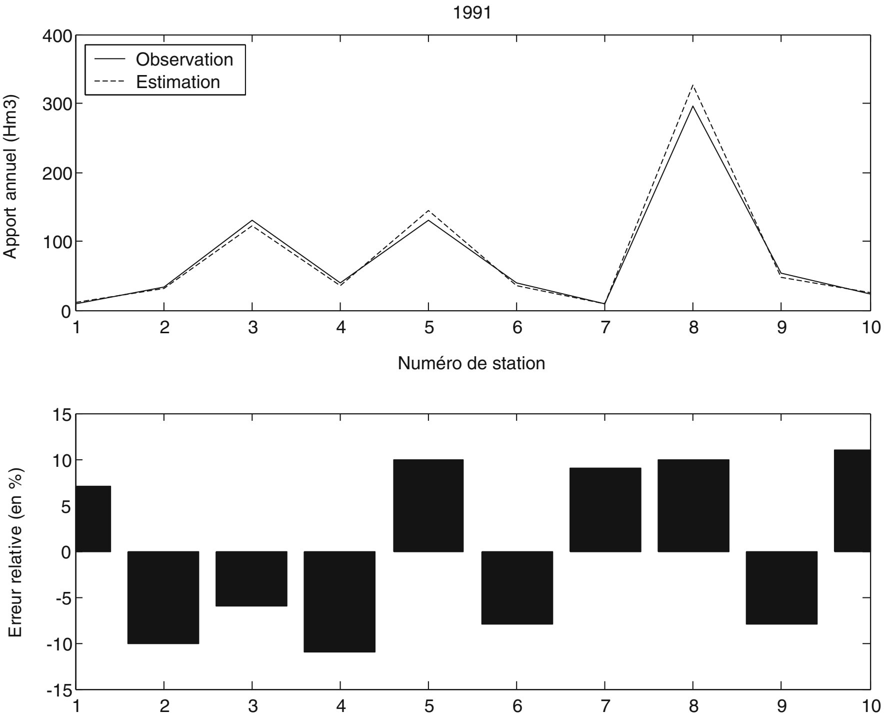

Fig. 3 Multi-site Kalman filter annual estimations and relative error for 1991

values are overestimated, and some of them are underestimated. At the beginning of calculations, more confidence is paid to records than to the model. Hence, Kalman gain (Fig. 4) is big and the prediction error (Fig. 5) is unavoidly greater, but after some iteration the model becomes more confident than observation, with a lesser Kalman gain, and predictions are definitively better.

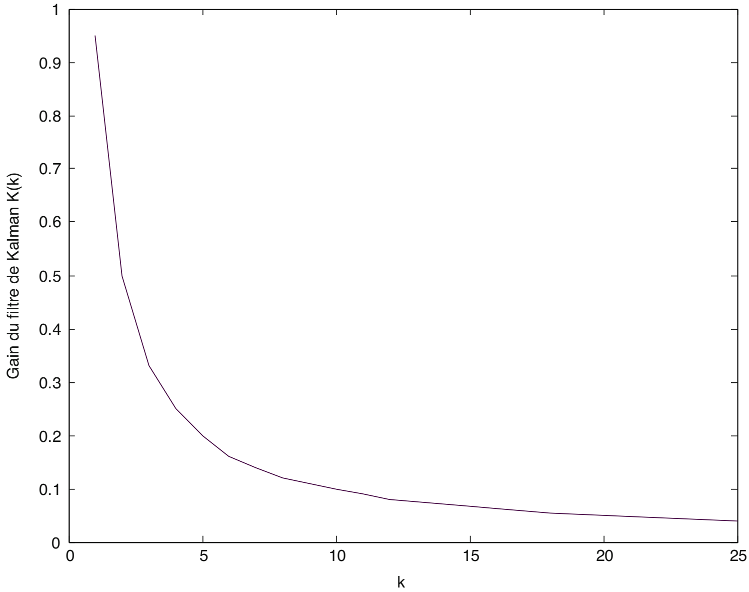

Fig. 4 Kalman gain over 25 years period (1968–1992)

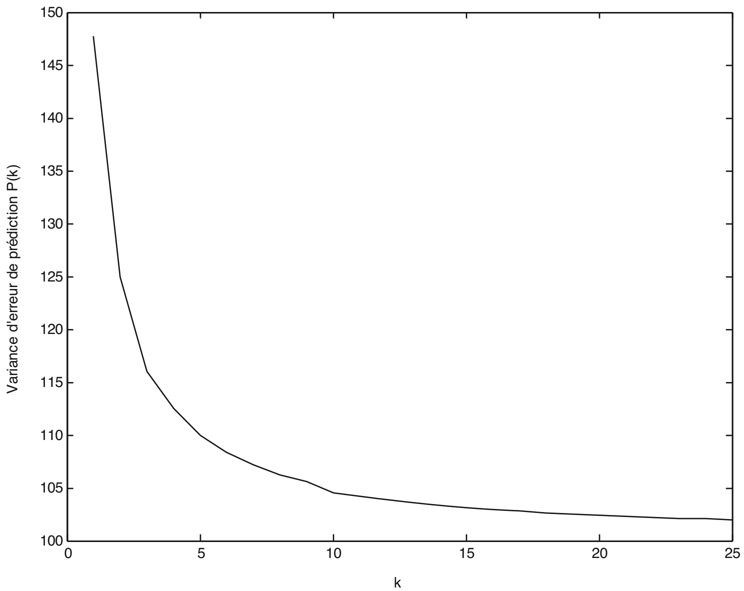

Fig. 5 Prediction error variance over 25 years period (1968–1992)

Table 1 provides with the annual prediction error statistics such as the mean, standard deviation, and the extreme values for the individual gauging stations during the estimation period of 25 years (1968–1992). Those statistics are considered as an additional argument to appreciate the quality of KF performance in a temporal point of view.

Table 2 illustrates the quality of the obtained results by providing some average statistical characteristics of annual observations, predictions, and relative error obtained at the ten concerned gauging stations (1968–1992) for both temporal and spatial points of view. It is obvious that the relative error for both temporal and spatial predictions is less than 10% which is acceptable.

From Table 2 it is clear that for observation all of mean and standard deviation are greater than those of prediction. This might be indicative of a possible slight tendency of multidimensional KF to underestimation.

3.2 Modeling and Prediction of Monthly Stream Flows

Kalman filter monthly predictions for the previous ten gauging stations are obtained via the same procedure as for the annual data. Regarding the model state-space formulation as well as the initial conditions, it is to be underlined that the dimensions of the considered vectors and matrices are different here. For example, the state vector is 25×12 since 12 monthly time records during 25 years period are considered. The 300 monthly data belong to the ANRH of Algiers; they are observed from October 1968 to December 1992 in the previous 10 gauging stations.

The monthly multi-site predictions are obtained after the KF convergence [19]. They can also be appreciated in either temporal (monthly) or spatial (areal) point of view, but, for reasons of space economy, only some of them are presented here for illustration. Figure 6 is an example of such results seen from a temporal point of view. It shows both observations and predictions estimated by the KF for the monthly stream flows at Pierre du Chat station during the period of September 1968 to August 1992.

One can see in this figure that predictions and corresponding observations are varying in the same manner with some under- or overestimations. These predictions are automatically bad at the beginning of calculations because more attention is paid for observations than for the model. Here, observations are heavily weighted by a large Kalman gain value which gives more weight to the observations, but just after some iteration, more confidence is assigned to the model. Hence the prediction errors become lesser, and predictions are better because of the filter convergence.

From a spatial point of view, the obtained KF monthly prediction error statistics are calculated for each one of the ten concerned stations. Table 3 provides the mean, standard deviation, minimum, and the maximum values of these monthly prediction errors. The smallness of them gives an overview about the quality of the obtained predictions.

Table 1 Kalman filter annual prediction error statistics in the ten concerned gauging stations (1968–1992)

Statistic	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Mean	−1.55	−3.65	−0.55	0.13	0.65	−0.45	2.96	3.45	2.14	0.89
Std	5.10	10.65	4.98	1.92	6.01	4.25	4.23	5.21	6.54	7.51
Min	−11.46	−21.19	−10.24	−2.78	−8.43	−5.28	−2.45	−0.56	−12.42	−14.98
Max	6.35	13.56	13.85	5.34	14.63	6.58	12.56	6.87	14.56	10.36

S1, Ain Berda; S2, Beni Bahdel; S3, Bouchegouf; S4, Bouhnifia; S5, Cheffia; S6, Ksob; S7, Mefrouch; S8, Mirebeck; S9, Pierre du Chat; S10, Remchi

Table 2 Some average statistical characteristics of annual observations and predictions obtained at the ten concerned gauging stations (1968–1992)

	Observation		Prediction		Relative error (%)	
	Mean	Std deviation	Mean	Std deviation	Mean	Std deviation
Temporal prediction	101.34	75.96	100.11	70.03	3.66	11.15
Spatial	101.23	111.30	99.70	104.26	7.88	15.54

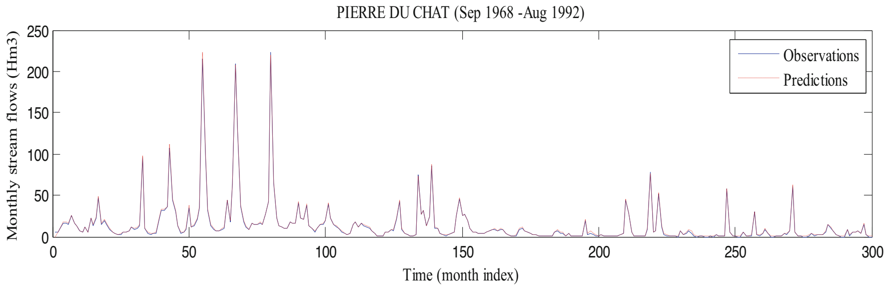

Fig. 6 Kalman filter monthly predictions and observations at Pierre du Chat gauging station (Oct. 1968–Aug. 1992) [20]

3.3 *Modeling and Prediction of Annual Rainfalls*

The study area of concern in this case study is the Cheliff watershed in northern part of Algeria. The data used are the annual rainfall registrations that belong to the National Agency for Water Resources (ANRH) of Algiers. These data are recorded in 39 rainfall stations constituting 39 time series that are observed in the Cheliff watershed on a common period of 51 years (1959–2009).

The same procedure of Kalman filter technique has been applied for the annual predictions of the 39 rainfall stations records. The common observation period for the 39 rainfall stations is of 51 years; the first 30 years are used to estimate the model parameters, while the last 21 are used to the model validation. It is not convenient to repeat all the details regarding the state-space model formulation as well as the initial conditions because of redundancy and space limitation; meanwhile one must know that dimensions of the considered KF recursive equations and their corresponding vectors, matrices, and loops must take account of the evolved data dimensions. For example, the state vector dimension is (51×1) since the annual estimation is processed over a time period of 51 years.

The obtained annual results for the 39 rainfall stations over the 51 years time period cannot be illustrated in their totality because of their huge quantity; hence only some of them are illustrated here. Those obtained results might also be viewed in time or in space dimensions; in all cases they show the same behavior between the historical observations and the corresponding predictions. The differences between the observed and their corresponding KF estimations (predictions) are very small,

Table 3 Kalman filter monthly prediction error statistics in the ten concerned gauging stations (Oct. 1968–Aug. 1992)

Statistic	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Mean	−1.22	−0.53	−0.62	−0.78	−0.98	2.84	0.89	2.91	1.89	0.79
Std	1.69	1.01	0.81	1.16	1.77	−28.2	−5.36	−26.8	−19.68	−6.27
Min	−17.01	−8.79	−8.36	−12.48	−18.58	1.23	5.85	0	1.72	5.34
Max	1.69	6	0.32	0	1.56	−1.69	−0.23	−1.90	−1.43	−0.51

S1, Ain Berda; S2, Beni Bahdel; S3, Bouchegouf; S4, Bouhnifia; S5, Cheffia; S6, Ksob; S7, Mefrouch; S8, Mirebeck; S9, Pierre du Chat; S10, Remchi

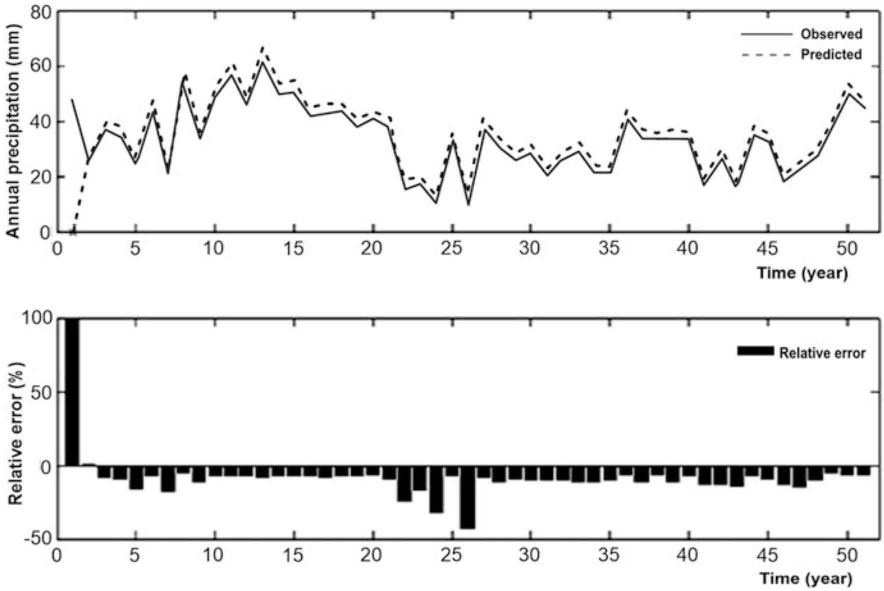

Fig. 7 Kalman filter annual predictions and prediction errors at Fodda Bge rainfall station for 51 years period (1959–2009)

except for the first iterations where the KF estimator is not sufficiently set to provide with confident estimations. The differences between observed and estimation values are given in terms of relative error in percent.

Figure 7 is an example of the quality of such results examined from a temporal point of view; it illustrates both of observations and corresponding predictions at Fodda Bge rainfall station. A great agreement can be observed between the observations and their predictions, and the degree of this agreement is given in terms of relative error in percent. This relative error is large when the calculations start which is a natural response due to the non-establishment of the model, but just after that the value of this error is considerably reduced to reach an average value of about 10% in the end of calculations when the filter has converged. The relatively large values in the 22nd, 24th, and 26th iterations might be due to miscellaneous information in the original time series that was reconstituted by using mean average method.

Figure 8 provides a second example of the obtained results approached from a multi-site point of view. It is constituted of two figures and gives the observed records together with their corresponding predictions obtained in the considered 39 rainfall stations with the relative prediction error in percent. The left one corresponds to the beginning of calculations (1966), while the right one corresponds to the end of these later (2006). Regarding the quality of these results, same thing as for the annual and monthly stream flow records can be said because the same behavior is once again observed between observations and their corresponding KF estimations.

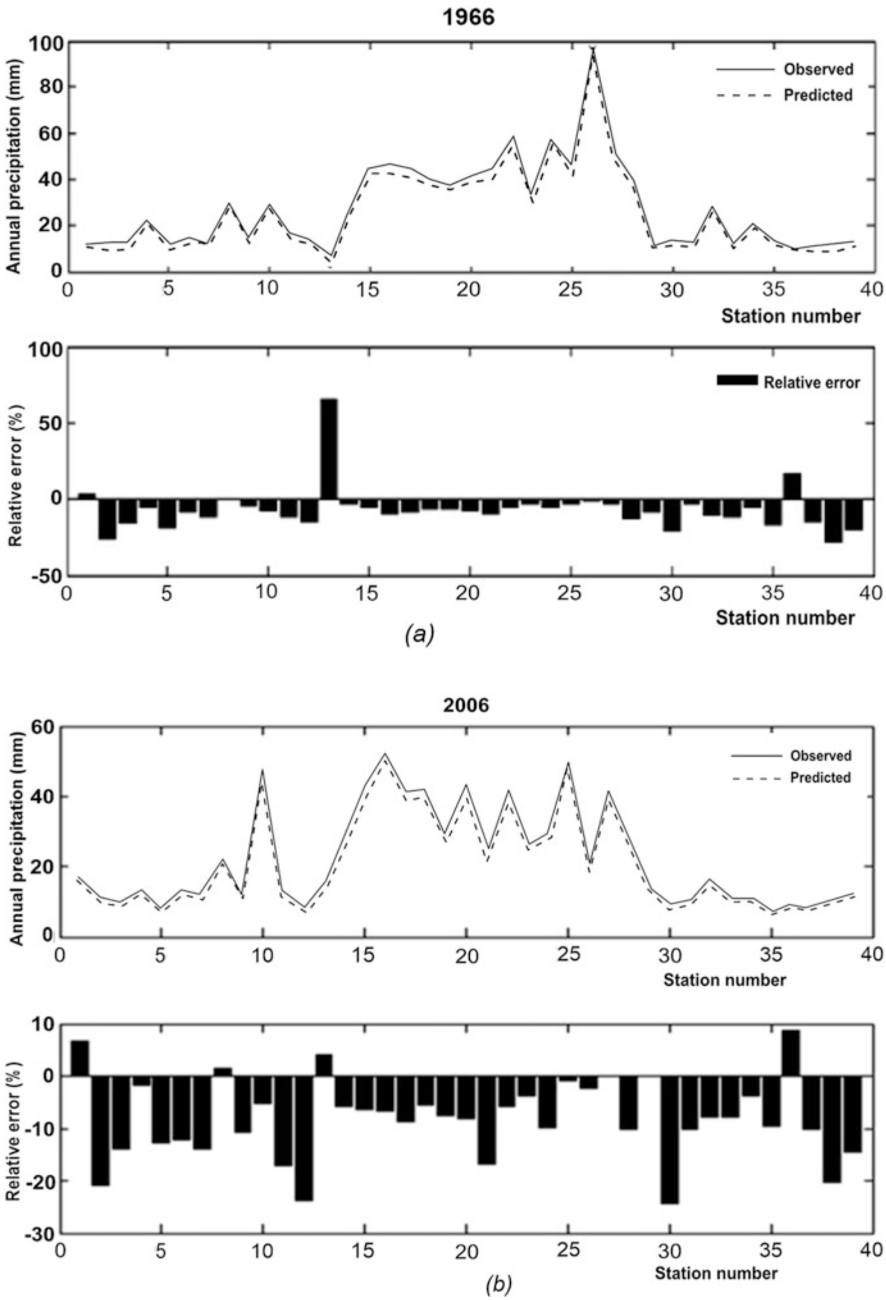

Fig. 8 Multi-site Kalman filter annual rainfall predictions and their relative error for 1966 and 2006

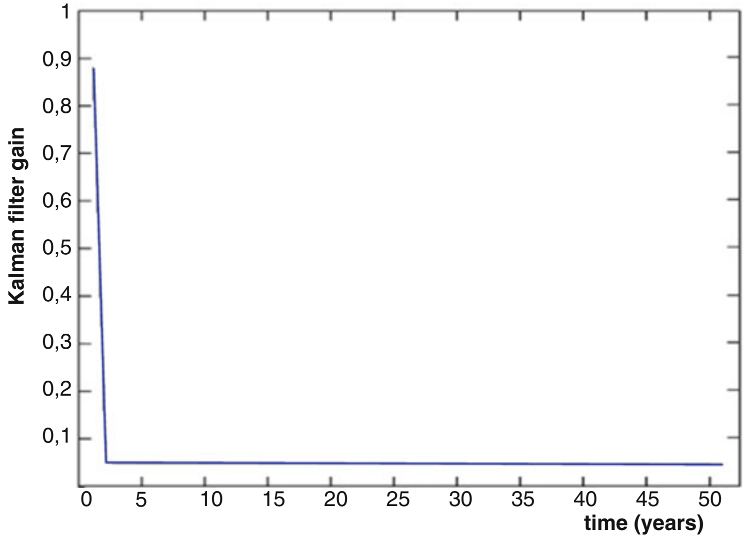

Fig. 9 Kalman filter annual prediction error covariance matrix trace over 51 years (1959–2009)

In terms of relative error in percent, a slight difference might be noticed between the beginning and the end of calculations which are observed in 1966 and 2006, with an average value of about 12% and 9%, respectively. This is indicative of an early convergence of the KF estimator where optimal estimations are provided.

The minimizations of the prediction error covariance matrix trace as well as Kalman gain matrix are both convergence signs and optimality criteria of the discrete Kalman filter estimator. Figure 9 illustrates the trace evolution of this matrix during the calculations process. According to the same figure, it is clear that the prediction error covariance matrix trace starts with very large values at the beginning of the calculations and, then, decreases rapidly to converge to a stable positive value very close to zero.

Figure 10 exhibits KF gain evolution in time during the 51 years estimation period. This evolution can be explained as follows: at the beginning of calculations, the model parameters are not yet well established to give good estimations. The model which is initialized with subjective values must then rely more on the measurement (as the only objective available information) in order to learn from the provided information; this is essential for the KF to adapt itself automatically as soon as a new piece of information (measurement) becomes available. The purpose of the gain matrix is to make sure that the measure is heavily weighted in the state parameters estimation. That is why the KF gain matrix is initialized with large values, and the result is automatically a bad estimation which justifies the relative big errors for the first iterations. But with the progress of calculations, when the confidence assigned to the accuracy of the model parameters begins to rise, the values of the gain matrix begin to gradually decrease to a value that is asymptotically

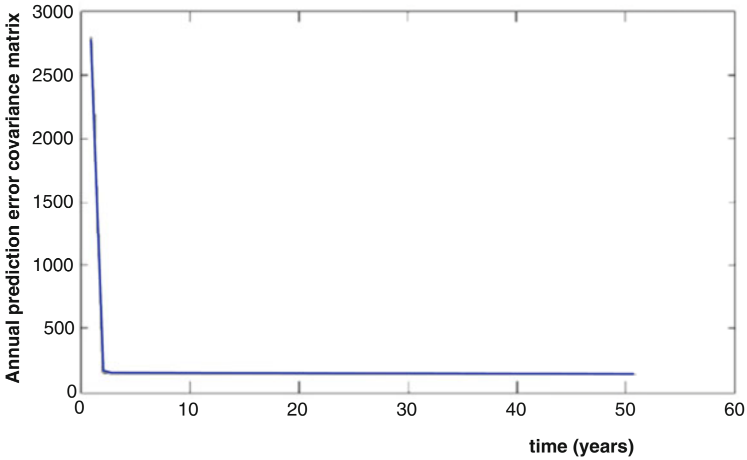

Fig. 10 Kalman filter gain over 51 years period (1959–2009)

Table 4 Mean and standard deviation of the annual rainfall observations and predictions together with their relative error at the 39 stations (1959–2009)

	Observation		Prediction		Relative error (%)	
	Mean	Std deviation	Mean	Std deviation	Mean	Std deviation
Temporal predictions	22.37	18.16	22.95	18.60	−4.22	−4.04
Spatial predictions	22.60	21.6	24.24	22.36	−7.28	−11.23

close to zero. This means a decreasing influence of the measurement in the model parameters estimation and, hence, confirms the adequacy of the adjusted model to the annual rainfall records making sure the optimality of the correspondent obtained predictions.

The adequacy of the estimated model can also be appreciated by comparing the observed and predicted values during the estimation period. This is done by calculation of some average statistics between observations and predictions in both temporal and spatial dimensions, together with the associated relative error in percent. Table 4 provides the abovementioned information in terms of average mean and average standard deviation. It is obvious that in both cases the mean relative error is less than 10% which confirms the performance of KF to predict annual rainfalls.

On another side, one can also notice from the same figure that the average mean of predictions is greater than the average mean of observations. This is true for both of temporal and spatial predictions and may express a possible tendency of KF to overestimation of the annual rainfalls. Figure 11 confirms this tendency by depicting the temporal evolution of the average standard deviation for the annual observations and the corresponding predictions which have been estimated for the 39 rainfall stations between 1959 and 2009.

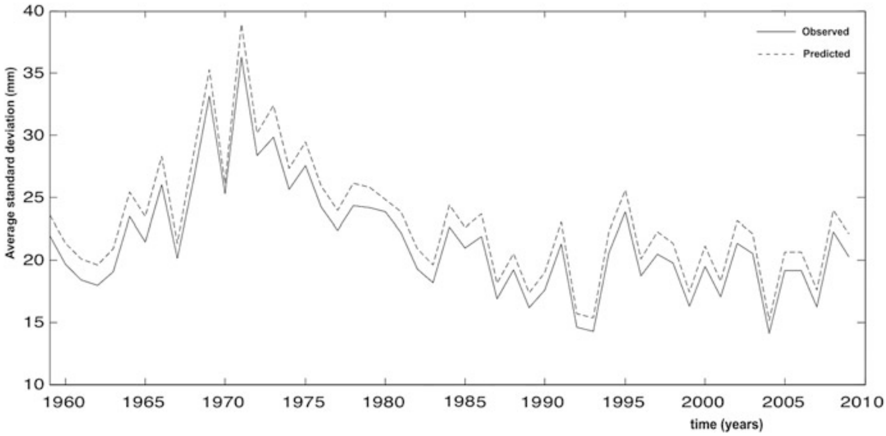

Fig. 11 Mean standard deviation of observed and predicted annual rainfalls at the 39 stations from 1959 to 2009

3.4 Modeling and Prediction of Monthly Rainfalls

In the same way, multi-site Kalman filter technique has also been carried on monthly rainfall records for ends of modeling and prediction. In this optic, monthly rainfall data at the previous 39 rainfall stations observed from September 1959 to August 2009 were utilized. Those data are registered by the ANRH of Algiers and present a total observation period of 612 months. The first 240 months have been used for model parameters estimation, whereas the remaining data have served for model validation.

Figure 12 is just one example of the obtained results; it illustrates the multi-site monthly predictions obtained over the 612 months and shows how closely the observations and predictions at ZAHRES rainfall station are varying together. The figure shows in the same time the prediction relative errors in percent which are less than 5% as large limit testifying of KF performance in such case study.

Figure 13 provides one of the obtained results in the spatial dimension (areal point of view) which illustrates the monthly observations and predictions obtained at the 39 stations during the month of September in 1959 at the beginning of calculations. Figure 14 shows the same thing but for September 2008 at almost the end of calculations. In both of these figures, the prediction errors that separate the observations from the corresponding predictions are so small that we can hardly distinguish between the two curves. Regarding the prediction errors, except for the first steps where unavoidably large values are observed for the relative error in percent, the corresponding values of this later vary between 0 and 8% to confirm once again the performance of the multi-site KF rainfall predictions in the monthly scale.

The optimality of the obtained results is illustrated by Figs. 15 and 16. The first one corresponds to KF gain matrix with a continuous decreasing behavior of the

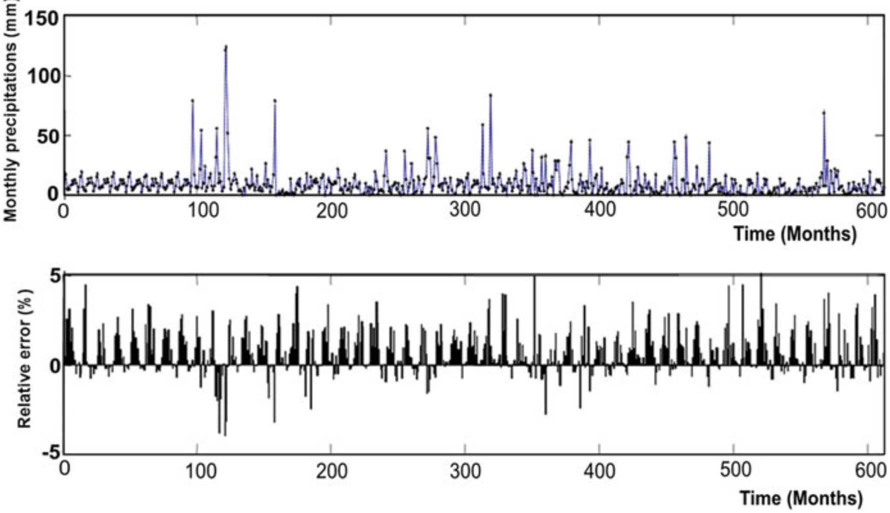

Fig. 12 Kalman filter monthly predictions and prediction relative error at ZAHRES rainfall station over 612 months (September 1959–August 2009)

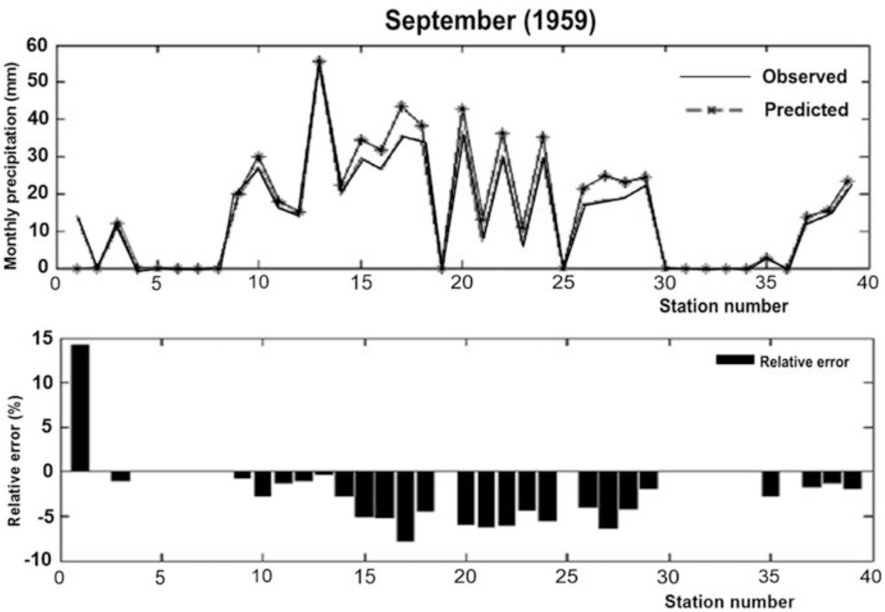

Fig. 13 Multi-site Kalman filter monthly rainfall predictions and prediction errors at the 39 rainfall stations for September 1959

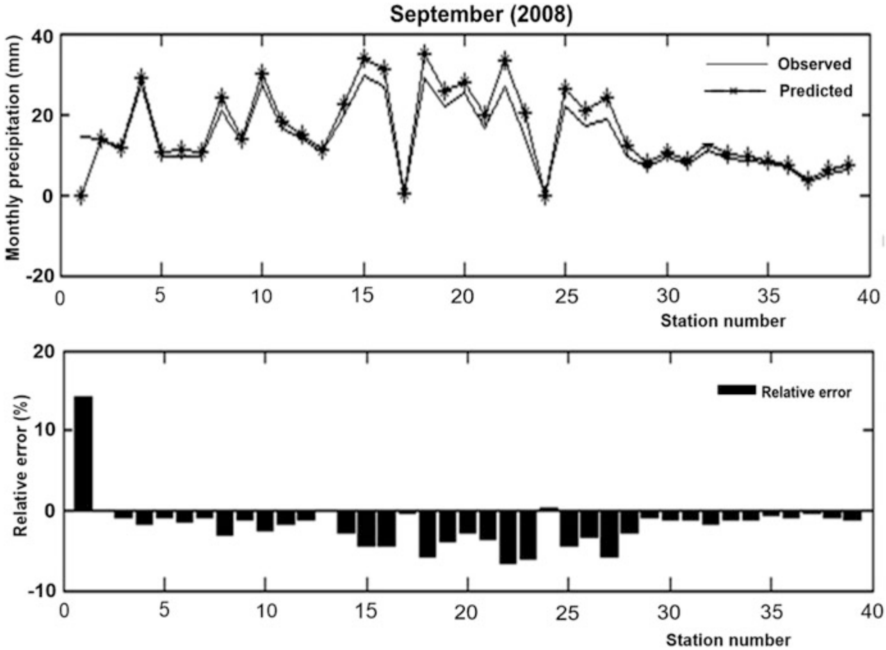

Fig. 14 Multi-site Kalman filter monthly rainfall predictions and prediction errors at the 39 rainfall stations for September 2008

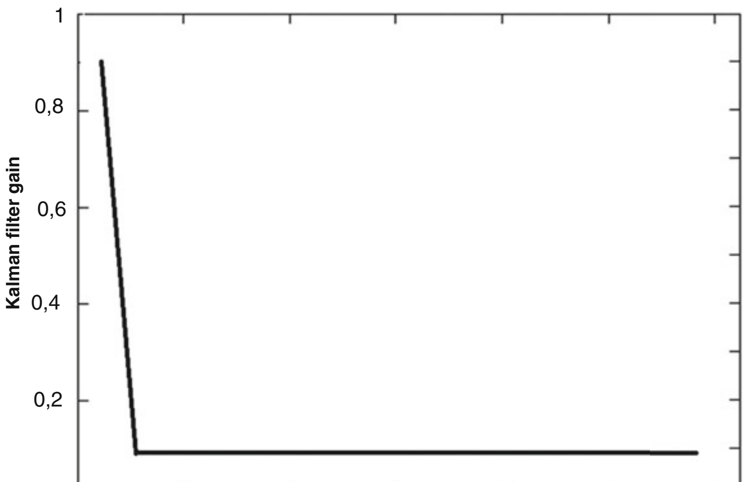

Fig. 15 Kalman filter gain over 612 months period (Sep. 1959–Aug. 2009)

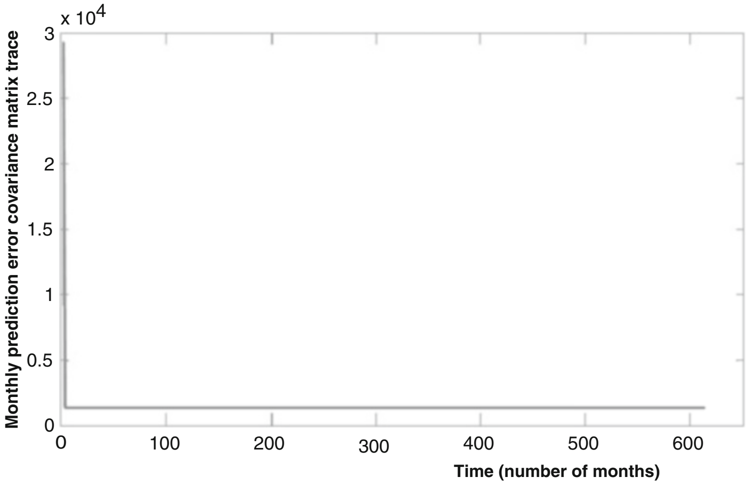

Fig. 16 Kalman filter monthly prediction error covariance matrix trace over 612 months (Sep. 1959–Aug. 2009)

Table 5 Mean and standard deviation of the monthly rainfall observations and predictions together with their relative error at the 39 stations (September 1959 to August 2009)

	Observation		Prediction		Relative error (%)	
	Mean	Std deviation	Mean	Std deviation	Mean	Std deviation
Temporal prediction	14.62	12.90	15.22	13.03	−3.37	−1.41
Spatial prediction	22.51	10.50	23.62	10.81	−4.95	−2.30

major diagonal elements. This means that the model parameters have reached their optimal values during the estimation period (first 240 months) and presents an additional proof for the model suitability. Figure 16 is the second illustration; it corresponds to the prediction error covariance matrix with similarly decreasing behavior of the major diagonal elements. Those major diagonal elements are nothing else than the prediction error variances. The initial major diagonal elements have large values in the beginning of calculations, but after some iterations they start and continue decreasing in a regular way to reach positive values close to zero, when the filter converges.

The eventual tendency to overestimation of the model developed throughout this study is also observed for the monthly scale. One can see from Table 5 that the average values of mean and standard deviation for predictions are higher than those for observations and this remains true both for temporal and spatial predictions. This overestimation is graphically illustrated and confirmed in Fig. 17.

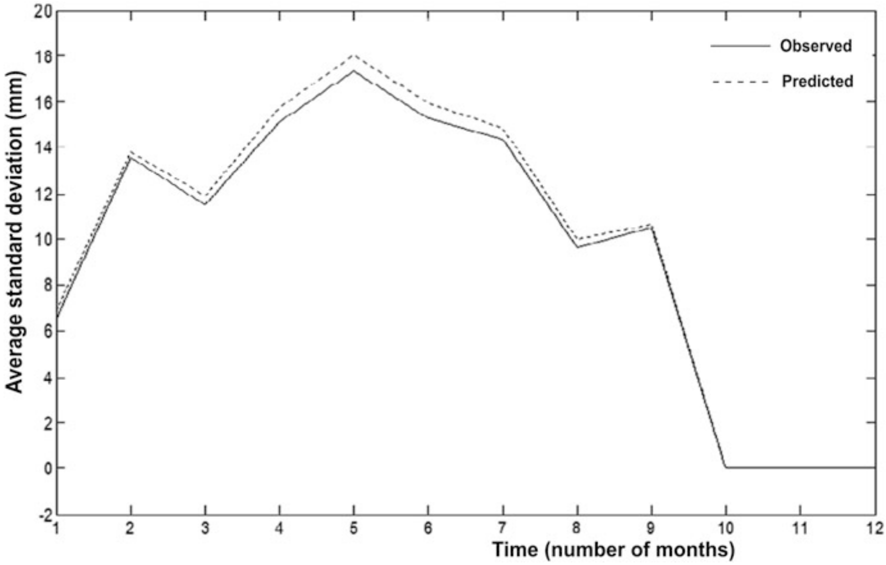

Fig. 17 Monthly average standard deviation of observations and predictions at the 39 rainfall stations

4 Conclusion

Due to the important socioeconomical development in recent years, the new sustainable development strategy in Algeria is a real challenge that is fundamentally based on a rigorous management of water resources potential, to cope with all forms of water demand for domestic, agricultural, industrial, and environmental needs [21, 22].

Such task is certainly hard and long to achieve, but in all figure cases, it must start by the respect of the hydrological processes as they occur in nature. An additional difficulty comes from the temporal and/or space variability of such hydrological processes.

The present chapter subscribes to this context by presenting some of our recent results in the context of the stochastic hydrological processes modeling and prediction in case of time-varying linear systems. It concerns water resources in northern part of Algeria, where discrete Kalman filter technique has been applied to the modeling and prediction of stream flows and rainfalls in a number of sites simultaneously (multi-site) for each of the monthly and annual scales.

The developed operators have the particularity of automatic self-adapting as soon as a new measure becomes available. This is an advantage of the KF algorithm recursive character that can be used in real-time predictions [23, 24]. As a result, optimal stream flow and rainfall predictions are obtained considering time variations of the underlying hydrological generating processes, as well as their stochastic character.

The obtained predictions can be appreciated from a temporal point of view, where observations and predictions in a single site are obtained during a period of time, but can also be extent to any further step where observation is available. These predictions can also be appreciated from a spatial point of view, where observations and predictions in all considered sites are obtained during a period of time, but can also be extent to any other site where observation is available.

One of the most important advantages of the developed operators is to provide the error prediction covariance matrix with certainty at each calculation step. This is of great interest because it constitutes a measure of the prediction accuracy, at each step calculation. The accuracy of the predictions, consequently the suitability of the operators, has also been checked by the prediction relative error in percent whose overall average value is less than 10% which is highly acceptable.

A slight tendency has been observed for those operators to overestimation for rainfalls and underestimation for stream flows.

Another advantage of the developed operators is that the algorithm may be initiated with a very little objective information and the prediction is obtained in time domain. This is of great interest because it offers a real-time forecasting possibility.

The developed operators are interesting because they can help policy and decision makers in water resources in Algeria acting efficiently for a better management and a sustainable development of such resources in the country.

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Hydrograph Flood Forecasting in the Catchment of the Middle Cheliff

Mohammed Renima, Mohamed Remaoun, Abdelkader Boucefiane, Abdelkader Sadeuk Ben Abbes, and Abdelkader Bouderbala

Contents

Abstract The impact of climate changes on flood peaks was the subject of several studies. However, a flood is not characterized only by its peak but also by the time, duration of the tip, as well as the rise time and shape of the flood hydrograph according to geographical distribution, leading to an understanding of these extreme hydrological hydrographs and to detect areas vulnerable to flood hazards. The flood-duration-frequency observed rate of chronic $Q(t)$ provides a theoretical multi-term flood quantiles description, directly meeting the needs of an integrated hydrological hydraulic modeling of the catchment. This article describes a statistical approach that aims to characterize the river in flood hydrology taking into account the notion of duration "*d*" and the return period "*T*." We realize that samplings were carried out for flood flows of 04 gauging stations in the watershed of the middle Cheliff, which reveal a higher value than the threshold. For this analysis, F-d-F was requested to define synthetic mono-frequency hydrographs (SMFH).

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Keywords Algeria, Floods, Flood-duration-frequency, Hydrographs, Middle Cheliff, Peaks-over-threshold, SMFH

1 Introduction

Among the Mediterranean countries, Algeria is the most vulnerable to floods caused by streams overflowing crossing towns and suburban. The sudden onset floods are often difficult to predict, rapid rise time and specific flow relatively important, these floods are generally linked to intense rainy episodes and are manifesting on middle size basins. Several catastrophes caused by those floods have been inventoried in Algeria (Algiers in November 2001, Sidi Bel Abbès in April 2007, Ghardaia and Bechar in October 2008, etc.)

Although some studies had to be devoted to F-d-F models, this approach remains not much used. The F-d-F models began to be developed in the year 1990 in France [1, 2]; the floods modeling by F-d-F models among other have been applied in France to a watershed regionalization flood. Furthermore, a converging and continuous F-d-F model has been proposed by Javelle et al. [3]. It is based on properties of flood distribution scale invariance. Applied in Martinique, by Meunier [4], this model has also been combined to flood index method [5] by [6, 7] bringing some improvements to the estimation procedure and applying this corrected model version for spring floods to Quebec provinces and in Ontario (Canada) [8, 9].

Moreover, the F-d-F modeling allowed to study 1,200 sites engaged in the Himalaya [10] and so on regions of Burkina Faso [11] and of Romania [12]. In Algeria this method was successfully applied in some basins [13–22]. Application of QdF modeling on three watersheds, Vandenesse, Soyans, and Florac, by Oberlin et al. [23] allowed defining a regional typology of flow regimes which makes it as a wide spatial representation [2]. In this work, one was thus interested in the study of the hydrographs of the extreme flood in the middle Cheliff watershed. In order to know the various types of hydrographs in the semiarid environment, by the analysis of the peak output, the form of the hydrographs, the fall and boarding times, to lead to a comprehension of these hydrographs hydrological extremes and to detect the zones vulnerable to the risks of the flood. There are many studies about the genesis and the danger of foods have been carried out for last years in the world Requina et al. [24], Zischg et al. [25], Mediero et al. [26], Hirpa et al. [27, 28], in the prone Mediterranean countries have this type of phenomena like France, Spain and Italy [29] in Saidi et al. [30], Boumenni et al. [31], and in Algeria [32–36]. Finally, this study also went on the determination of the peak output of flood. For that, the F-d-F analysis was requested to define hydrograph synthetic mono-frequency (HSMF) which ables to characterize the behavior of a flood for a given period of return.

2 Material and Methodology

The basin of Cheliff occupies area of 44,630 km^2; it is located between geographic coordinates 34° and 36°30′ of latitude North and 0° and 3°30′ of longitude East. It affects the shape of an axe-blade north-south (Fig. 1). The middle Cheliff watershed is located in the north-west of Algeria. It is characterized by a Mediterranean arid to semiarid climate. Rainfall in this watershed is very regular in time and in space, and we can distinguish two extreme zones: the first one is rainy with an annual average of 658 mm (Elanab in Dahra station) and 524 mm (Theniet El Had station in O), and the other zone has an annual average of 355 mm (Chlef NAHR station).

These stations are located in the watershed of Cheliff code 01 recorded by NAHR (National Agency of Hydraulic Resources). The flow chronicles show irregularities in the time (Table 1 and Fig. 2).

For the interpretation of graphics, two commonly used methods were used [37]:

Selecting the annual maximum values. It consists to select only one maximum value over a hydrological year or a season-at-risk [38]. The main disadvantage is that

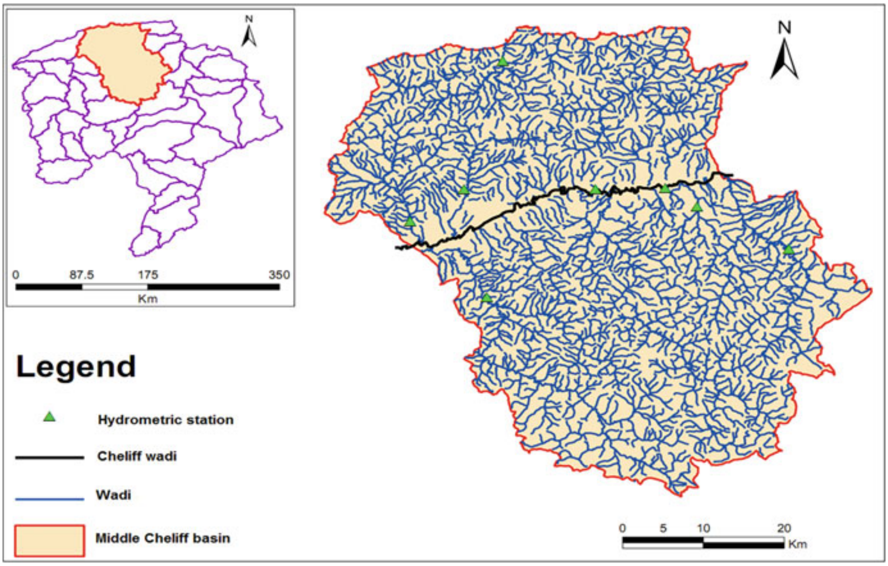

Fig. 1 Location of the study area

Table 1 Characteristics of hydrometric posts

Station code	Wadi	Latitude	Longitude	*Z* (m)	Surface (km^2)	Available period
11905	Zeddine	36.°6′	1.°57′	376	872.57	1990–2013
12201	Ouahrane	36°13′	1°13′	181	262	1983–2012
12004	Tikazel	36°11′	1°44′	262	130	1990–2009
20207	Allala	36°28′	1°18′	120	295	1983–2009

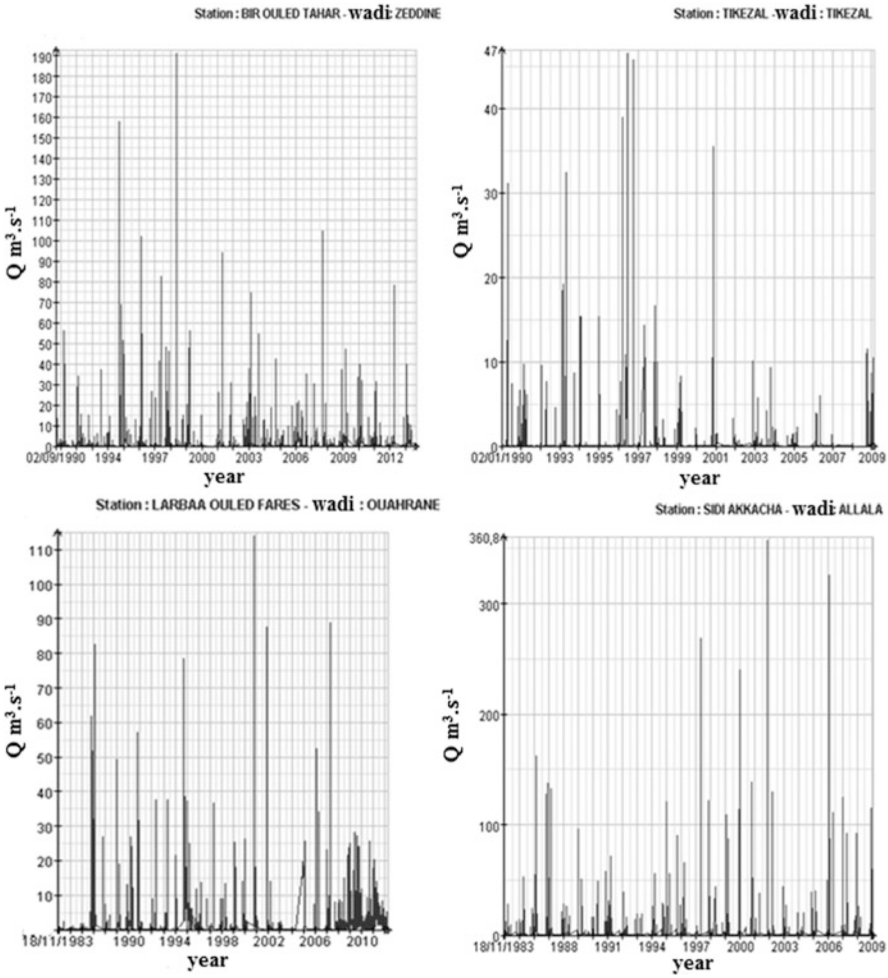

Fig. 2 Chronic of discharge of the middle Cheliff

the formed sample may contain non-significant events (e.g., no major events are recorded in a dry year) and lack of important ones happening during the same year.

Sampling the greater value than a threshold (*sup-threshold*). It consists in retaining the maximum value of a set of independent events having exceeded a given threshold [39]. It offers greater flexibility and robustness since it allows a greater number of selected events to be gathered, if the threshold is high enough; only the major events will be retained. Bezak et al. [40] in Serbia, Fischer and Schumann [41] in Germany, and Lang et al. [42] in France considered this method more reliable than the annual maxima method.

The concept of modeling the flood-duration-frequency has been established on an objective basis (Galéa and Prudhomme [2, 43]) and its extension toward ungauged watershed; it supplies a theoretical frequency description of multi-duration of flood quantiles. It is essentially focused on hydrological variables representing by basin flood regime, extracted from annual flows chronicle $Q(t)$. In addition to hydrological variables, two indices of watershed flood regime are essential to be determined, which are the maximum instantaneous flow of 10-year return period *QIXA10* and flood characteristic duration of watershed *D*.

We can retain as a definition of flood characteristic duration *ds*, the duration during which half of the peak flow *Qs* is continuously exceeded. For each observed and recorded flood, it studied the level of each subwatershed, and its characteristic duration *ds* and its peak flow *Qs* have been determined. In a plan (*Qs*, *ds*), the characteristic duration of watershed flood *D* according to SOCOSE method [44] is defined as being the value of the *ds* conditional median for the value of the corresponding instantaneous maximal annual decennial flow *QIXA10*. The pairs (*Qs*, ds) of the used flood periods in the Bir Ouled Tahar refers the parameter *D* to the time when the mean peak flow is exceeded when it shows the characteristic duration of Bir Ouled Tahar is 3 h as shown in Fig. 2. By using the same method, the characteristic duration for Tikazel, Larabaa Ouled Fares, and Sidi Akkacha are 3, 4, and 6 h, respectively (Fig. 3).

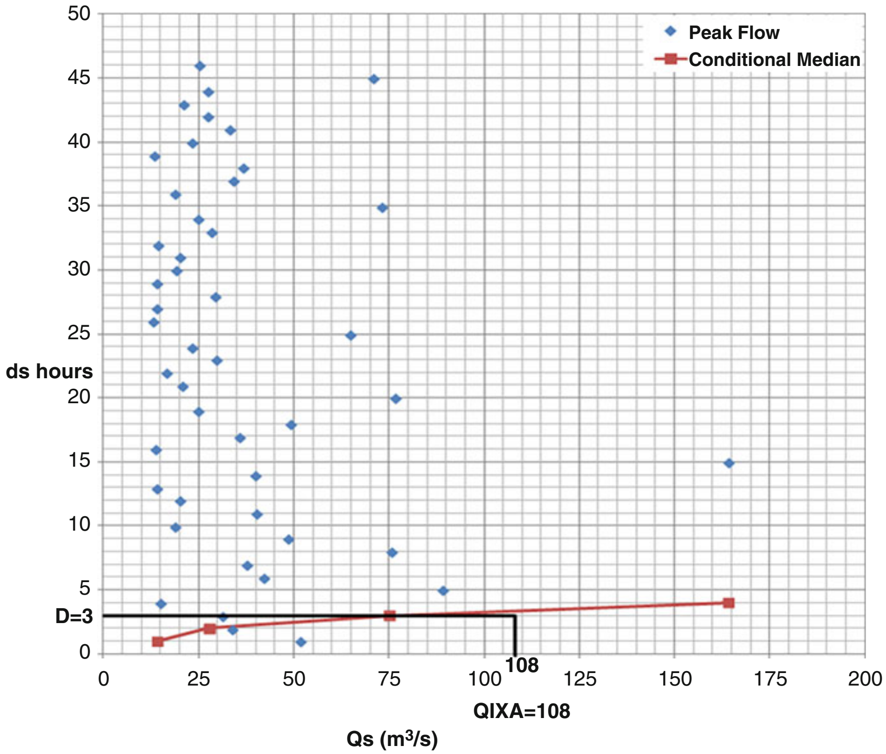

Fig. 3 Estimation of the characteristic flood duration

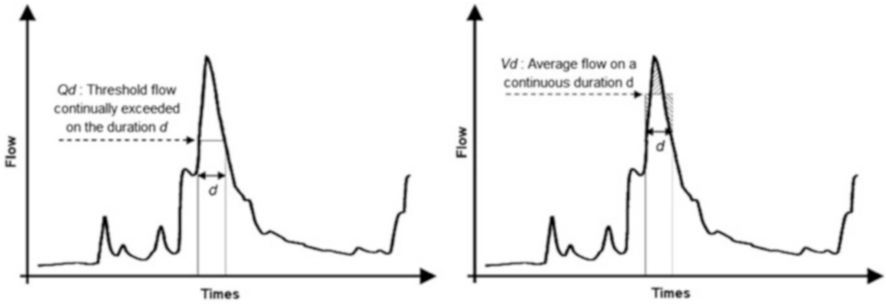

Fig. 4 The variables under consideration of flood episode [45]

The converging F-d-F model is born from a property observed on a large number of hydrological chronicles treated: adjustments $Qd(T)$ have tendency to meet at the same point toward the weakest return periods

$$Vd(T) = aq_d \ln(T) + x_{0,d} \tag{1}$$

where aq_d is the grades of flows or even scale parameter of adjustment law; X_od is the position parameter of adjustment law or simultaneously on the whole durations by adjustment of a mathematical function $V(d, T)$ and/or $Q(d, T)$ on samples, Vd and Qd knowing that Vd is the average flow on a continuous duration d, maximal during the flood episode; Qd represents the threshold flow, continually exceeded on the duration during the flood episode (Fig. 4).

The first manner to reach $V(d,T)$ and/or $Q(d,T)$ consists therefore to use mathematical expressions of a dimensionless bookshelf model named “by reference.” It comes to choose the best model among the Vandenesse, Soyans, and Florac according to meteorological criteria and to distort formulations with the help of two characteristics: one inflow and other in duration, all of them obtained from interest site of the study zone.

The second possibility is to apply the “converging F-d-F”; this formulation is based on a property observed on a great number of treated hydrological chronicles: adjustments $Vd(T)$ have tendency to meet in the same point toward the weakest return periods and on orthogonal affinity property of theoretical laws of probability of relative quantiles of different durations [16]. The converging F-d-F model allows synthesizing in the unique analytical formulation, flood quantiles relating to different durations, independently of laws of probabilities retained.

$$V(d,T) = \frac{V(0,T)}{1 + d/\Delta} \tag{2}$$

With:

V(0,T): theoretical distribution of peak flows (QIX) consolidated by modeling

Δ: parameter to be set, homogeneous to time, and linked to the flood dynamics

One speaks of consolidated adjustment V(0,T) because all durations participate in parameter estimation of the theoretical distribution. Duration distributions of d(2) are deducted from modeled distribution of the peak flows $V(0,T)$ knowing Δ. Several approaches may be considered to evaluate Δ and to obtain simultaneously a consolidated distribution $V(0,T)$ [7, 43, 46]. The preferred procedure lets intervene a setting process of Δ by using successive iterations on the principle of the least squares. It presents advantages to be a simple application and economical in the hypothesis.

From the expression Eq. (2), and taking into account the following property:

$$V(d,T) = \frac{V(0,T)}{1 + d/\Delta} V(d,T) = \frac{1}{d} \int_0^d Q(t,T)dt \tag{3}$$

We deduct a formulation for quantiles estimations of threshold flows $Q(d,T)$:

$$Q(d,T) = \frac{V(d,T)}{(1 + d/\Delta)^2} \tag{4}$$

In case of adjustment $V(O,T)$ for the exponential law, it comes:

$$V(d,T) = \frac{x_0 + a_0 \ln(T)}{(1 + d/\Delta)^2} \tag{5}$$

$$Q(d,T) = \frac{x_0 + a_0 \ln(T)}{(1 + d/\Delta)^2} \tag{6}$$

where parameters a_0, x_0, and Δ are to be determined.

The statistical analysis shows that it is possible, starting from a sampling multi-durations of hydrometric chronicles presumed stationary, to describe the characteristics of the raw catchment area studied in flow-duration-frequency [47]. Work of synthesis is completed on the description of the hydrograph synthetic mono-frequency (HSMF) of a hydrometric station starting from three parameters characteristic of the area catchment, namely, the flow (Q) instantaneous annual maximum decennial *QIXA10*, duration characteristic of believed of area catchment D, and boarding time characteristic of believed of the area catchment. Synthetic mono-frequency hydrographs are built by making the first assumption over the time boarding of believed and an assumption. It consists in a linear rise of the hydrographs, between an initial basic flow. It can be the quantile of flow continuously exceeded for the fifth length of time sampled (D in days) for one period of 1-year return and points of raw or the maximum instantaneous flow of the period of return considered *QIXT* (Fig. 5).

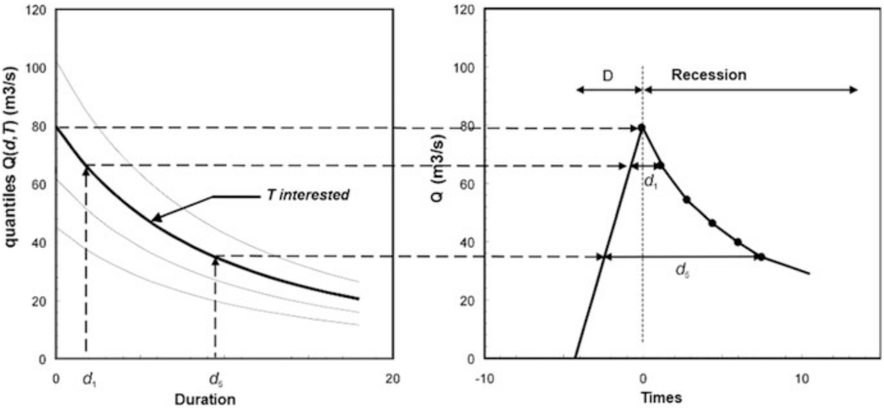

Fig. 5 The procedure of construction of *SHMF* synthetic hydrographs mono-frequency

3 Results

Figure 6 represents the hydrographs in basin of middle Cheliff with the time of appearance of each rising and the averages of these risings in black thick. These hydrographs show that the extreme risings are mainly concentrated in autumn and winter seasons, with a very marked occurrence of the extraordinary events practically for the whole of the stations with 37.5% of total reserves for the season of autumn, 32.5% for the season of winter, and for the season of spring represented by 27.5% of these risings.

Figure 7 visualizes the F-d-F modeling obtained for floods of the low or large return period and so samples observed or estimated by events sampling exceeding a threshold.

4 Discussions

We recorded two or three exceptional peak events of theoretical return period close of the centennial for all stations studied. It flows on the large durations, with a little scarcer, even very rare for one of them. As for time step, the relative extrapolation checks the rare experimental quantiles estimated from sup-threshold samples adjustment by an exponential equation (Fig. 7). Each sampling duration has respective results: the average annual flow, maximum flows, threshold, adjustment parameters (scale parameter and position) and many flood events corresponding, and at last a theoretical quantiles estimated. In effect, all values and flow diagrams are set in the function of sampling duration or in the return period.

The sup-threshold events observed in the hydrographs are adjusted very well with the QdF curves mainly for the hydrometric stations of Zeddine (Fig. 7a), Ouahrane

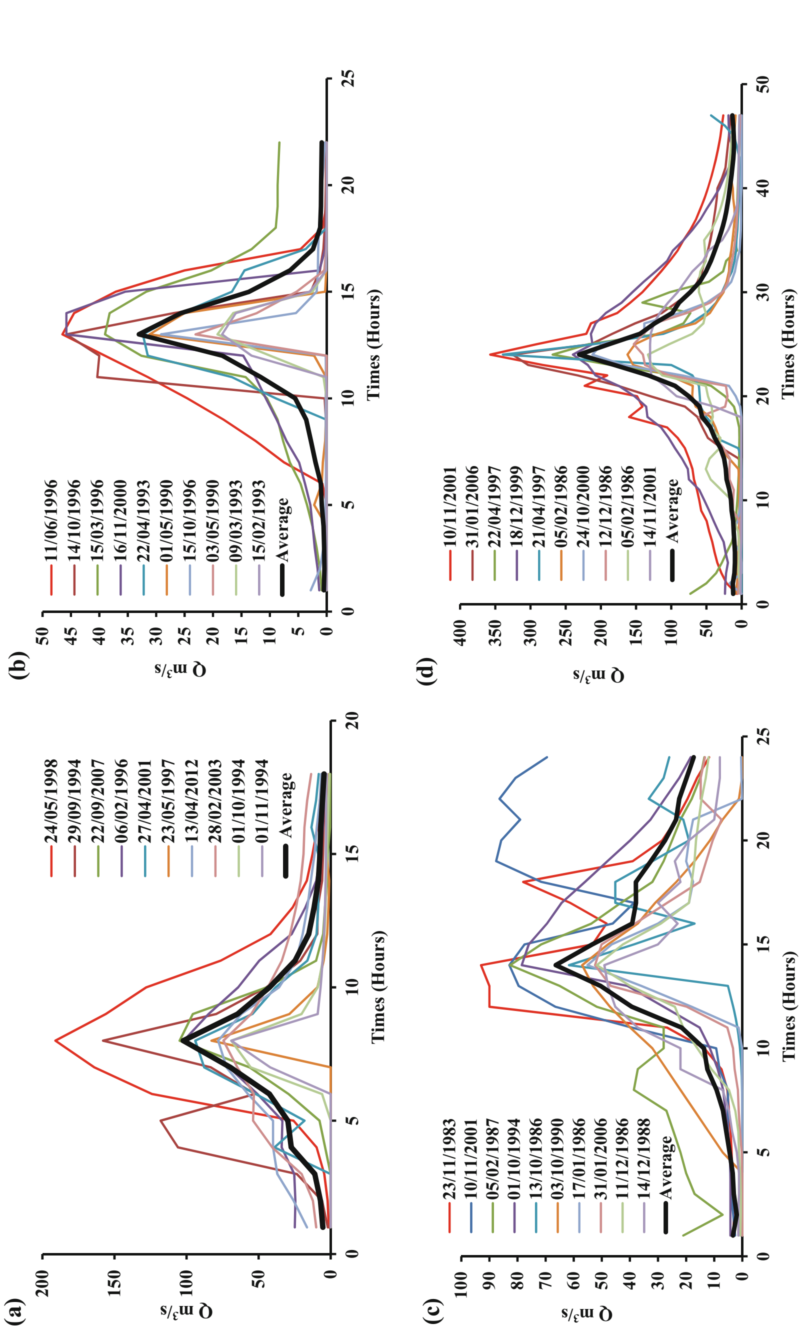

Fig. 6 Hydrograph of observed floods of the basin of the middle Cheliff: (**a**) Bir Ouled Tahar, (**b**) Tikazel, (**c**) Larabaa Ouled Fares, and (**d**) Sidi Akkacha

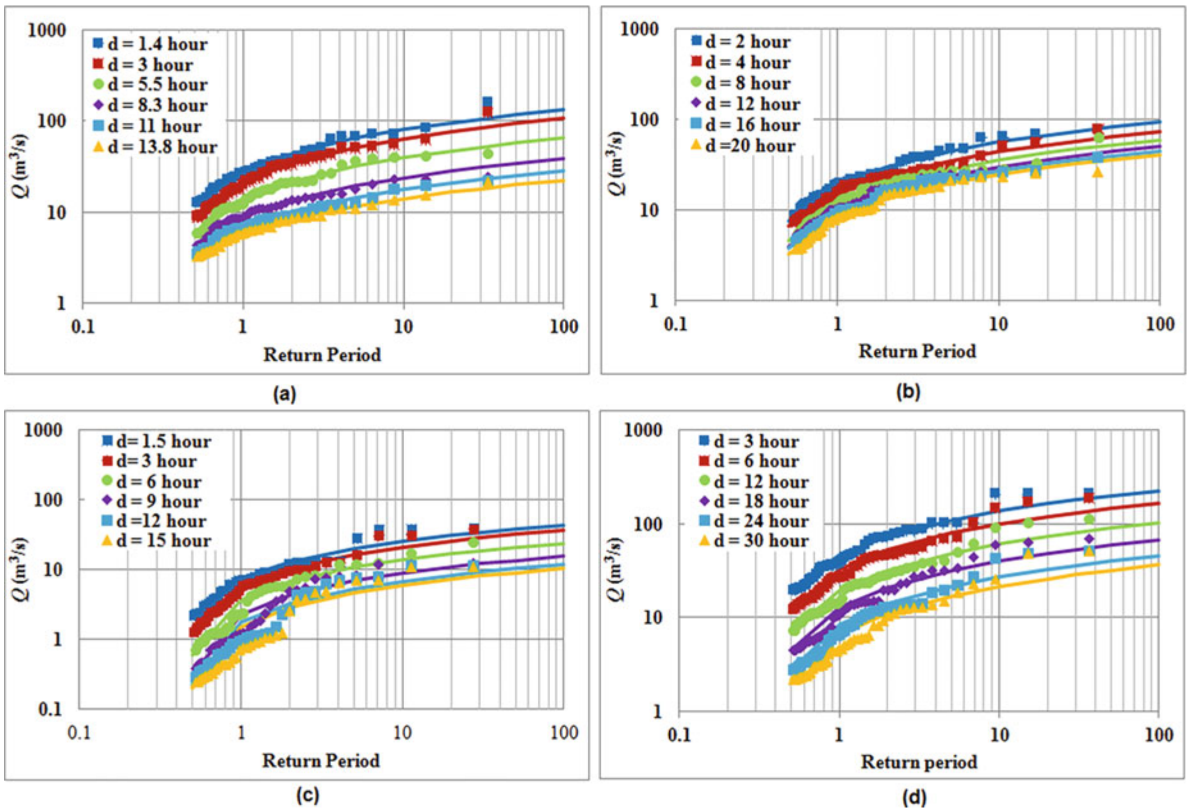

Fig. 7 Application of a local model for threshold flows $Qd(T)$ of stations: (**a**) Bir Ouled Tahar, (**b**) Larabaa Ouled Fares, (**c**) Tikazel, and (**d**) Sidi Akkacha

(Fig. 7b), and Allala (Fig. 7d), except the Tikazel station (Fig. 7c) which has duration *Q* from (9 h, *T*) to *Q*(15 h, *T*).

Six durations are considered, giving six series of threshold flows *Qd* with *d* included between 1.5 and 15 h for Rouina basin, between 2 and 20 h for Ouahrane basin, between 1.5 and 15 h for Tikazel basin, and between 3 and 30 h for Allala basin. The converging model *Q*(*d*, *T*) applied to a series with sup-threshold values of flows *Qd* (Fig. 8). Chronicle examination of the raw data of Rouina shows that water flows on durations less than 24 h are substantially equivalent to peak values. This is translated into distributions of quantiles *Q*(1.5 h, *T*) and *Q*(15 h, *T*) relatively close (Fig. 8a). However, adjustments obtained for basin of Ouahrane and Tikazel for a range of lower durations less than 24 h are very distinct and reveal a rapid collapse of water flows with duration (Fig. 8b, c). The quantile *Q*(1.5 h, *T*) is the double of *Q* (24 h, *T*) for this station. Parameter Δ gives the shape of hyperboles defining quantiles *Q*(*d*, *T*) for *T* fixed. If Δ is weak, hyperboles are much curved. Reversely, if Δ is strong, hyperboles are much flattened. Whereas is schematized by (Fig. 8), the shape of hyperboles is linked to those of the floods observed.

In effect, the whole studied flood is rapid, more is the difference between peak flows, and the average maximum flows on a duration *d* (for instance over one day, on Fig. 8d) is large. This difference between peak flows and middle flows is translated for *F-d-F* curves (in function of *T*, for *d* fixed) by more or less strong *F-d-F* highly arched curves (Fig. 8b, c). Reversely, if it is characterized by slow floods, its F-d-F curves are more flattened (Fig. 8a). Parameter Δ is used to describe the shape of hyperboles (Fig. 8); its value informs us, thus, on the dynamics of studied floods. Δ, which has a time dimension, may, therefore, be considered as a characteristic duration of the studied basin flood. On the other hand, duration Δ may also be translated by the following way. Distribution of threshold flows relative to this duration is at half-distance between instantaneous flows, distribution *Q*(0, *T*), and the right being ordinate of convergence point. This relation is checked whatever be *T* due to the convergence property of distributions. Duration Δ obtained for the four studied subbasins, with rapid dynamics, is lower at 12 h (Table 2).

The procedure of construction (Fig. 5) makes it possible to have different hydrographs synthetic mono-frequency from the basin of the middle Cheliff (Fig. 9). The events of rising really observed in the rivers cannot be qualified in terms of frequency or period of return for the good reason that this one varies according to the duration over which one analyzes the phenomenon observed.

The knowledge of the flow threshold made it possible to trace the synthetic mono-frequency hydrographs, which are essential components of hydrodynamic model entry in order to determine the risk of a flood characterized by a return period. The station of Sidi Akkacha (Allala) and the station of Bir Ouled Tahar (Rouina-Zeddine) are characterized by very important quantiles for long return periods.

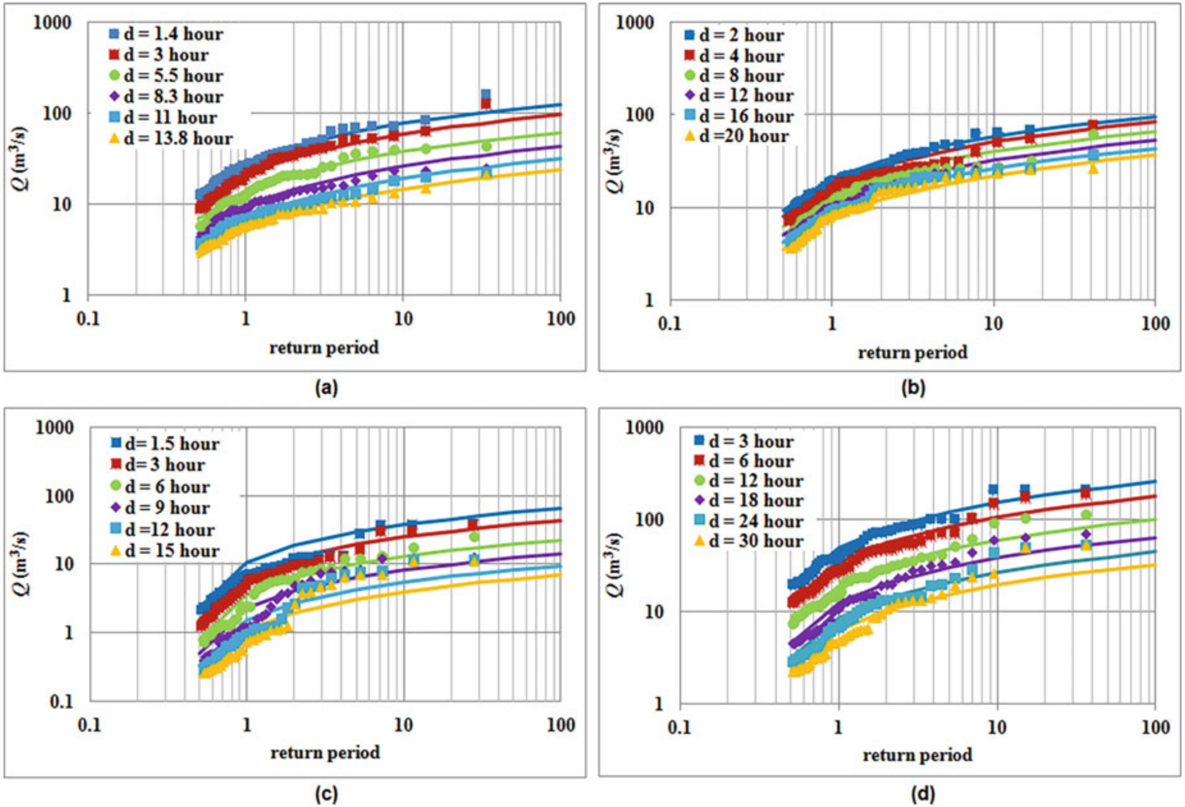

Fig. 8 Application of converging model to threshold flows $Qd\,(T)$ of stations: (**a**) Bir Ouled Tahar, (**b**) Larabaa Ouled Fares, (**c**) Tikazel, and (**d**) Sidi Akkacha

Table 2 Estimation of the characteristic duration of flood D and QIXA10

Station	*D* (h)	QIXA10 (m^3/s)	Δ (h)	Q_{max} (m^3/s)
ST011905	3	108	10.08	164
ST012004	3	33	6	40
ST012201	4	76	12	79
ST020702	6	220	12	214

5 Conclusions

The flood regime modeling has been established according to quantiles of threshold flows coming from the statistic adjustment, which is compared with taking into account flood regime characteristics of the watershed (*QIXA10* and *D*), to different counterparts quantiles from F-d-F models.

The relative quantiles with low flows are better reconstituted than equivalent or superior quantiles to *QIXA10*. The converging model applied to tested basins constitutes equivalent values to those which could be obtained by adjustment on each duration taken separately. In general terms, using approach of F-d-F seems to be well adapted, and it is able to take into account duration, which is the essential notion when we are speaking about flood; it therefore considers "variable time step." So the description in flow-duration-frequency, whatever be the formulation, has several uses: estimation of flood quantiles in middle flows or threshold flows to estimate of hydraulic works, insertion in a flood regime typology, definition of hydrologic reference scenarios for flood risk estimation, validation of hydrologic models outputs, and characterization of the regime evolution of high water level.

The knowledge of the flow threshold made it possible to trace the hydrograph synthetic mono-frequency, which are essential components of hydrodynamic model entry in order to determine the risk of a flood characterized by a return period. The station of Sidi Akkacha (Allala) and the station of Bir Ouled Tahar (Rouina-Zeddine) are characterized by very important quantiles for long return periods.

6 Recommendations

The synthetic hydrographs are potentially useful and easy to use for the determination of project floods, but they have several limitations because they are based on the return period and describe the specific behavior of a watershed by ignoring the variability of the processes represented by different types of floods. This property ensures consistency between hydrograph and the average flow rate corresponding quantile as we highlighted theoretical studies on these hydrological operators. As a result, their use in studies of floodability [47] ensures coherence between the rolling effects or volume management study and quantification of synthetic variables for defining risk.

The flood events actually observed the river could not be described in terms of frequency or return period for the reason that it varies according to the period over

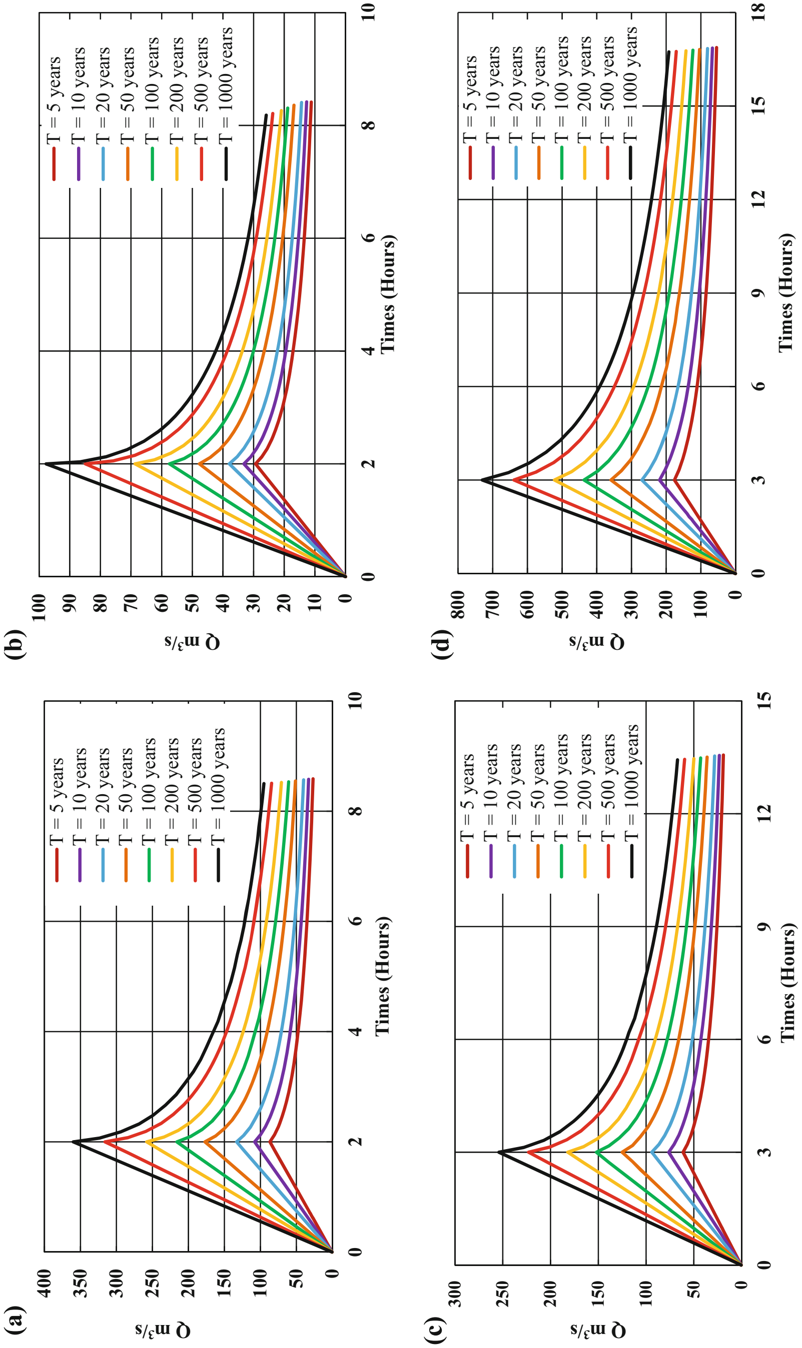

Fig. 9 Hydrograph synthetic mono-frequency of the basin of the middle Cheliff: **(a)** Bir Ouled Tahar, **(b)** Tikazel, **(c)** Larabaa Ouled Fares, and **(d)** Sidi Akkacha

which we analyze the phenomenon observed. For this reason, it seems irrelevant to us to analyze the flood risk on the basis of an actual flood that can be pessimistic and optimistic peak volume or vice versa.

The contributions to the hydraulic model will be calculated simply from QdF models. If working steady, reading the maximum instantaneous flow rates obtained for different return periods gives the rates corresponding to the inputs of hydrodynamic models (such as Saint-Venant). If working in a transient state, it is first necessary to build single-frequency synthetic hydrograph.

Another common use of single-frequency synthetic hydrograph is used in flood routing in order to determine the height poured through a spillway of a dam because these hydrographs are also a hydrometric characteristic of the watershed.

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Part IV
Development and Future of Water Resources

Overview of Water Resources in Steppe Regions in Algeria

Salah Eddine Ali Rahmani, Abdelkader Bouderbala, and Brahim Chibane

Contents

Abstract The water supply actions have been influenced by climate change effects. In the last 2 years, the surface runoff was reduced, and this caused a diminution of water levels in dams and water table. Under bad scenarios and difficult meteorological conditions, the authority must move rapidly to solve the problem of water shortage in the short, medium, and long range to avoid a probable water crisis in the future years. In steppe regions, the population water supply system was articulated essentially to the groundwater. In this chapter, we illustrate the actual situation of water supply program of some province of the steppe in Algeria to simulate the situation of water supply capacity in the next 10 years. Simulation of water demand is realized by two bad scenarios.

Keywords Climate change, Scenarios, Water shortage, Water supply

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1 Introduction

Water resources management is the magic key of the national water resources planning and strategy. As a results of social and environmental pressures, the overexploitation of groundwater as a result of population growth, industrial and agricultural emergent activities makes the planning efficiency more complicated [1–4]. In the field two questions appear in our mind: (1) what are our water resources potentialities?; (2) What are the procedures to avoid the rapid depletion of these resources?

The answer to these two questions depends not only on the actual and the available statistics on water resources but also on the actual and future climate situation, population growth rate, and the frequency of water availability [4].

Climate change has influenced the atmospheric circulation, which makes big changes in the hydrological cycle. If the direct effects of these changes can be identified, the solutions and the management strategy can be easily established for the local and regional watershed scales [5].

Studies of climate variability and change have been of interest to the global community following several large-scale climatic events. Among these, we note the drought that has affected the two tropical bands of our planet since the 1970s [4]. In addition to this drought, the World Meteorological Organization (WMO) findings on global warming of more than 0.7°C since the beginning of the last century and the recent El Niño phenomena [6].

The North West and the North east of Algeria, have been passed in the last decade more episodes of drought. Dam's volumes and water table levels are decreased. The drought in those regions is Meteorological, caused by the continuous reducing of average rainfall [7]. The Algerian steppes have great importance in the National Development Strategy (Higher Plate Development Program). The rapid demographic growth applies a high pressure on water resources [2]. Since the last few decades, water resources in steppe were limited in terms of quantitative availability and quality.

The five provinces which form the central steppe area are supplied by a total water debit of 366,623 m^3/day assured by 66 wells and boreholes and 4 dams. The average daily water endowment is about 112 l/hab/day (ADE 2016).

The chart in Fig. 1 shows the principal water flux components in a local watershed scale. This flux has depended totally on climatic conditions (precipitations, temperature). The climate depends on large-scale atmospheric circulation and the local watershed has big influences on the local or the regional climate, for this reason, the watershed water cycle is directly dependent on the general atmospheric circulation, and any changes in this circulation influence directly the watershed locally or regionally [8].

The lack of precipitations in the last 10 years makes a great pressure on groundwater by more implantations of wells and boreholes. However, the dam capacity has reduced due to sediment transport and lack of surface runoff [9]. Industrial growth and transformation in the Algerian strategy, needs to mobilize a lot of water in order to meet the industrial need, which arise our challenges for a durable water resources management.

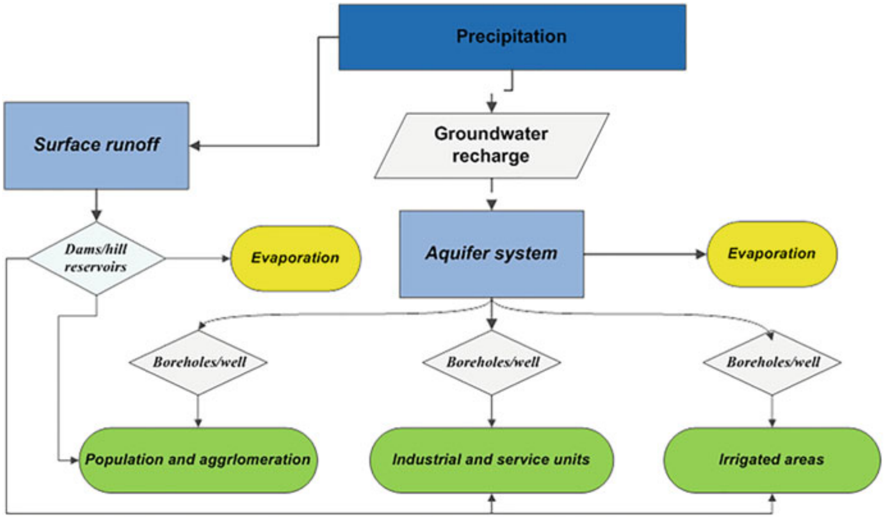

Fig. 1 Global water flux in semiarid regions

2 Population Projection

Quantification of current and future population is a primary required procedure in local and regional water planning policy. The estimation of the population growth rate (PGR) let to the water manager to calculate the water need of a given population and to map a regional process to increase water production and population daily allocation to avoid the future crisis due to the scarcity of water in short ,medium, and long range. This projection was made by using the equation (Eq. (1)):

$$P_n = P_0 \times (1 + \alpha)^n \tag{1}$$

Parameters of this model are defined in Table 1.

Table 1 Different facilities exist in the region of study

Type	Number	Capacity	Unit
Boreholes	328	318,999	m^3/j
Wells	10	1,910	m^3/j
Spring sources	28	16,762	m^3/j
Pumping stations	77	438,923	m^3/j
Water treatment stations	5	109,382	m^3/j
Reservoir/tank	433	452,150	m^3
Adduction networks	2,125		km
Distribution networks	5,064		km
Total	7,189		km

3 Water Daily Need

The populations' daily water needs were calculated directly using the daily endowment (d) for a given municipality (Eq. (2)):

$$Q_p = P \times d \times 0.001 \quad (2)$$

Q_P is the daily average water requirement of the population in (m^3/day); an, ands the population and d is the daily water allocation (L/day).

4 Water Production and Cost

Evaluation of the cost of water production needs a special interest to calculate the cost of production of water for citizens. This may implicate all cost entered in production as energy, employees, chemical product, and hydro-mechanical equipment. In this chapter, we give this important point a special interest to make a financial budget for water resources production and distribution.

The cost of production was calculated by Eq. (3):

$$Co = Vp \times \sum_{i=0}^{n} U_i \quad (3)$$

where Co is the total cost of water production, V_P is the total produced water, and U_i is the unitary cost (energy, employees, mechanic equipment).

5 Methodology

This chapter aims to simulate the future water demand and where the situation of water supply program is in the next 10 years. We begin by introducing the geographical situation of the study areas, and we illustrate the principles; flowchart in Fig. 2 shows the detailed flow of methodology.

The evaluation and interpretations of simulation results allow the user a good comprehension of the hydraulic system. Actual situation of water supply program gives us an idea about the dysfunction in the hydraulic system of the region. Simulation of water supply situation for the next years helps the policymaker in avoiding any bad water strategy. The flowchart in Fig. 2 gives a general visibility on the methodology used to study the water supply program in the next years.

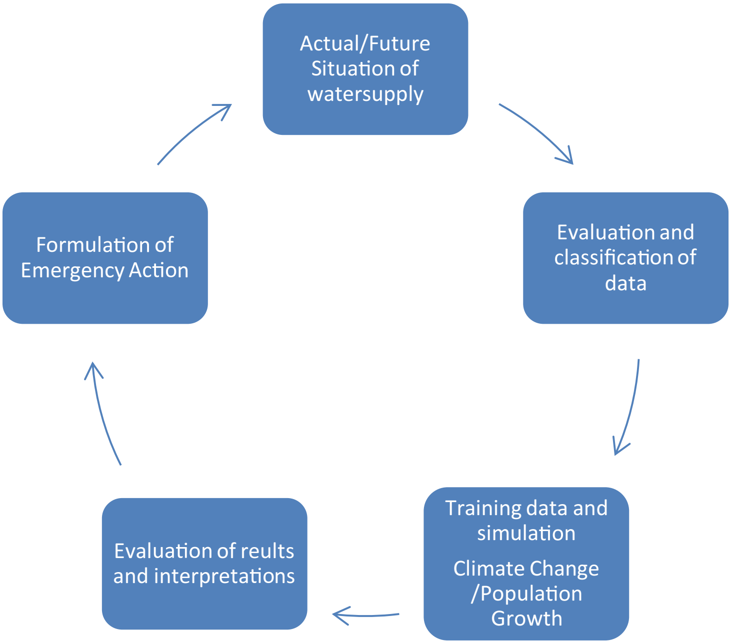

Fig. 2 Flowchart of methodology used

Region of Study
The Highlands are located between the Tell Atlas to the north and the Saharan Atlas to the south, at more or less important altitudes of 900–1,200 m. They consist of salt depressions, chotts, or sebkhas, and they are separated from the Sahara by the Saharan Atlas, which forms a series of chains with arid character.

The Algerian steppes are devised to the western steppes, which are located in southern Oran and southern Algiers. The altitude of these High Plains decreases from Djebel Mzi in the west to the salty depression of Hodna in the center. The Eastern steppes (east of Hodna) are located in southern Constantine. They are bordered by the Aures and Nememcha mountains. We focused to study the water resources situation in the center steppes of Algeria which are formed by the provinces of Tissemsilt, Djelfa, Tiaret, Msila, and Bordj Bou Arreridj; this area is shown in Fig. 3.

Demographic Situation
The central Algerian steppes have a total population of 4,660,555 inhabitants which present 11% of the total population of Algeria; the population concerned by this study is about 2,907,884. Figure 4 shows the variation of the actual population in each province.

From the data delivered by the National Office of Statistics, the population of the provinces of Djelfa and Msila is the most important; in the other case, the

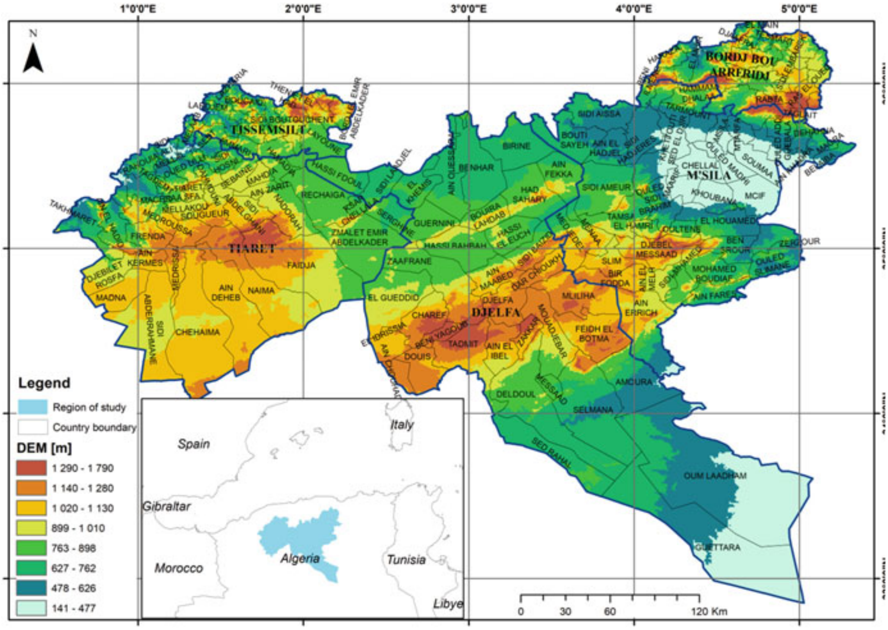

Fig. 3 Location of central Algerian steppes

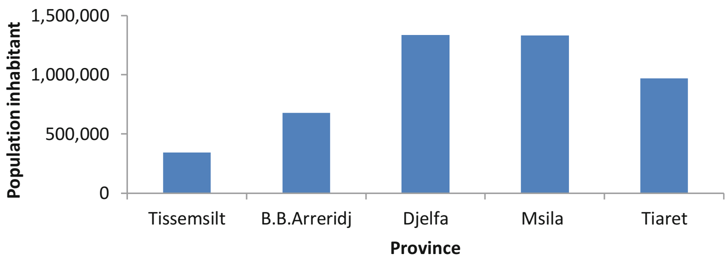

Fig. 4 Population weight in each province

demographic growth of the province of Tiaret appears to be important in the coming few years. The population growth simulated for the ten future years, will achieve 5,895,074 inhabitants in 2027. At the same scale, the growth coefficient calculated is about 2%.

Hydraulic Facilities

The study region was supplied essentially by groundwater with a total number of 366 boreholes, traditional wells, and spring sources. Secondarily, it was supplied by surface water from the four dams with a daily flow of about 113,769 m^3/day. In Table 1 we report the main hydraulic facilities which exist in the central Algerian steppes for population water supply.

The population water supply system was reinforced by multiple pumping stations about 77 stations with an average capacity of 438,923 m^3/day. The total adduction networks are about 2,125 km and distribution network are about 7,189 km.

Water Production and Distribution

The water production data were provided by the Algerian water company (Table 2); it represents the average daily water abstraction from the aquifer and dams. The groundwater abstraction is about 252,853 m^3/day, and the abstraction from dams is about 113,769 m^3/day. The total abstraction is around 366,623 m^3/day. Future water demand was simulated in function of the actual abstraction data.

The distribution of water to citizens is conditioned by the existence of a good distribution network and a sufficient reservoir to secure a continuous water supply.

The actual yield of the distribution networks is about 92.3%; according to these data, the ratio V_d to V_p is about 7.7%, which represents a total of lost water of 26,733 m^3/day about (802,000 m^3/month). The insufficient resources in the region led us to limit the loss of water in the distribution networks.

The existence of any illegal network connection may reduce again the theoretical yield of our water distribution networks. In addition, the bad distribution networks materials play a role in lost of an important part of production by the different leakages along the production and distribution networks (Table 3).

Population Growth Rate

The population growth is rapid in steppe region. Population will increase from 4.6 million in 2017 to 5.9 million in the beginning of 2027, with an average growth coefficient of 2.03%. The rapid population growth indicates a global extension of

Table 2 Water production by resources

Province	Groundwater	Surface water	Total
Tissemsilt	6,297	37,205	43,502
Tiaret	63,234	33,619	96,853
B.B.Arreridj	26,322	31,300	57,623
Djelfa	86,289	0	86,289
Msila	70,711	11,645	82,355
Total	252,853	113,769	366,623

Table 3 Water distribution and lost by leakage in distribution networks

Province	Daily production V_p	Daily distribution V_d	Lost $L = V_p - V_d$
Tissemsilt	43,502	38,282	5,220
Tiaret	96,853	88,974	7,879
B.B.Arreridj	57,623	55,114	2,509
Djelfa	86,289	80,139	6,150
Msila	82,355	77,381	4,974
Total	366,623	339,890	26,733

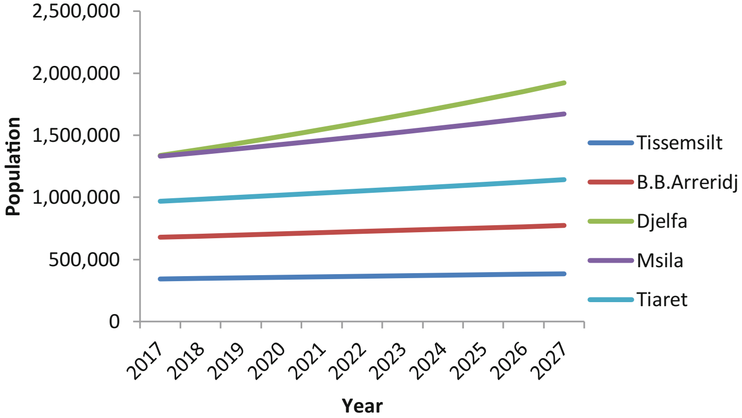

Fig. 5 Population growth in function of province period (2017–2027)

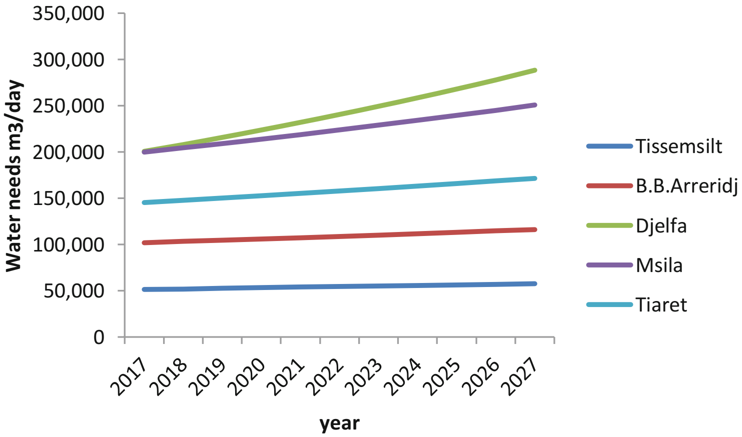

Fig. 6 Water needs for the period 2017–2027 in function each province

irrigation, industry, and raring to assure the population demand. Time evolution of population for each province is given in the graph of Fig. 5.

Water Need
Figures 6 and 7 illustrate the evolution of water demand for the different provinces and in function of different water endowment.

The high water demand is observed in the Djelfa and Msila provinces, because of emerging demographic and economies.

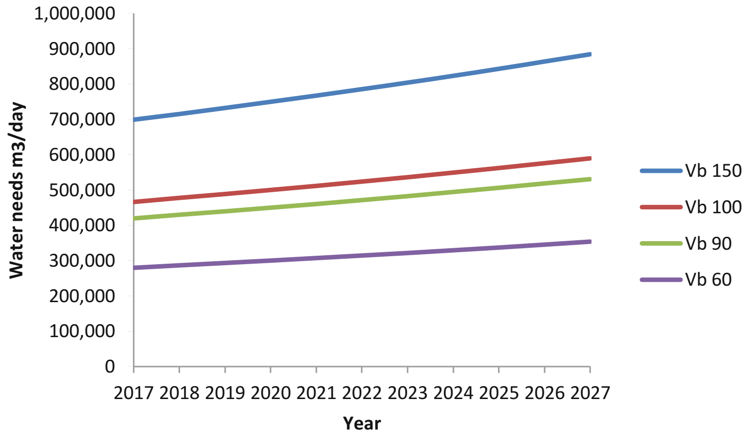

Fig. 7 Water needs for the period 2017–2027 in function of daily water endowment (150, 100, 90, and 60 L/capita/day)

6 Simulation of Water Demand

This study aims to describe the situation of water resources under the pressure of population growth and climate change. The simulation was done by taking the actual situation as a reference. We note that water demand has continuously increased with population growth.

The deficit of water satisfaction for population water supplies is calculated by the simple formula:

$$D = 1 - \frac{Va}{Vn} \tag{4}$$

where D is the deficit or excess in water supply; V_a is the available water; and V_n is the total water needs or demand. If $D > 0$, the balance is a deficit; if $D < 0$, the balance is excess (Fig. 8).

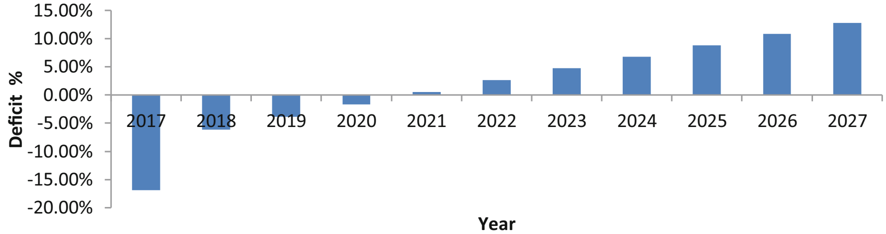

Fig. 8 Variation of the deficit in water demand balance during 2017–2027 (Simulation I)

Scenario I: Normal Evolution of Water Production

The water supply deficit ranges from −16.88% and 12.80% for the period 2017–2027. From this calculation, we conclude that there is an excess in water production against population needs. However, the deficit begins in 2021 with a deficit of 0.51% and will reach 12.80% at the beginning of 2027. Figure 9 shows the average variation of water production and water needs for the period 2017–2027.

Scenario II: Water Production with the Influence of Climate Change

In this scenario we take the same parameter as the scenario I; just we add the climate change parameter (fixed at −1% of the total water production). The simulation steals the same as scenario I with a small variation. Results of simulation are shown in Fig. 10; the deficit variation for the simulation period is given in Fig. 11.

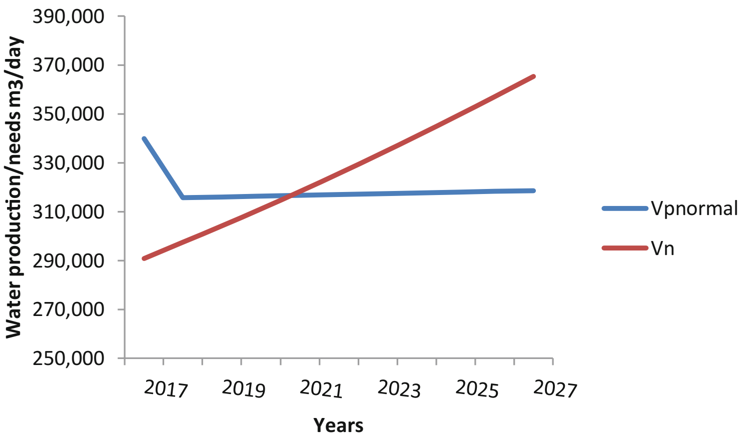

Fig. 9 Variation of production and water need during the period 2017–2027 (Simulation I)

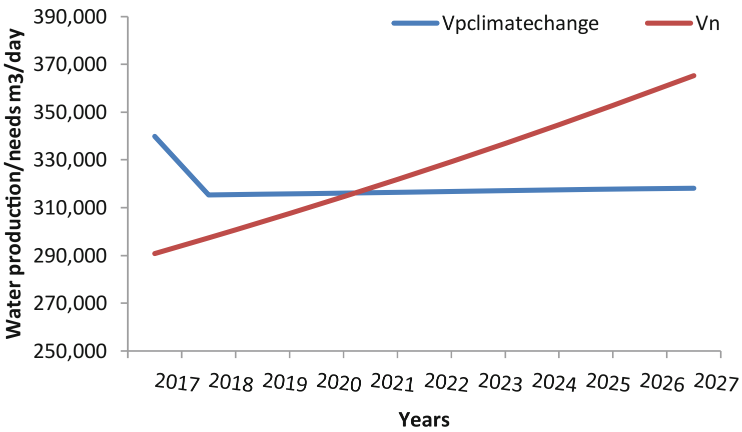

Fig. 10 Variation of production and water need during the period 2017–2027 (Simulation II)

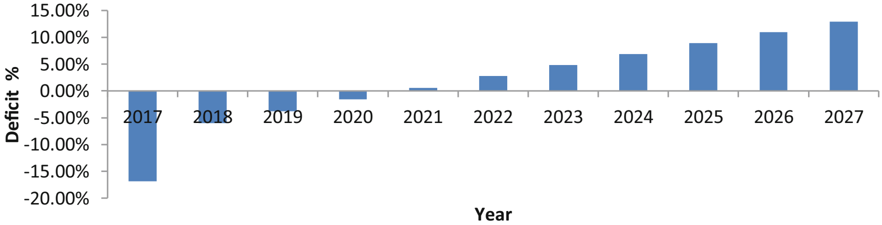

Fig. 11 Variation of the deficit in water demand balance during 2017–2027 (Simulation II)

The water supply deficit ranges from −16.88% and 12.89% for the period 2017–2027. The deficit begins in 2021 with a rate of 0.61% and will reach 12.89% at the beginning of 2027.

The comparison between the two scenarios shows a small difference between the two models; here we conclude that the impact of climate change increases in the long range and is not observed clearly in the small range; during the period 2017–2027, the impact of climate change is (12.89−12.80 = 0.09%) of the global deficit of 12.89.

7 Conclusion and Recommendations

In this study, we have simulated the situation of groundwater resources in the next 10 years, by introducing an actual parameter of exploitation. Two scenarios have been implemented to show the evolution of water demand and water deficit during the simulation period. The results show that the water deficit in the coming years is about 13% of this deficit by taking water demand as a reference for a population of 100 l/capita/day. The situation may be complicated in the future years by groundwater quality degradation and reducing the mobilized water from dams. An emergency plan must be implemented to secure the population of such kind of regions from water shortage in the medium and long range. Some of these projects propose (1) the transfer of desalinated water from the north, (2) water reuses, and (3) reducing the loss of water in distribution networks.

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Water Resources, State of Play, and Development Prospects in the Steppe Region of Naâma (Western Algeria)

Abdelkrim Benaradj, Hafidha Boucherit, and Touhami Merzougui

Contents

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Abstract The Naâma region contains significant underground water potential that has been little exploited, especially in the steppe plains around the chotts (El Chergui and El Gharbi), in the Naâma syncline. It has relatively large water resources and indeed benefits from many natural assets: heavy rains, a mountain water tower with large infiltration areas and snow-capped peaks, perennial rivers, and large underground aquifers continental intercalary (Albien).

The water resources of the department are subject to constraints that affect the quantitative and qualitative potential of the waters.

This integrated water management approach will contribute to sound planning taking into account the various social, economic, and environmental interests. It emphasizes the participation of stakeholders at all levels in the development of legal texts and emphasizes good governance and effective institutional and regulatory arrangements to promote more equitable and sustainable decisions. The approach must be implemented using the economic, institutional, and technical tools to increase the efficiency of irrigation, improve the operation and maintenance of perimeters, improve drainage, and reduce soil salinity.

Integrated management of water resources must be learned from the perspective of sustainable development, to control its scarcity and excess; to ensure the supply of drinking water, agricultural, and industrial; and to preserve the quality of the environment.

Indeed, it should be noted that the water resources of the department are appreciable but require to be evaluated in a precise way to ensure their use in a rational and sustainable manner. Water, which is a resource that is both limited and vital, is increasingly sought after and raises problems of sharing between the different economic and social users: between the supply of drinking water and irrigation, between water and water and irrigation and industry, and between urban and rural populations.

Keywords Integrated management, Naâma, Threats, Use, Water resources

Acronyms

ADBADF	African Development Bank African Development Fund
DA	Algerian dinars
DE	Direction of the Environment
DPPM	Direction of Program Planning and Monitoring
DWR	Direction of Water Resources
DWS	Drinking water supply
IWRM	Integrated Water Resources Management Approach
MWR	Ministry of Water Resources
NAHR	National Agency of Hydraulic Resources

1 Introduction

The Naâma region is part of the arid territory of the South Mediterranean; it undergoes contrasting climatic influences where the rainfall is insufficient and irregular, the inter-annual and seasonal variations very marked, and the intense evaporation and the high temperatures with amplitude more or less contrast [1].

The issue of water resources is vital. It is at the center of a large number of interests: food security, agriculture, biological diversity, and desertification, land use planning, poverty, health, peace, conflict, etc. However, the risks of degradation of agro-ecological resources, including water resources, are still persistent, and levels of agricultural and pastoral production are still rather modest compared to the significant needs of a growing region [1].

The chapter presents a diagnosis of the current state of water resources and their challenges through the analysis of various natural, climatic, and anthropic constraints. According to OCOD [2]; and in the context of growing water scarcity exacerbated by rapid population growth and urbanization, misallocation of resources, environmental degradation, and mismanagement of water resources, this diagnosis requires the implementation of management strategies for available water resources, be it at the level of households, peasants, pastoralists, cities, companies, and developers. It is divided into two parts:

– The first part of the chapter is devoted to the characterization of the physical and natural environment of the department of Naâma, as well as to the analysis of its demographic characteristics.
– The second part presents the general state of the water resources of the department, their mode of exploitation, and the consequences that can result on the prospects for sustainable development and the environment.

2 Presentation of the Study Area

The department of Naâma extends over a vast territory of three million hectares. It is located between latitude 32°08′45″ and latitude 34°22′13″ North and longitude 0°36′45″ East at longitude 0°46′05″ West (Fig. 1).

It is located between the Tell Atlas and the Saharan Atlas in the western part of Algeria. It is limited:

- To the north by the departments of Tlemcen and Sidi-Bel-Abbes
- To the east by El Bayadh department
- To the south by the department of Bechar
- To the west by the Algerian-Moroccan border the Kingdom of Morocco

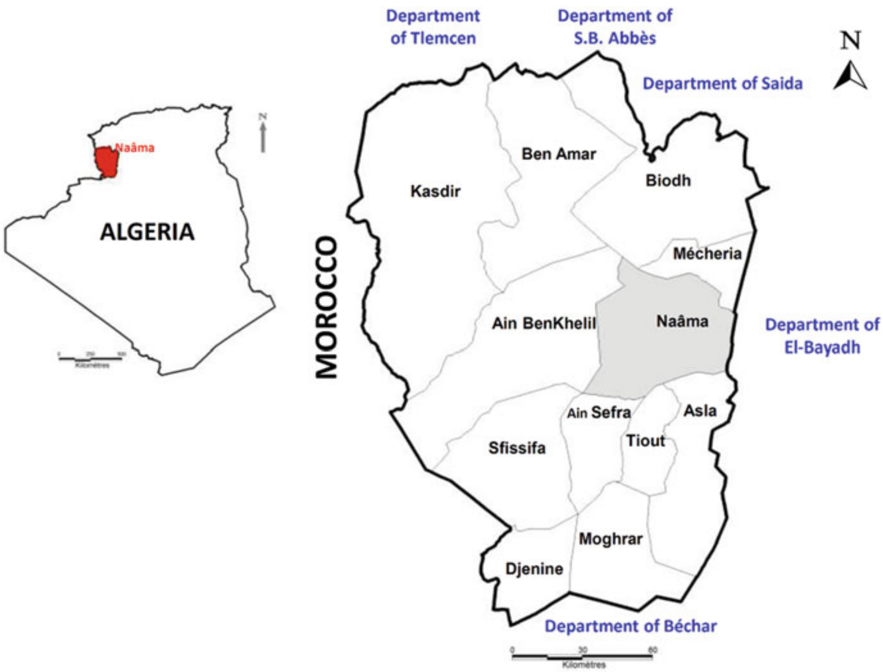

Fig. 1 Geographical location of the study area (department of Naâma-Algeria)

2.1 Physical Framework

Knowledge of the physical environment data in its different forms is essential in understanding the phenomena related to different aspects of the environment and its components. The analysis of the natural environment should enable us to identify and characterize the potentialities and physical constraints as well as their geographic interaction and variation. It will make it possible to appreciate the current use of the resources and the potentialities of the physical environment.

Geographically, the department of Naâma is a vast territory with stratified reliefs consists of three large geographical units [3, 4]:

– A steppe area with monotonous topography constituting most of the rangelands occupies about 74% of the total area.
– A mountainous part with a fairly massive aspect forming an integral part of nearly 12% of the Saharan Atlas chain, which is commonly referred to by the name of Ksour Mountains.
– A southern pre-Saharan zone, which extends over the remaining 14%, which is actually a subspace of the Ksour Mountains materialized by their southern piedmont. Indeed, it is the southern space bounded by the line of ridges going from the Djebel Bou Amoud stretching towards Djebel Bou Lefrhad.

Geologically, it is located on quaternary glacis belonging to the sub-sector of the atlas Saharan Oranian. The study area as a whole constitutes a transition zone of the geological formations of the Atlas Tellian and that of the Atlas Saharan. It is characterized by the juxtaposition of two sedimentary series, marine and continental, and this is according to the phases of regression and transgression of the sea. The base of the deposits is constituted by marine series of the Jurassic where the sandstones predominate and then the continental Cretaceous series consisting of sandstones and some dolomites and calcareous past in the late Cretaceous [1].

2.2 Socioeconomic Framework

2.2.1 Evolution of the Population

The department of Naâma is occupied by a population located along the road axis Oran-Bechar on a space of more than one million hectares or a third of the surface, which translates a bad occupation of the space.

According to the data of the Direction of Program Planning and Monitoring (DPPM) of the department of Naâma [3], the population has a significant increase in the last decades. The demographic development of the department passed 62,510 inhabitants in 1966 to 268,721 inhabitants in 2016 (a density of 9.01 inhabitants/km^2) with a rate of increase of the department of 2.95%. This demographic change in number requires increasing water requirements.

The analysis in Table 1 shows a change in the population of the department of Naâma. The population has tripled in 30 years: the increase in the number of inhabitants affects the consumption of the inhabitants of the region. The department ranks 45th nationally and represents 0.7% of the total population of Algeria. This increase can be considered as a transition in the demographic behavior of the population.

Despite a decline in the population growth rate, growth is still very important. In fact, after registering an average annual growth rate of 3.40% between 1987 and 1998, the department recorded a demographic growth of around 2.5% per year over the period 2008–2016 compared with 1.72% at the national level.

The distribution of the population is mainly concentrated in the three main centers (Mecheria, Ain Sefra, Naâma) as well as other agglomerations located along the national road number 06 (Fig. 2). Nearly 58% of the total population resides in an area not exceeding 7% of the total area of the department.

2.2.2 Evolution of Agro-Pastoralism

The vocation of the department is essentially agro-pastoral traditional where cereal productions dominate. The morphological configuration of the department of Naâma

Table 1 Evolution of the population in the department of Naâma [3]

Years	1966	1977	1987	1998	2008	2010	2012	2014	2016
Number of inhabitants	62,510	82,555	113,700	165,578	209,470	225,530	239,522	253,934	268,721

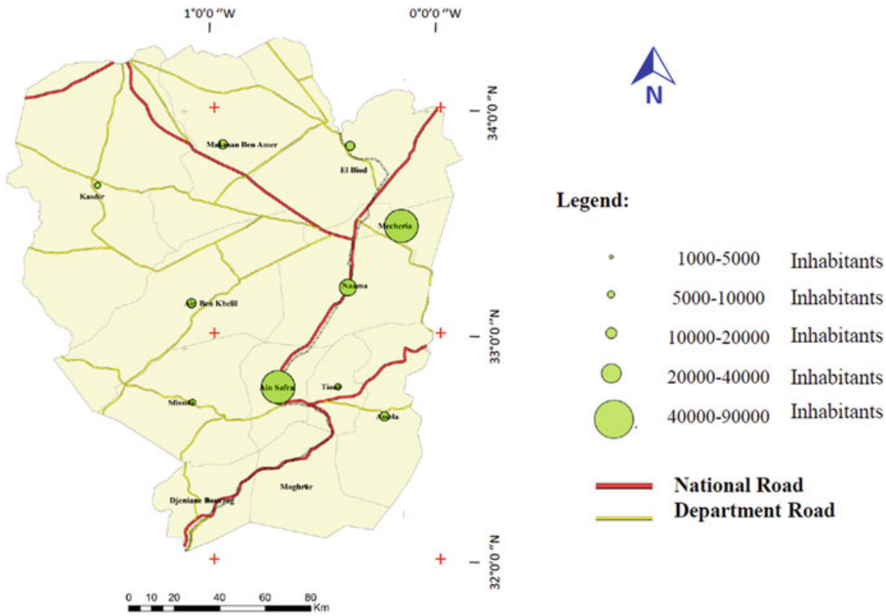

Fig. 2 Population map of the Naâma region [4]

Table 2 Evolution of agricultural land (Ha) in the department of Naâma [3, 4]

Years	2006	2008	2010	2012	2014	2016
Agricultural area	20,395	20,961	23,335	23,766	26,228	28,283
Irrigated agricultural area	6,539	95,305	11,160	13,571	15,374	15,405
Grazing and courses	2,183,005	2,182,439	2,180,065	2,179,634	2,177,172	2,176,117
Total	2,203,460	2,203,460	2,203,460	2,203,460	2,203,460	2,203,460

reveals several spaces for the development of agriculture, particularly in the southern region.

Agriculture

According to Table 2, land intended for agriculture requires water supply, which shows that a considerable amount is intended for these irrigated areas. In recent years, economic development, particularly in agriculture, has resulted, on the one hand, in increased water requirements and, on the other hand, has caused degradation of groundwater quality [5].

The increase in the useful agricultural area will be essentially at the expense of pastures and rangelands. This will support the thesis that agriculture is increasingly pushed back in unfavorable agro-climatic zones and requiring significant investments (drilling, access, electrification) for its practice, to the detriment of the previous use of these zones.

Pastoralism

The data in Table 3 highlight the importance of the sheep herding in the foreground. The numbers of ruminants vary from 1 year to the next mainly due to uncontrolled commercial transactions and the transhumance practiced by breeders.

This herd requires consumption of water like all living beings (Table 4). Livestock watering differs from one animal to another, depending on the environment and the practices of breeding, the season, the physiological state, the age, the quality of the feed, etc.

2.3 Climate Framework

The climate of the Naâma region is characterized by a low and irregular rainfall (100 and 300 mm/year) and a fairly long dry period of 6–7 months, characterized by low temperature that generally falls below −4°C (Fig. 3). This explains its membership in the arid bioclimatic stage. Irregular rainfall from year to year combined with prevailing dry winds causes a degradation of the vegetation cover and accelerates the phenomenon of aridization.

2.4 Hydrological Framework (Hydrography and Hydrogeology)

The hydrology of the department of Naâma strictly obeys the topography and the nature of the soil characterized by a strong dissymmetry between the north and south part of the department. The presence of water in the soil is related to the nature of lithological formations [8]. All formations of marine or continental cover are likely to store water bodies except clayey and marly facies. However, clays and marls there alter very frequently with sandy formations or sandstone aquifers. Only formations consisting of quartzites, shales, hard sandstones, and uncracked eruptive rocks do not contain a body of water [9].

Table 3 Livestock evolution in the department of Naâma [3]

Years	2000	2002	2004	2006	2008	2010	2012	2014	2016
Sheep	565,368	817,570	831,570	842,140	864,000	1,116,500	1,150,249	1,200,000	1,400,000
Goats	56,949	36,000	36,360	56,625	57,500	63,440	68,619	37,605	82,986
Cattle	21,334	32,820	33,148	37,200	37,500	37,500	37,560	37,560	73,167
Camels	500	755	784	799	812	953	1,004	1,015	1,048
Total	644,151	887,145	901,862	936,764	959,812	1,218,393	1,219,872	1,276,180	1,557,201

Table 4 Daily water consumption by sheep, cattle, and camels

	Average water consumption	Authors
Sheep	4.4–10.4 L/day	
Cattle	9–115 L/jour	[6]
Camels	200 L/min/for 14 days	[7]

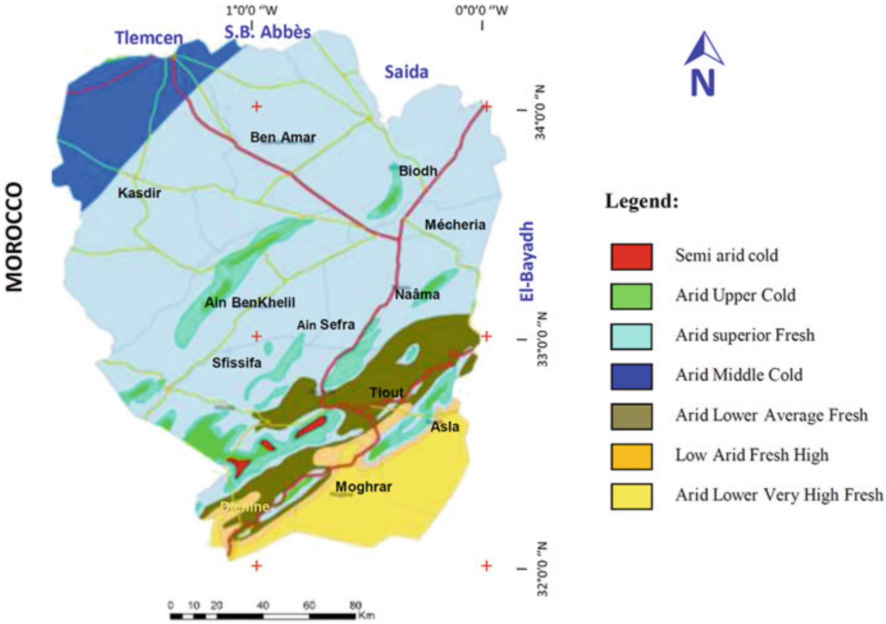

Fig. 3 Bioclimatic map of Naâma [2]

2.4.1 Hydrogeology

The groundwater resources of the department of Naâma come from several aquifer systems whose formation is favored by the geological context.

In general, the work of the National Agency of Hydraulic Resources (NAHR) [9, 10] reports four main aquifers:

- The Chott El-Chergui aquifer, exploited for the benefit of four departments: Naâma, El Bayadh, Saïda, and Tiaret
- The tablecloth of Chott El-Gharbi
- The tablecloth of the syncline of Naâma
- The tablecloth of the syncline of Ain Sefra

Potential groundwater aquifers fall into two types, deep aquifers, mainly exploited by boreholes and aquifers and mainly exploited by springs. Also, the excessive depth of the boreholes in the department testifies to the presence of deep aquifers in the Cretaceous (Albian) formations.

Overall, the region covering the extension field of the Naâma syncline contains formations that may be aquifers that are as follows:

- Tertiary infill formations: 20 and 120 m deep, favorable intrinsic properties of the development of small aquifer horizons.
- The sandstone of the Upper Jurassic, e.g., Callo-Oxfordian, Kimmeridgian contains important aquifer levels located at depths between 50 and 450 m.
- The dolomitic limestone fractures of the Middle Jurassic (Bajo-Bathonian) whose stratigraphic position within the synclines places them very deeply. A second synclinal (south limit of the Naâma syncline) with a NNE/SSW direction takes over and is none other than Tirkount.
- The Mio-Pliocene and Mesozoic formations of this synclinal contain a cylindrical sheet with a parabolic profile whose general flow takes place from NE to SW.
- This Mio-Pliocene aquifer is fed from Jurassic and Cretaceous formations of the NW flank of the Djebel Aissa and the NE flank of the Djebel Morghad.
- South of the Tirkount depression. Another layer of lesser importance is contained in the alluvial deposits of the Breidj valley: it is developed in a scene of sandy-clay alluvial deposits about 10 m thick exploited by wells and whose general flow at SSE/NNW management [1].

2.4.2 Hydrographic

The hydrographic network is poorly developed in the north, while in the south, it is denser with an important inferoflux crossing the Saharan Atlas [11]. The northern part of the High Steppe Plains had an undeveloped hydrographic network characterized by relatively flat topography and dotted with depressions, which is at the origin of the endorheic nature of these valleys. The surface waters are temporary; they flow in the direction of three closed basins: Chott El-Gharbi to the West, Chott Ech Chergui to the North-East, and sebkha to Naâma to the South-East [1].

In the south, the existence of reliefs gives rise to a more dense flow and a more hierarchical hydrographic network, thus forming some valleys whose flow takes a direction parallel to the structures. Valley of El Breidj has a south-west/north-easterly flow, while valleys of Ed-Douis and El Rhouiba have a north-east-southwest flow.

The lithostratigraphic and structural context prevailing in the Naâma department space has favored the formation of aquifer units or systems from various horizons captured by drilling. However, if these aquifer systems exist, their identifications and knowledge remain uncertain. Currently, the only data available relates to information provided by drilling and shallow wells. Most of these drill holes are exploited from Upper Jurassic formations, particularly the Callovo-Oxfordian, which appears to contain significant aquifer horizons with depths ranging from 50 to 450 m [12].

In the synclinal structures of the region of Ain Sefra and Tiout, the Cretaceous (Albian) formations offer appreciable potentialities in groundwater at depths of 150–200 m with flow rates varying from 10 to 84 l/s. For shallow and medium depths, the more or less coarse levels of the tertiary base may contain small aquifer horizons.

Also, fractured Bajo-Bathonian formations may be able to accumulate groundwater [1].

3 Potentiality of Water Resources

The region of Naâma has a significant wealth of surface water resources and above all underground, which however is very little exploited.

Potentialities in groundwater are poorly known because of the lack of detailed and recent hydrogeological studies, but they can be considered significant given the number of boreholes in operation and flows achieved [1].

3.1 Surface Water

A rather dense flow, hierarchical, originating on the slopes of the massifs of the Saharan atlas and directed entirely towards the south towards the great western erg crossing thus the whole of the mountainous barrier. This is the case of the waters of the valley of Breidj, which supports the drainage waters of the valley of Tirkount and Sfissifa, crossing the entire Ain sefra depression and then heading south through a low point located between the mountain Cheracher and Djara and then moving towards the West and finally to the south while changing names (Oued Rhouiba and then Oued Namous) to finish in the great Western erg. The 8,492 km^2 Ksour watershed receives on average 190 mm of precipitation per year, generating an average inflow of 30–36 Hm^3/year. A diffuse intermittent flow network that is poorly developed in this region, is located mainly in the north of the Saharan Atlas, and ending in the most cases on depressions (dayas, sebkhas, and chotts).

This is the case of all superficial flows draining the plains located north-west and north of the mountainous ridge extending from Djebel Oust to Djebel Hafid. Indeed, the streams that come from slopes of these ridges and plains are ending on the depression of Chott El-Gharbi when liquid flows are sufficient.

It is the same for other flows that end their journey in small closed depressions that serve as their base level: this is the case of the water of the valley El Adjedar that ends in the Mekmen-Abiod, where the water runoff from the northwestern side of Djebel el Mellah is ending in the sebkha of Naâma (Fig. 4).

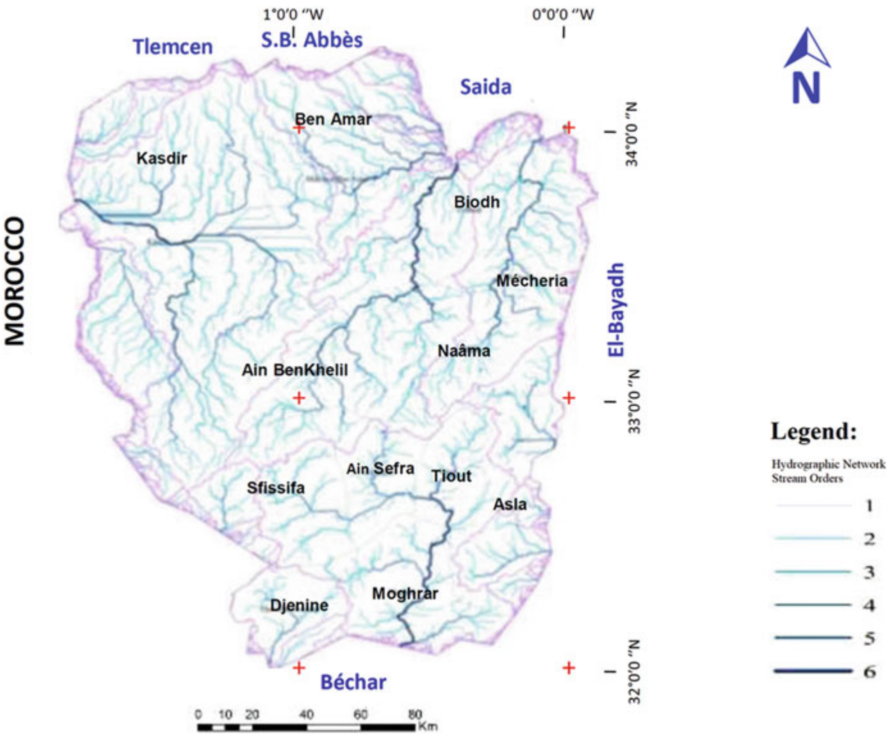

Fig. 4 Hydrographic map of the department of Naâma

3.2 *Groundwater*

Groundwater is an important part of the water resource. They have the advantage of their regularity, their low mobilization costs, and their good spatial distribution. It is also a resource less vulnerable to climate hazards and pollution. This resource is unique, which gives it an exceptional value.

The implantation of the boreholes indicates that the aquifer potential is particularly concentrated around the chotts (El-Chergui and El-Gharbi), in the syncline of Naâma, and the valley of Ain Sefra-Tiout (Table 5).

However, the estimation of these potentialities, by the various sources of information consulted, reveals an appreciable potential. The main aquifers that exist throughout the department of Naâma are essentially the aquifer of the Albian, Barremo-Aptian, Kimmeridgian, and Turonian [12].

Table 5 Assessment of groundwater resources [10]

Aquifer	Exploitable resource (Hm^3)	Operated volume (Hm^3)
Chott Chergui	46	31.6
Chott Gharbi	40	–
Synclinal of Naâma	15	15
Synclinal of Ain Sefra	11	11

3.2.1 The Aquifer Field of the Syncline of Naâma

It contains interesting potentialities thanks to its geological layers favorable to the formation of aquifers:

– Tertiary formations located between 20 and 120 m deep
– Upper Jurassic sandstones, located at depths between 50 and 450 m
– The fractured dolomitic limestones of the Middle Jurassic, located at great depths

3.2.2 The Aquifer Field of the Tirkount Syncline

This Mio-Pliocene aquifer is fed from the Jurassic and Cretaceous formations of the northwestern flank of Djebel Aissa and the northeastern flank of Djebel Morghad.

3.2.3 The Alluvial Aquifer of the Valley Breidj

Limited to the northeast by the city of Ain Sefra, to the south by the Djebel Mekter, and to the northwest by the valley Breidj, this layer, developed in a series of sandy-clay alluvial deposits of about 10 m thickness, is exploited by wells.

Although the department of Naâma is close to the large sheets of the Saharan Atlas (see Fig. 5), it has significant underground water potential, especially around the aquifers of the chotts (El-Chergui and El-Gharbi), as well as the aquifers of the synclinal of Naâma and in the valley of Ain Sefra-Tiout, the exploitation of the ignorance of the intrinsic characteristics and the geometry of the different aquifers.

3.3 Potentialities in Water and Their Mobilization

The semiarid climate and the lack of surface water mobilization structures mean that the department of Naâma is essentially supplied with groundwater.

Mobilizations in surface water are insignificant; they amount to 0.092 Hm^3, captured by two hill reservoirs intended for irrigation:

– A capacity of 0.062 Hm^3, located in the commune of Naâma
– A capacity of 0.030 Hm^3, located in the municipality of Tiout

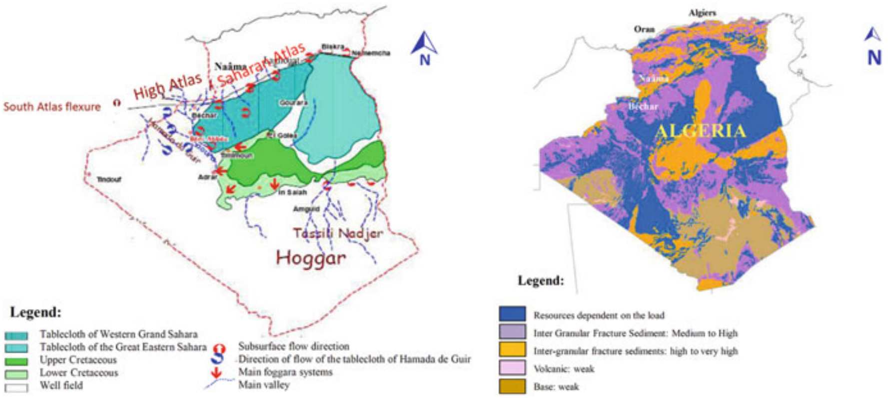

Fig. 5 The great water potential of southern Algeria [10, 13]

The overall situation with regard to water mobilization and their assignments is shown in the following table (Table 6):

The analysis in Table 6 and the data from the DPPM show very clearly:

- The data presented in the table provide very significant indications.
- The balance of mobilizations by type of works (drilling, wells, sources, and Collin Dams), number of structures, and their flows.
- Groundwater resources are very significant, especially for deep aquifers.
- In terms of water mobilization, boreholes and water points have all been positive. The flows achieved vary between 5 and 80 l/s.
- The department has 89 storage facilities with a total capacity of 39,200 m^3.
- Mobilization by 1,163 boreholes across the territory with a cumulative flow of 5,131 l/s.
- Mobilization by 905 wells throughout the territory with a cumulative flow of 464 l/s.
- The wells collect shallow water; these shallow groundwater mainly for irrigation are appreciable (in the perimeters of the region of Ain Ben Khellil).
- Mobilization by five sources across the territory with a cumulative flow of 5.3 l/s per unit is located in the municipalities of Ain Sefra and Asla.
- The mobilization of surface water through three hilly reservoirs across the territory of the department is generally intended for irrigation (Table 7 and Fig. 6).
- The problems of exploitation related to the networks of drinking water supply (DWS) result notably from the defects of the study of conception and realization, as well as from the dilapidated networks in some cities (Mecheria, Ain Sefra and Asla). Also, the pumping of water from the boreholes is conditioned by the electrical energy; the power cuts sometimes cause disturbances in the drinking water supply.

Table 6 The situation of mobilized resources (DPPM of Naâma [3, 14–16])

Topics	2010	2012	2014	2016
Drilling				
Number	1,074	1,151	1,129	1,163
Flow (L/S)	3,706	5,999	5,054	5,131
Destination (L/S): – Drinking water supply (DWS) – Irrigation – Other	 1,386 1,990 330	 1,381 4,288 330	 1,381 3,673 219	 1,267 3,864 244
Well				
Number	1,006	1,011	901	905
Flow (L/S)	2,035	516	466.00	464.00
Destination (L/S): – Drinking water supply (DWS) – Irrigation – Other	 24 1,992 19	 13 503 19	 13 453 0	 11 453 0
Sources				
Number	5	3	5	5
Flow (L/S)	9	5.80	5.80	5.30
Destination (L/S): – Drinking water supply (DWS) – Irrigation – Other	 4 5 0	 4 2 –	 4 2 –	 3,8 2 –
Hill dams				
Number	5		3	3
Storage capacity (Hm^3)	11.45	11.421	10.719	10.719
Destination (L/S): – Drinking water supply (DWS) – Irrigation – Other	 0 0.09 11.36	 0 0.0165 8.33	 0 0 3.60	 0 3.60 0
Underground resources mobilized (flow: L/s)				
Daily water allocation (L/D/H)	480.09	475.00	482.10	439
Number of tanks and water towers	83	86	86	89
Production and consumption of drinking water (m^3)	36,550	38,550	38,550	39,200
Drinking water roduction and consumption				
– Mobilized volume (m^3/day) – Volume produced (m^3/day) – Distributed volume (m^3/day)	119,750.4 32,529.4 30,902.93	119,318.4 38,565.1 36,535.20	119,318.4 44,929.8 42,302.50	109,468.8 43,604.0 42,066.00

Table 7 Probable availabilities from hill dams and small dams in Horizon 2030 [2]

2006 (Hm^3/an)	2010 (Hm^3/an)	2020 (Hm^3/an)	2025 (Hm^3/an)	2030 (Hm^3/an)
10.10	10.6	11.7	12.2	12.8

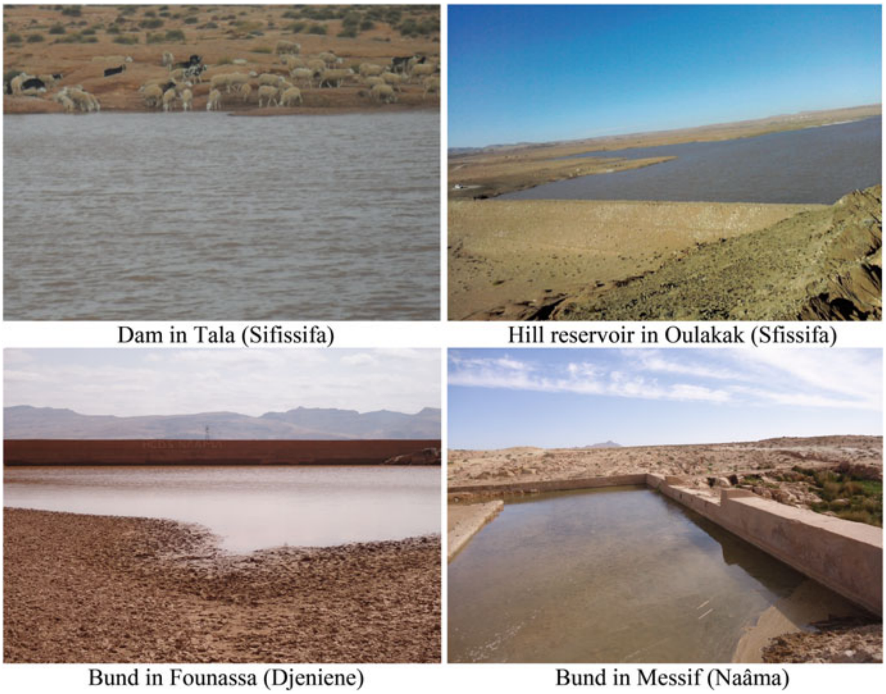

Fig. 6 Hydraulic water storage structures in the area of Naâma

- The rational mobilization of this resource requires capital importance in the development of this region in the agro-sylvo-pastoral field.
- Regarding the projections of the use of recycled wastewater, through the construction of wastewater treatment plants in the main cities of the department (Naâma, Mecheria and Ain Sefra), with a resource capacity of nearly 02 Hm^3.
- The theoretical daily average water allocation, at the scale of the department, assessed through the volumes of water distributed to the agglomerated population recorded in 2016, reaches 439 l/d/ inhabitants. This level, compared to the national standard (150 l/d/inhabitant), remains appreciable. Per capita water availability has deteriorated significantly since independence. By 2020, per capita water availability in Algeria is estimated at 473 m^3/inhabitant/year. The scarcity threshold set by the World Bank is 1,000 m^3/inhabitant/year [17].

4 Threats and Environmental Challenges of Water Resources in the Naâma Region

The problem of water is certainly seen from new dimensions such as delegated management, profession of water, rigor, and economy. However, face to this situation, the rationalization of daily consumption of water of users becomes a necessity to keep the durability of water resources in this region. Leaks are still present, and as important as before, the dissatisfaction of the users is still visible; the changes made in the management were not the taste of the workers of the sector, etc. For that, a diagnosis, even summary, of the situation will enlighten us on the subject.

The water resources of the department are subject to several threats (climatic, socioeconomic, and ecological), which affect the quantitative and qualitative potential of the water [18].

4.1 Climate Threats

The most cited causes are climate changes, which are marked by a decrease in rainfall and an increase in evaporation. These phenomena could notably be reflected in the frequency of droughts or floods.

– Belonging from the Naâma region to the arid and semiarid bioclimatic level.
– Climatic aridity and climatic changes recorded during the last decades (climatic fluctuations).
– Drought is one of the most common natural hazards in Algeria with negative effects on agriculture and water resources.
– Annual rainfall weakness: Like the other departments of High Plains, precipitation is, on the physical and natural levels, the first constraint for the department. Indeed, the rainfall regime is characterized by very low annual rainfall (between 100 and 300 mm on average), often of a stormy nature and presenting a great inter-monthly and inter-annual variability; their height decreases from north to south. This climatic characteristic, combined with other environmental factors (relief and lithological formations), implies many handicaps and threats:

  (a) Insufficient rainfall, which is a limiting factor for rain fed agriculture and groundwater recharge, as well as a major factor in the degradation of steppe vegetation cover and the desertification process.
  (b) The irregularity of the precipitations and their seasonal and annual variations, which makes any production in random dryness.
  (c) The intensity of the rains which is generally reflected by strong floods and the flooding of inhabited areas (Ksour Mountains and mainly the city of Ain Sefra). Floods are among the most common and unpredictable natural disasters. Regarding the department of Naâma, the threat to floods is mainly seen in the Ksour Mountains, where the stormy character of the rains, combined

with the declivity of the relief and a hydrographic network with banks undermined, gives rise to significant floods that flow on inhabited areas. The most convincing case for the illustration of this phenomenon is the city of Ain Sefra, which saw its former European village ravaged by the great flood of 21-10-1904. In the urban areas of the plain, like Mecheria, the problem of flooding in low-income neighborhoods is mainly due to the absence or insufficiency of rainwater drainage networks [19].

(d) Effect of evaporation on the water balance. It is itself based on several factors including wind, sunstroke, and temperature. The longer the dry season, the greater the importance of evaporation. Precipitation largely absorbed by intense evapotranspiration [20].

4.2 Socioeconomic Threats

4.2.1 Demographic Pressure

Given the single problem of meeting the need for drinking water, demographic factors and urbanization are very heavy constraints in terms of water resources, notwithstanding the economic aspects and the pace of investments that characterize the water supply [21]. With a significant demographic growth, even if today the slowdown is significant, Algeria is confronted with the problem of the adequacy between its population and the physical limits of water availability. These can only increase over time as demand for water steadily increases under the combined effects of population growth and increased domestic, industrial, and agricultural needs related to economic development and rising standards of living. Today, the demand for water is important because of the economic and social changes recorded by the country: the increase in irrigated areas and urban growth.

4.2.2 An Accelerated Urbanization Process

The accelerated urbanization experienced by Algeria since its independence is the result of a historical fact, a spectacular demographic growth, and migratory movements which were no less so, especially during the first three decades. The impact is doubly negative. In addition to the removal of agricultural land, urbanization has a more insidious effect on the agricultural sector because of water consumption, both superficial and underground. It follows a lowering of the water tables and a drying of the wells, requiring either a deeper sinking or a sinking of new boreholes.

4.2.3 The Overexploitation of Groundwater and the Development of Interregional Transfers

The two aquifers of the Naâma syncline and the Ain Sefra syncline are exploited to 100% of their capacities, whereas the usual practices recommend, for a preservation of groundwater, a farm must not exceed 70–80% of their capacity [1]. The exploitation volume exceeds the tolerated level for the aquifers of the Naâma syncline and the Ain Sefra syncline [22]. Overexploitation of groundwater can cause a lowering of the piezometric level [23].

4.2.4 The Wastewater

The wastewater does not only concern the agricultural sector. In cities, pipes are often old and poorly maintained. The losses of network water are still impressive, up to 50%, whereas in a modern system, they must not exceed 10% [24].

4.2.5 Leaks

It is clear that the problem of leaks is not recent, and we can affirm that from a quantitative point of view, losses, especially in the form of leakage networks that only rational use and a more efficient operation can reduce, are one of the main causes of the deterioration of the rate of satisfaction of domestic needs. The result is that the leaks are at a still high level; however, improvements are reported. Experts agree that reducing losses by as much as 30% saves 1.5 billion cubic meters per year and therefore meets the needs of around 4 million consumers. Leaks in individuals are also quite important. Just imagine what a leak of 0.1 l/s (split between flush and different faucets in a dwelling) to measure the wasted volume. According to Touati [24], the water loss per day is estimated to 8640 l, which give an annual quantity of 3,153,600 l, that leads to an important financial loss around to 20,000,000 Algerian Dinars (the price of one cubic meter is 6 AD excluding taxes). Total losses in irrigation systems are estimated globally at 40% of abstractions; they would exceed 50% in the cities.

4.2.6 Extension of Agricultural Irrigation in Algeria

The development of irrigation is a mandatory step to ensure food security of the country. Irrigation is poorly developed in Algeria. However, it has evolved in recent years with a doubling of irrigated areas. The importance of water for life and as a component of the global ecosystem is well established. This resource, which meets the basic needs of man, is a key element of development, but even more, agricultural water appears as one of the major levers of development. The dramatic increase in demand and the consequences of climate change have made water the most valuable resource on our planet. The water deficit is one of the most important factors limiting crop production in the world [25].

4.2.7 Energy Pressure

Increased energy demand will also weigh in the future on water resources. Hydroelectric generation is expected to grow by around 60% by 2030 [26].

4.2.8 Geopolitical Problem

Water in relation to society is represented as a fundamental problem related to the management of conflicts, sources of income, etc.

4.3 Ecological Threats

4.3.1 Mining and Shale Gas

One of the most harmful impacts of shale gas exploitation is the risk of groundwater pollution and methane pollution of drinking water.

4.3.2 Risk of Pollution of Surface Water and Aquifers

Agriculture, industry, and urbanization have exploded the consumption of water causing discharges of astronomical quantities of wastewater which eventually make this precious resource unsuitable for the consumption. This pollution of surface water and groundwater is a process caused by the rejection, in the valley, of urban wastewater (domestic or industrial) without prior treatment. This phenomenon affects the majority of valley located near settlements, to more or less severe degrees. Groundwater is increasingly subject to voluntary discharges of polluting effluent, wastewater, or storm water runoff into urbanized areas [27, 28].

4.3.3 Salinization of the Waters

The risks of salinization of the waters of the water tables of the department are because of two main reasons: the presence of the two depressions with salty waters, Chott El-Chergui and Chott El-Gharbi, and the presence of north and south flexures Atlas, which favor the ascents of the triad.

5 Prospects for the Development of Water Resources in the Department of Naâma

The region of Naâma has relatively large water resources and indeed benefits from many natural assets: fairly heavy rainfall (rain, snow), a mountain water tower, valleys, and large underground aquifers. The concern to save and exploit the environment rationally involves acquiring the basic data needed to understand how ecosystems function and to evaluate their potential.

Groundwater is an important part of the water resource. They have the advantage of their regularity, their low mobilization costs, and their good spatial distribution. It is also a resource less vulnerable to climate hazards and pollution. This resource is unique, which gives it an exceptional value.

Because of their economic, social, and environmental importance, water resources are the cornerstone of sustainable development. The growth of drinking water needs is due to the population growth, the development of cities, and the growth of water-consuming economic activities such as agriculture, industry, and tourism.

This growth imposes large-scale challenges and requires solidarity sometimes going beyond the limits of departments or even regions, just as the satisfaction of these needs requires the use of new techniques and methods of mobilization and exploitation of resources in water [1].

The phase of development of the territory of the department of Naâma "allowed delivering an inventory of fixtures and an analysis of the current situation of the department." This examination related at the same time on the water resources and the assets of the department, its constraints, as well as on its general level of equipment and development. The development of all these resources and potentialities, within the framework of thoughtful and coordinated actions of promotion of the investment and in respect of the principles and orientations in the matter of preservation of the environment, may allow the department to initiate a dynamic of growth and sustainable development.

For its water needs, the department of Naâma has water resources, especially underground, which allow it to envisage favorable projections of demand satisfaction (all uses combined), according to the forecasts by 2030, elaborated by the Ministry of Water Resources. Although they are not sufficiently known, the underground water resources of the department are considered appreciable; however, they must be rationally exploited and protected against the risk of pollution. Projections of the demand and availability of water resources by 2030, developed in the framework of the national water plan, presented in the following table, show that the overall balance sheet (all uses combined) remains largely positive for the Naâma department, whether short, medium, or long term [1, 23].

Prospects are still worrying because of the contamination of available water resources by the intensification of human activities. Many of the efforts to manage available water resources are to realize the need, to protect groundwater quality, and to limit impacts on groundwater quality. Among the possible actions of development of the water resources in the department of Naâma:

1. Assessment and mapping of water resources
2. Integrated Water Resources Management Approach
3. Sustainable Development of Water Resources Approach

5.1 Studies and Mapping of Water Resources

The development of a mapping of the vulnerability of groundwater makes it possible to optimize the use of the territory to minimize the risks of the appearance of contaminations. Also, the delimitation of catchment protection perimeters is a measure to help prevent contamination during the supply. Thus, undertake the necessary studies to determine with precision: the real water potential of the department, its location, its degree of exploitation, and its economic cost.

5.1.1 Improving and Securing the Situation of the Drinking Water Supply

- Improvement of the living environment of the populations
- Protection of water resources against all forms of pollution
- Protection of works and human settlements
- In-depth knowledge of water resources in quantitative and qualitative terms
- Mobilization and strengthening of the drinking water supply
- Extension, rehabilitation, and construction of networks for water supply and sanitation
- Equipment coming within the framework of local development and responding to a collective need
- Establishment of a comprehensive inventory of water points (boreholes, wells, springs, etc.)
- Priority to the mobilization of the surface water resource from structures adapted to the region (diversion hillside dams, flood spreading works) which also allow groundwater recharge
- Construction of works and devices for the purification of wastewater and reuse of these treated waters for agriculture and industry

5.1.2 Fight Against the Flood Problem

To fight against the flood problem, the measures to be considered to stem this phenomenon will have to relate to:

– The development of storm water drainage networks at the level of agglomerations and their permanent maintenance
– The cleaning of valley
– Biological treatment of watersheds and riverbanks

5.1.3 Fight Against Waste and Leaks

To fight against waste, it is necessary that the water professionals carry out campaigns of sensitization and descend until the consumers (schools, mosques, public or private establishments, farmers), by the implementation of an effective policy, regular and sustained information, training, and extension. Education courses should be done from the primary level of the economy and the good management of water. The water policy will involve civil society (community movement), local authorities, and, of course, watershed management representatives, and in this context, funding must be defined [24]. Thus, implement measures to minimize losses on networks (supply, storage, and distribution).

5.1.4 Preservation and Valorization of the Water Resource

Because of their economic, social, and environmental importance, water resources are the cornerstone of sustainable development. These resources are in high demand due to growing needs, water supply and irrigation, as well as industrial, service, and other activities.

The semiarid climate and the lack of surface water mobilization structures mean that the department of Naâma is essentially supplied with groundwater. Potentialities in groundwater are considered appreciable given the number of boreholes in operation and flows achieved;

however, they are poorly known because of the lack of detailed and recent hydrogeological studies. The Program of Action that is defined in this area relates to the knowledge, the preservation, and the greater exploitation of the water resource [1, 29].

5.1.5 Flood Control

The department of Naâma is highly exposed to floods. These are the result of meteorological situations, characterized by intense precipitation over a very short period, combined with unfavorable topography. They mainly affect the Ksour Mountains area, where people, communication infrastructure, and agricultural land often suffer serious damage.

The recommended action plan recommends, firstly, the establishment of an inventory of the flood zones and then a set of actions of protection (improvement and regular maintenance of the sewerage networks, cleaning, calibration and maintenance of wadis in agglomerated zones, construction of protective works, and regulation of building zones) [1].

5.1.6 Pollution Control

The fight against pollution to the environment and water resources involves the completion of wastewater treatment in the large agglomerations (Mecheria and Ain Sefra) and lagoon stations near other agglomerations [1].

5.1.7 Saving and Rationalizing the Consumption of Drinking Water

To better control the demand for water, it is necessary to review the current pricing of drinking water (pay the actual cost) and the implementation of a policy that generally guides consumer decisions to achieve a collective economic optimization and reduce the excessive exploitation of this resource. The many opportunities are to reduce the water consumption in agriculture and industry. The technologies provide significant water savings in irrigated agriculture. Thus, the drip system saves up to 50% of the water normally used for irrigation. In industry, with the modern techniques, it is possible to reduce up to 90% [30] of the quantity necessary for cooking, cleaning, etc.

5.1.8 Hydraulic Awareness

According to Touati [24], the hydraulic consciousness induces a real saving of water. It is obvious that no policy can succeed without the massive and convinced adhesion of all users. At the same time, the latter will only become involved the day they feel that, together with the water economy, the State's water policy aims to substantially improve their own standard of living individual and collective by limiting or even eradicating all leaks. On the other hand, the limitation of the consumption passes by:

– A choice of plant species adapted to the climatic conditions of the region
– The implementation of modern irrigation technologies (drip) to achieve real water savings
– Training farmers in modern irrigation practices
– Improvement of the conditions of management and maintenance of treatment plants, to encourage irrigation by wastewater
– Improvement of distribution networks and the fight against leaks and waste
– The introduction of water-saving technologies (closed circuit cooling, pressure washing, automatic shutdown of pumps, pressurized taps, etc.)
– Recycling in the process
– Awareness and information of the staff on the water economy and the protection of the environment

5.1.9 Adaptations and Practices on Water Demand By

- The mobilization of conventional water resources and the creation of new hydraulic dams for surface waters
- The creation of new boreholes for the mobilization of deep aquifers
- The mobilization of unconventional water resources: by the purification of wastewater and the protection of resources against pollution

5.1.10 Adaptation of the Water Demand Climate Change

We must keep a system adaptable to the hazards and structurally reduce the demand by implementing a system of supply which will have to be more flexible and flexible so as not to be too vulnerable to climatic hazards, as soon as possible when we manage the balance between resource and demand on the edge of the razor.

5.2 Integrated Water Resources Management Approach "IWRM"

Integrated water management is an approach that has been the subject of a large number of documents for various purposes; whole websites are devoted to it. It has been widely developed since the international conferences on water and the environment held in Dublin and Rio de Janeiro in 1992, until that of Kyoto in 2003. It encourages the development and management of the environmental water, to maximizing the resulting economic and social well-being in a fair way, without compromising the sustainability of the vital pastoral ecosystem. It aims at all the actions to be carried out to guarantee optimal use of the water resource qualitatively and quantitatively for the benefit of the populations and their need of the economic activities.

The integrated water management approach is widely developed following the national water policy by various international and national laws on water and the environment to give guidelines through integrated and sustainable management instruments resources. The two laws (83–17 and 05–12) relating to water, give all the actions to be carried out in order to guarantee an optimal use of water resources qualitatively and quantitatively for the benefit of the citizens and their need for different activities. It promotes the development and management of water, with a view to maximizing the resulting economic and social well-being equitably, without compromising the sustainability of the vital pastoral ecosystem. It aims at all the actions to be carried out to guarantee optimal use of the water resource qualitatively and quantitatively for the benefit of the populations and their need of the economic activities.

The concept of integrated management aims to improve the current management of water by promoting a better harmonization between the various needs and interests of human communities and those of aquatic ecosystems. It integrates the protection of public health, the security of populations and their property (floods), the protection of wildlife, and the restoration of habitats [31].

To this end, the rational management of water resources has become a necessity today, even an obligation, to ensure a harmonious and sustainable development that requires for its success a combination of technical, economic, and financial solutions, moreover institutional to meet growing needs.

Integrated management of water resources must be learned in a perspective of sustainable development, to control its scarcity and excess; to ensure the supply of drinking water, agricultural and industrial; and to preserve the quality of the environment [32].

To this end, the rational management of water resources has become a necessity today, even an obligation, to ensure a harmonious and sustainable development that requires for its success a combination of technical, economic, and financial solutions and institutional. However, it will be necessary to launch programs of economy and progress in the efficiency of use, to revise certain allocations of resources, and to answer the increasing needs. Future choices are therefore likely to be critical.

This approach has contributed to rational management by taking into account the various social, economic, and environmental interests. It emphasizes the participation of stakeholders at all levels in the development of legal texts and emphasizes good governance and effective institutional and regulatory arrangements to promote more equitable and sustainable decisions. Therefore, the development and implementation of these approaches will need to use economic, institutional, and technical tools to increase the efficiency of irrigation, improve the operation and maintenance of perimeters, and improve drainage and the reduction of soil salinity [33].

5.3 Approach to Sustainable Development of Water Resources

Achieving sustainable development requires equating social, economic, and environmental concerns with the essential factor and limiting water. Available resources could, however, be used much more effectively by reducing reservoir contamination and evaporation, recycling, maintaining networks, reducing waste, and growing less water-intensive varieties or more and salt tolerant. Efficient, sustainable, and equitable management of water will provide a solid foundation for the recovery, preservation, conservation, and protection of water resources.

Alternative water resources management should involve political, scientific, technological, economic, and technical cooperation. It is a strategy based on:

– Water resource governance with a water policy oriented towards supply management by improving access to drinking water and food security for the population.

- Rationalization of agricultural water.
- Better knowledge of water resources through ongoing and systematic data and information collection programs, analyses, syntheses, and research on the range of water issues.
- Valorization of water and management of water scarcity by technical measures by the development of water conservation structures such as dams to allow the storage of a larger volume of water to use during periods of drought and water transfer facilities to allow water to be transferred from surplus areas to deficit areas.
- Flood mitigation measures such as watershed conservation, storage facilities to mitigate extreme events, stream regulation and regulation, and floodplain management.
- Water conservation through the creation of storage and the replenishment of the water table are measures to be considered for periods of drought.
- Integrate the relationship between solid waste management and integrated water resources management into their national integrated water resources management policies and include appropriate measures in national environmental action plans.
- Wastewater treatment to protect surface water and groundwater against the harmful effects of waste. Garbage dumps must be located and controlled in such a way as to eliminate any risk to human health.
- Awareness and information of all stakeholders in water management, and first of all users, are a paramount condition for the effective application of regulatory, technical, or financial instruments.
- The establishment of an effective and concerted groundwater management policy to mitigate the depletion and degradation of this strategic resource.
- Environmental education is necessary to awaken everyone's awareness of their responsibility for the protection of water resources, their rational management, and a fight against their pollution.

All of these measures can be planned and implemented as part of the integrated water resources management policy [34]. The human factor is primarily responsible for the protection, treatment, and management of this precious natural resource by its preponderant place in any preservation strategy and its sustainable development because it is a strategic and essential matter for the development of the society.

6 Conclusions

The department of Naâma is a region with a pastoral and agro-pastoral vocation which has considerable pastoral and underground water resources. With an arid climate and the absence of structures for mobilizing surface water, the department of Naâma is mainly supplied with groundwater.

The water resources of the department are appreciable but require to be evaluated in a precise way to ensure their use in a rational and sustainable way. Water, which is a resource that is both limited and vital, is increasingly sought after and raises problems of sharing between different economic and social users: between drinking water supply and irrigation and between the potable water of urban and rural populations, water irrigation, and industry.

It should be noted that the water resources of the department are appreciable but require to be evaluated in a precise way to ensure their use in a rational and sustainable manner. So the availability of water of good quality is essential for the well-being of the man.

The department of Naâma is a worrying situation where water must be at the center of the concerns of local authorities, management bodies, users, and all citizens. Faced with this situation, and in order to avoid potential conflicts, we must involve all those involved in water, where individual practices must become more aware and more respectful.

The major concern for the sustainable safeguarding of the water resource in these arid regions is to implement a strategy of safeguarding and exploitation rationally by resorting to plan based on short-, medium-, and long-term forecasting models for detecting trends, future patterns of water use, socioeconomic development, and population growth.

7 Recommendations

The rational, optimal, participatory, and sustainable management of water resources represents a forward-looking approach involving the mobilization, exploitation, and protection of this resource in an efficient and competent manner.

The recommendations to be considered at the end of this study should focus on the following areas:

- Undertake the necessary studies (hydrogeological, hydrological, bacteriological analyses) to determine with precision the real water potential across the department, its location, its degree of exploitation, and its economic cost, by estimating the volumes stored and not yet exploited, notably the synclines of Naâma and Ain Sefra, the Ksour Mountains, as well as the Chott-Gharbi and the northeast of Mecheria.
- Learning how to manage the water resource in a perspective of sustainable development is learning to control its scarcity but also its excesses, to ensure the supply of drinking water, agricultural and industrial, to use it for its energy potential, and to preserve the quality of the environment.
- Water development and management should be based on a participatory approach, involving users (users), managers, planners, and policymakers at all levels.
- Quantitative and qualitative assessment of water resources and the planning of the development of hydraulic infrastructures.

– Implement measures to minimize network losses (supply, storage, and distribution) by modernizing and expanding infrastructure.
– Rehabilitation and optimization of infrastructure by better management of pumping stations with a policy of preservation and effective and continuous maintenance of the equipment of dewatering are supervised by qualified personnel and able to provide for any failure.
– Improve the water economy by adapting agricultural practices to local climatic conditions and by using new irrigation techniques.
– Promote water purification technologies, which aim to find the mechanisms for the extension of the rational exploitation of water, the recycling of wastewater (treatment and purification of wastewater), and their exploitation in the agricultural or industrial fields.
– A policy of rational pricing of water is necessary, in particular the implementation of the progressive scale for the large consumers of water.
– Integrating climate change into water resource management strategies.
– Adoption of a strategy to increase the storage of water by the construction of hydraulic structures (dams, dikes and hill dams, etc.).
– Adaptation of the legal and institutional framework of water.
– Develop and improve public information and specialized education and training for integrated and sustainable water management.

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Desalination in Algeria: Photovoltaic Power Plant for TMM (Tahlyat Myah Magtaa) of Oran as a Case Study

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Abstract The relationship between the water used for energy production, including both electricity and sources of fuel such as oil and natural gas, and the energy consumed to extract, purify, deliver, heat/cool, treat, and dispose of water (and wastewater) is sometimes referred to as energy intensity (EI). The relationship is not truly a closed loop as the water used for energy production need not be the same water that is processed using that energy, but all forms of energy production require some input of water making the relationship inextricable. Industry reforms, increasing demand, and more recently climate change are bringing into sharp focus the links between water and electricity in unprecedented ways. Models for climate change indicate that rainfall could decrease by more than 20% by 2050, which would result in even greater worsening water shortages in different basins of Algeria. The construction of 70 dams planned will provide only small additional volumes. The particular challenge for Algeria in the coming decades will be to adapt to a decrease in renewable water resources. The country will have to carefully manage these resources. Mobilization of non-conventional water resources (desalination and wastewater reuse) will be a strategic component of future water policy. The development of unconventional resources and the management of water demand will increase more the energy consumption of the water sector. This consumption would reach nearly 12% of the country's consumption and must be integrated dice now in the country's energy forecasts. More coordinated planning and action will consequently be required between the water and energy sectors if further aggravation of the water deficit is to be avoided. Moreover, the revolution in renewable energy (solar power) in terms of technological development and costs may help reduce the consumption of fossil fuels and ensure reserves for future generations by fostering decentralized renewable energy projects for the energy supply of pumping stations.

The depletion of fossil resources in more or less *long term*, the soaring prices of oil and gas, and the fight against gas emissions (global warming) make urgent control of consumption and diversification of energy sources, a truth that interpellates louder than ever the development of renewable energy. The present chapter focuses firstly on the desalination means as an adaptation option to climate change whose adoption should not intervene in substitution for other possibilities "sustainable," such as the rational use of water. It should also favor the production of drinking water for human consumption. Secondly, the chapter also studies the option of using photovoltaics in the desalination plant of El Magtaa (Oran) as a contribution means to achieve the target of 27% of electricity consumption from renewable sources in the country. The third objective is a comparative study (cost of water output) between the use of photovoltaic and the central grid of Sonelgaz.

Keywords Cost of water, Desalination, Energy, Photovoltaics, Renewable, Solar power

1 Introduction

The interdependency between the world's two most critical resources, water and energy, is receiving more and more attention from the academia as well as the general public. A comprehensive and in-depth understanding of the water-energy nexus is essential to achieve sustainable resource management.

It is also clearly evident from the above discussion that the nexus is multidimensional. The studies also suggest that the dimensions influence each other, quite often antagonistically.

The economic dimension of the water-energy nexus is gaining in prominence, due in part to reforms occurring in both industries. In Algeria, the reforms have brought about changes to the structure, ownership, and regulatory arrangements in both industries. The industries have been functionally unbundled, competition has been introduced in the competitive segments, and monopoly segments have been opened to third-party access. Further, pricing policies have shifted from the support of subsidies to full cost recovery. In the electricity industry, a national electricity market was established across the eligible electricity customers (HT). In the water sector, an urban water market was created (ADE, SEAL, and SEOR) to distribute water users and promote the effectiveness of water (Act of 4 August 2005 on water) [1].

In the electricity sector, the wholesale market and the long-term contract prices have increased significantly through the CREG (Law No.02-01of 5 February 2002).

Water is something of a rare commodity in Algeria. Renewable natural water resources are estimated at approximately 15 billion m^3 per year, which is approximately 404 m^3 per capita per year, near the threshold of 500 m^3 per capita per year, which is widely recognized as the scarcity threshold that indicates developing scarcity and underlying crises.

Nevertheless, the Algerian water sector is facing several limitations and problems which could, if not properly handled, limit the dynamic of economic growth that Algeria is looking for by launching a huge range of large-scale projects. These limitations and problems relate primarily to decreased water resources due to the impact of climate change which has become a reality in Algeria and whose effects on our environment are already visible.

The future development of water resources depends on solutions characterized by high energy consumption, for example, seawater desalination, the reuse of wastewater, and the introduction of drip irrigation. The development of the water sector will therefore be closely tied to the development of the energy sector.

This sector must conduct a large-scale program of studies to understand the current and future impact of climate change, identify and quantify associated costs and its interactions with water and energy, and specify adequate solutions for adaptation.

This chapter provides for Algeria an inventory of water resources, water demands, and energy, presents the strategic development of the sectors of water and energy, and analyzes the interactions between water and energy.

Energy is the basis of all human activity. Today, much of the global demand for energy is provided from the limited supply of fossil fuels. Some developed countries have turned to nuclear energy, while this can pose risks of serious accidents.

The production of electricity using a photovoltaic system connected to the grid is of great interest to developing countries, especially for countries suffering for these last years from the quality of their central grid.

Photovoltaic can have undeniable advantages, particularly for its cleanliness and durability. Also, it can be used in various applications such as agriculture, desalination, etc.

In this context, this study is a contribution to the design and integration of renewable energy sources in the central power grid, particularly in areas of high human concentration.

This study is an initial step in the project to design a photovoltaic plant for desalination station “El Magtaa” of Oran in Algeria.

Such project certainly requires huge investments which will surely influence the cost of m^3 of water produced. To reduce this cost, we were interested by:

- Local products (Algerian photovoltaic technology) particularly those of Condor Electronics [2]
- The optimization of consumption of electrical energy in the station by energy recovery and automation of circuits (Algerian Desalination Program 2010, [3])

2 Water in Algeria

2.1 Resources

2.1.1 Non-conventional Water Resources

Non-conventional water resources offer a significant water resource potential in Algeria. They involve reusing wastewater, artificial recharge of groundwater, and freshwater production through the desalination of seawater or demineralization of brackish water. The Algerian National Water Resources Strategy estimates the volume of water that could be exploited from non-conventional water resources at over 2 billion cubic meters.

Wastewater Potential Document of Algerian Ministry of Water Resources [4]

Park of sewage treatment plants

In operation:

- Total = 145
- Total treatment capacity = 12,000,000 EQH
- Volume = 800 Hm^3/year

In progress:

- Total = 106
- Total capacity of treatment to the end of 2012 = 7,965,058 EQH
- At the end of the current program in 2014 = 1.2 billion m^3/year

Seawater Desalination

Desalination has overcome technical difficulties and is now a viable, economically competitive, and technologically achievable alternative for drinking water or agriculture and the irrigation of some profitable crops. The reverse osmosis technique now used involves passing seawater at a pressure of 70 bars through a special membrane to produce freshwater. This technique has made a significant contribution to reducing operational costs, such that it has been adopted by a large number of countries as the method of choice.

- Desalination is now technically feasible. It provides a reliable resource that can be assessed in advance, making it possible to plan investments and construction projects better.
- Desalination facilities can be built using a BOOT (Build, Own, Operate, and Transfer) system.
- Desalination facilities can be built quickly (12–24 months including the design stage).

Algeria is only just starting to produce freshwater by desalination or demineralization (2005). Overall production capacity is already around 2,310,000 m^3 per day.

Seawater desalination may be the most appropriate solution to the situation faced by many regions in Algeria to plug the gap between water demand and supply (See Table 1).

Table 1 Stations of desalination of seawater (Algerian Desalination Program 2010, [3])

Region	Localization	Capacity (thousandm^3/day)	Status
West	Arzew/Oran	90	Aug 05
	Souk Tlata/Tlemcen	200	May 11
	Honaine/Tlemcen	200	July 12
	Mostaganem	200	Sept 11
	Sidi Djelloul/Ain Temouchent	200	Dec 09
	Magtaa/Oran	500	Work in progress
Center	Hamma/Alger	200	Feb 08
	Cap Djinet/Boumerdes	100	Aug 12
	Fouka/Tipaza	120	July l, 11
	Oued Sebt/Tipaza	100	SDEM not launched
	Tenes/Chlef	200	Work in progress
East	Echatt/El-Taref	100	SDEM not launched
	Skikda	100	Mar 09
Total		2,310	

The national strategy estimates the contribution of seawater desalination at approximately 1,000 Mm^3 by 2030 (Presentation of Algerian Ministry of Water Resources in Cairo).

Brackish Water
In Algeria, around a quarter of groundwater is, either in whole or in part, brackish water. This water is mostly situated in the country's desert and semi-desert regions.

Exploitation of brackish water resources began in 2000.

The volume of brackish water mobilized is estimated at 510,160 hm^3/year whose 160 hm^3/year are used to satisfy the drinking water supply.

Twelve (12) stations are operating in the provinces of Tlemcen, Oran, Tizi Ouzou, Bejaia, Illizi, Biskra, Ouargla, Medea, and Ain Defla. The production of drinking water is 24.2 hm^3/year [8].

Also, 241 hm^3/year of brackish water will be demineralized from a mobilized volume of 464 hm^3 through 35 stations which are actually under study and work (included in different programs). The overall capacity of stations is 91.5 hm^3/year. Overall throughput mobilized in upstream exceeds 428.9 hm^3/year.

The situation is as follows [8].

- In study: 06 stations (Tamanrasset 4, El Oued 2) with 04 stations whose studies were completed (Tamanrasset 2 and El Oued 2)
- Study and realization: 01 station (Bechar)
- In works: 12 stations (10 Ouargla, El Oued, and Tamanrasset (ADE))
- Launching work in progress: 02 stations of ADE (Tindouf and Illizi)
- Installation of mono-blocks: 15 stations (El Oued) whose 01 station was completed and commissioning (Réguiba C.)

2.2 *Current Use of Non-conventional Water Resources*

Since the 1990s [1], Algeria has adopted an appropriate policy of water resources development focused on the construction of dams which has provided drinking water supply security for all the towns and cities in the country and made it possible to develop approximately 1,234,985 ha of irrigated land, of which approximately 228,787 ha are part of large irrigated areas [4].

This supply policy means water infrastructure of 84 large dams (19 under construction), a storage capacity of 8.9 billion m^3 (96 dams planned for 2016), 10 water transfer structures, and large structures for abstracting groundwater are now available (See Table 2).

This water infrastructure has been designed and built to provide an overall volume in the region of 10 billion m^3 in a year with average rainfall year.

This infrastructure provides significant benefits to the Algerian economy. This can be seen in the strategic role of the contribution of the sectors associated with dams to the country's water and food security, the growth in farmers' incomes, employment, the opening up of different regions, and access to various public services (drinking water, etc.).

Table 2 Major transfer systems (North-North/North-South/South-South)

Transfer systems	Destination (Wilayas)	Capacity of treatment (m^3/day)	Population (M inhab)
Beni Haroun	Constantine-Mila-Jijel-Batna-Khenchela	440,000	4
Teksebt	Alger-Tizi Ouzou	600,000	5
Mostaganem-Arzew-Oran(MAO)	Mostaganem-Oran	560,000	1.5
Koudiat Aserdoune	Bouira-Medea-Tizi Ouzou-M'sila	346,000	2
Tichy Haf	Bejaia	120,000	1.5
Mexa	El Taref-Annaba	173,000	1.5
In Salah-Tamanrasset	Tamanrasset	100,000	0.45
Sétif High Plains East Lane West Lane	Sétif Sétif	136,000 191,000	0.75 1.107
Chott El Gharbi	Tlemcen-Naama-Sidi Bel Abbes	71,000	0.25
South Highlands	Djelfa-M'sila-Tiaret	350,000	6.15

Table 3 Drinking water sector indicators [5]

Indicators	1999	2011	2012
Linear drinking water systems (Km)	50,000	102,000	105,000
Connection rate	78%	94%	95%
Staffing (liter/day/capita)	123	170	175
Water production (million m^3/year)	1,25	2, 9	3, 1
Frequency distribution daily 1 day per 2 1 day per 3 and more	45% 30% 25%	73% 17% 10%	75% 17% 08%

Source: Note PNE, Jan 2013

2.2.1 Drinking Water

Over the last three decades, the Algerian government has operated an ambitious policy of securing drinking water supply to all in towns and cities, reaching a coverage rate of 95% in rural environments.

The drinking water production capacity for urban areas multiplied by 2.5 between 1999 and 2012, reaching 3.1 billion m^3 per year [5].

Everyone has access to drinking water in urban areas. The urban population served now exceeds 36 million inhabitants, 95% of whom are supplied by individual connections.

The Table 3 summarizes the progress made in the drinking water sector.

2.2.2 Sanitation and Wastewater Treatment

The sanitation sector in Algeria lagged significantly behind until 2000, due to the low priority given to wastewater management issues and operator regulation.

As part of the Millennium Development Goal associated with sanitation, Algeria produced a National Program for Liquid Sanitation and Wastewater Treatment (PNA) in 2005. The result of the investigation into the sewage system at the end of the second half of 2012 reported 43,000 linear network kilometers in service. The national average connection rate calculated on the basis of the average connection rate of 48 provinces is 87%, for a total volume of wastewater discharged of 1.2 billion m^3/year [8].

Since its launch, a significant quantitative step has been made in terms of numbers of sanitation and wastewater treatment projects and the volume of investment in this sector. The government's political will was implemented with increased financial resources allocated to the PNA under the Algerian Finance Acts, and contributing partners showed a keen interest in this program and agreed on funding and significant assistance to get it launched.

The impact of this program can be summarized as follows:

- Reduced pollution on the Mediterranean and Atlantic coast, since almost all wastewater from towns and cities discharged into the Mediterranean Sea and the Atlantic Ocean will be treated.
- Almost all wastewater discharged from towns and cities into watercourses will be treated. Treatment of this wastewater and taking into account the environmental aspect of water resource management will lead to an improvement in surface water quality.
- Increasing the water potential which could be used in the development of irrigation. The National Water Resources Strategy, defined in 2009, estimated this potential at approximately 1.2 billion m^3 per year in 2014 to be reused in watering golf courses and green spaces as well as for irrigation of crops that are suited to it.

2.3 Future Water Demand for the Supply of Drinking and Industrial Water

Forecasts for future domestic water use are based on population growth, rural to urban migration, and water demand per capita projections.

Overall, drinking, industrial, and tourist demand forecasts for the whole of Algeria by 2030 are evaluated at 3.5 billion m^3 (See Table 4).

2.4 Non-conventional Water Resources Projection

Non-conventional resources primarily consist of artificial groundwater recharge, seawater desalination, and treated wastewater.

The Algerian National Strategy for Development of Water Resources gives a significant place to the exploitation of non-conventional water resources.

Table 4 Current needs of drinking water per basin (Mm^3) [24]

Basin	Volume (Mm^3)	Satisfaction rate (%)
Oranie – Chott Ech Chergui	396	52.5
Cheliff – Zahrez	558	78
Algérois – Hodna – Soummam	927	89
Constantinois – Seybouse – Mellegue	794	83
Sahara	225	57
Total	2,900	76.75 (Average)

Table 5 Forecasting of unconventional waters for 2030 per basin in Mm^3 [6]

	2011		2030	
Basin	Wastewater	Desalination	Wastewater	Desalination
Oranie	153.33	383.432	In study	In study
Cheliff	99.23	111.325	In study	In study
Algérois	293.00	276.743	In study	In study
Constantinois	166.54	053.400	In study	In study
Sahara	87.90	0	In study	0
Total	800	824.900	2,000	1,000

This strategy estimated the proportion of this resource at around 1.624 billion m^3 per year, of which 824 Mm^3 are from seawater desalination and around 800 billion m^3 are from wastewater.

The forecasts are levels in 2030 to nearly 3 billion m^3. This water potential is intended to be used for watering green spaces and sports fields and developing irrigation around urban areas.

The Table 5 presents the anticipated contribution of desalinated seawater and treated wastewater.

3 Electricity in Algeria

In Algeria, the forecast for electricity demand is established by the system operator (SO) Sonelgaz Subsidiary.

Based on the country's energy policy, the OS matches supply to demand in two steps:

- An initial step to study electricity demand
- A second step to define an equipment program to satisfy that demand at the lowest possible cost

Study of the Demand

In general, the SO conducts a detailed analysis of past consumption trends (at the national level, by sector, by branch, by voltage level, etc.) to shed light on the different factors that determine demand and assess how they affect it.

1. Retrospective analysis of demand

First, a retrospective analysis of the demand is developed. Generally, a 20-year period is considered for the analysis of overall electricity consumption to detect an overall trend and variation in average annual growth. This variation is compared to the average rate of economic growth during the study period and to population growth [9].

The analysis is based on:

- A calculation of the elasticity of the electricity demand to GDP
- A comparison of the population trend index, GDP, and electricity consumption over the period studied
- An analysis of electricity consumption per capita, considered as representing the economic and social dynamics in Algeria
- An analysis of the characteristics of the electricity demand, overall and by sector

The OS finds that the electricity sector has registered a steady increase in demand over the last decade, due mainly to the increasingly widespread electrification of the country, to government urbanization efforts, to the improvement in household incomes, and to the implementation of large-scale infrastructure projects in various regions of the country.

The relevant OS departments examine the fine detail of changes in demand at peak times and seek to highlight the main reasons for these changes, largely caused by a sharp increase in residential consumption.

The OS's electricity sales history is broken down automatically and a customer analysis performed, making a distinction between OS direct clients and distributors' clients (state distribution companies and concession holders). The impact of the different energy saving campaigns and actions is also considered.

Over the last 20 years (1992–2012), overall electricity consumption has more than tripled, far exceeding economic and population growth.

The elasticity of electricity demand to GDP, estimated over this period, is almost two units. Over a period of two decades, the growth rate of electricity consumption has continuously exceeded GDP and population growth rates, and the difference has become more pronounced since 1998 [9].

For the same period, electricity consumption per capita increased from 721.53 kWh per capita in 2001 to around 1,406 kWh per capita in 2012, equivalent to an average annual increase of 6.25%. The graph below traces these developments.

Moreover, between 2002 and 2012, electricity demand increased from 20.53 to 54.09 GWh, reflecting an average annual growth rate of approximately 9.5%. (See Figs. 1, 2 and 3).

2. Projected electricity demand

Projections of demand are established over long periods and revised for short- and medium-term periods.

For the short term, demand forecasts are automatically revised to reflect the needs expressed by the different client segments, whether direct clients or those of public or private distributors.

For the medium and long term, forecasts of changes in electricity consumption reflect a combination of various types of factors relating to the economic activity, demographics, user behavior, technical progress, development of new uses of electricity, the relative market shares of energy, and energy conservation.

Planning to incorporate these factors into long-term forecasts is based on a detailed breakdown of electricity consumption into segments, performed as follows:

There is an initial distinction between the industrial, service, and residential sectors in total consumption.

Within these areas, further divisions are made, by a branch of economic activity (agriculture, manufacturing, etc.) and by use.

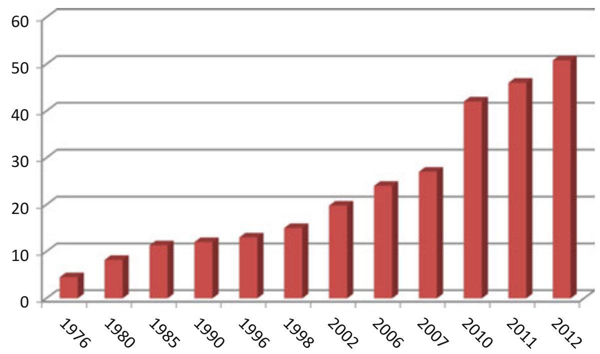


Fig. 1 Evolution of the power consumption (Twh)

It should be noted that this growth has been uneven, however, as illustrated in the graph below: moderate growth between 2000 and 2005, followed by a period of burgeoning demand for electricity from 2006 to 2012, with an annual average of 10% reflecting the economic and social dynamism experienced by Algeria, in particular in terms of increased access to basic infrastructure.

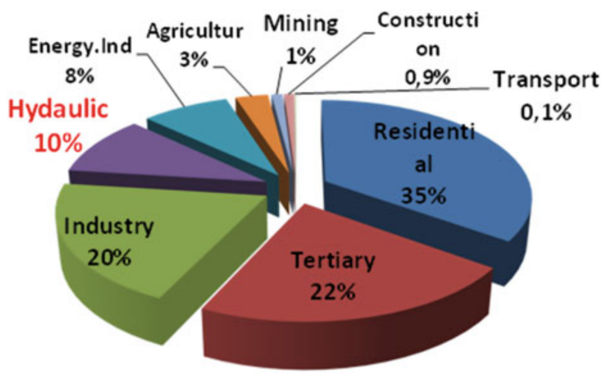


Fig. 2 Distribution of electricity consumption by activity sector in the year 2011

The peak maximum power demand increased from 3,913 MW in 2001 to 8,850 MW in 2011 and 10,464 MW by 2013. This represents an average annual growth rate of 8% over the first 10 years (2001–2008) and 12% for the second period (2009–2013). In 12 years, the peak maximum power demand has thus experienced an average annual growth rate of 9.35%.

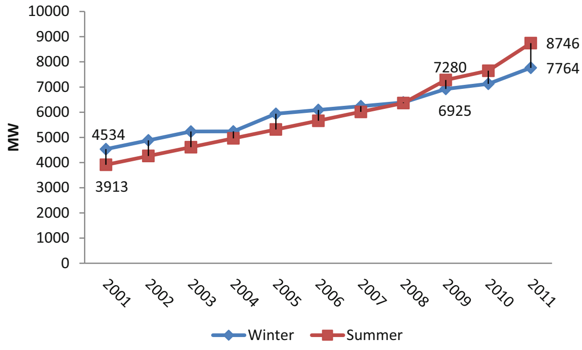


Fig. 3 Electricity demand growth rate trend

For each branch or use, characteristic technical-economic variables are identified in order to calculate energy consumption (ownership rates, unit consumption of appliances, number of households, neighborhood, etc.).

From this detailed segmentation analysis, the choice of assumptions about changes in characteristic descriptive variables can be used to predict consumption for each branch or use. The consumption forecasts thus obtained for the different segments are then aggregated to arrive at forecasts for each sector.

To guard against the growing uncertainties about changes in the energy and socioeconomic environment, three macroeconomic scenarios are considered, selected on the basis of the report from the Algerian High Commission for Planning, entitled "Economic growth and human development: Elements for strategic planning 2011-2017" [9].

By 2017

The "emergency scenario" was adopted as a baseline for developing the equipment plan. This scenario predicts a 7% increase between 2012 and 2017, leading to a net energy demand of 75.79 TWh by 2017. In this scenario, growth is driven mainly by the development of services and tourism in the service sector and by construction in the secondary sector. Growth in the residential sector is also extremely strong as a result of demographics, urbanization, and, especially, the development of new specific uses.

The "economic efficiency prioritization scenario" involves an 8% growth rate of net energy demand between 2012 and 2017, resulting in net energy demand of 79.4 TWh by 2017.

The "exhaustion scenario" predicts a 6% energy increase between 2012 and 2017, limiting consumption to 72.32 TWh in 2017 [10].

By 2020

A "segmentation" study, through the identification and consideration of different factors explaining the changes in electricity demand, conducted by Sofreco, analyzes the economic and social contexts that prevailed during the past period and plausible future changes for Algeria, in the light of its potential but also regional and international opportunities and constraints.

The study was set in the context of the scenarios mentioned above. Each of these identifies a plausible situation that could describe possible future electricity consumption trends.

These three scenarios were constructed based on the determining factors considered as explanatory of the electricity consumption of the different sectors.

Thus, the emergency scenario is characterized by 6% annual growth between 2017 and 2020; the economic efficiency prioritization scenario would involve an annual growth rate of net energy demand in the region of 7.2%; the exhaustion scenario would see an average annual increase of 5.2%.

By 2030

It is assumed that by 2030 a form of saturation will have occurred in a number of sectors of economic activity, that consumption in the residential sector will have stabilized, and that tangible effects of the energy efficiency policy will be felt throughout the country.

At this point, then, the emergence scenario would be limited to the growth of 4.2% per year and the economic efficiency prioritization scenario, 5.5% per year, and the exhaustion scenario would not exceed an average annual rate of 3.5%.

The growth in consumption at the various dates quoted above is summarized in Table 6.

Study of the Supply

The aim is to develop a production facilities equipment program to meet, at minimum cost and according to predefined quality and continuity of service criteria, changes in demand.

The development of the equipment program takes account of:

- The continued development of national primary energy resources
- The diversification of external fuel supply sources
- The quest for greater energy efficiency

It is determined by minimizing the sum of the following discounted costs:

- Investment costs
- Operation and maintenance costs
- Fuel costs
- Cost of energy not served

It takes into account a number of constraints and criteria, including:

- Satisfaction of priority irrigation and drinking water needs
- Satisfaction of energy demand

Table 6 Projected electricity demand in TWh [26]

Date	2012	2017	2020	2030
Exhaustion scenario	54.04	72.32	93.18	110.67
Emergence scenario	54.04	75.79	101.42	124.58
Efficiency scenario	54.04	79.40	112.40	146.90

- Monitoring fluctuations in power demand (load curve)
- Planned and unplanned outages
- The reserve margin

The Electric Power Supply

In late 2011, the total installed capacity of the generating facilities was estimated at 11,389.8 MW. The park existing at that date is detailed in Table 7.

The installed capacity increased from 1,852 MW in 1980 to 5,600 MW in 2001, peaking at 11,389.8 MW in 2011. This resulted in an average increase in capacity of 178.5 MW per year between 1980 and 2001 and of around 526.35 MW per year between 2001 and 2011. The additional capacity changes in increments that are easier to view in Table 8.

New Electricity Strategy

The Algerian power sector is facing many challenges related to security of supply, diversification of energy sources, organizational and legal aspects, as well as strategic planning.

For this reason and in accordance with the country's government guidelines, the Ministry of Energy named the electricity sector as one of its major concerns to be addressed as part of a vision for the future. The aim is to set as a priority, the adoption of an electricity policy that will generate action plans designed on the basis of a clear vision for reform. These plans are broken down into concrete measures and feasible projects. The overall aim is to ensure competitive power supply in the service of the national economy at all times.

The Ministry of Energy and Mines has involved a broad range of national and international experts along with all stakeholders, to develop documented, widely

Table 7 Distribution of total electricity production in 2011

Type of equipment	Production GWh	Rate (%)
Steam turbine	9,653.7	19.8
Combined cycle	15,701.3	32.1
Gas turbine	22,055.3	45.1
Hydraulic	378.3	0.8
Diesel	463.9	0.9
Hybrid site	618.7	1.3
Total	48,871.2	100

Table 8 Changes in installed capacity

Capacity of production (MW)	1980	1990	2001	2010n	2011
Sonelgaz (SPE)	1,852	4,567	5,600	8,446	8,503.8
Independent	–	–	–	2,886	2,886
Total	1,852	4,567	5,600	11,332	11,389.8

shared visions of three elements that constitute the foundations of the national power strategy:

- Changes in domestic demand and potential major discontinuities
- The advantages and constraints specific to Algeria
- The economic and technical characteristics of the available power generation technologies

3.1 New Opportunities

- Considerable Solar Resources
  - With more than 3,600 h per year of sunshine, equivalent to irradiation of 6 kWh/m^2 per year, Algeria has a high solar capacity (average equivalent to Southern Europe).
  - Especially high potential in underserved areas in terms of grid and power production capacity.
  - Particularly attractive cost (9% below the reference cost) (See Fig. 4).

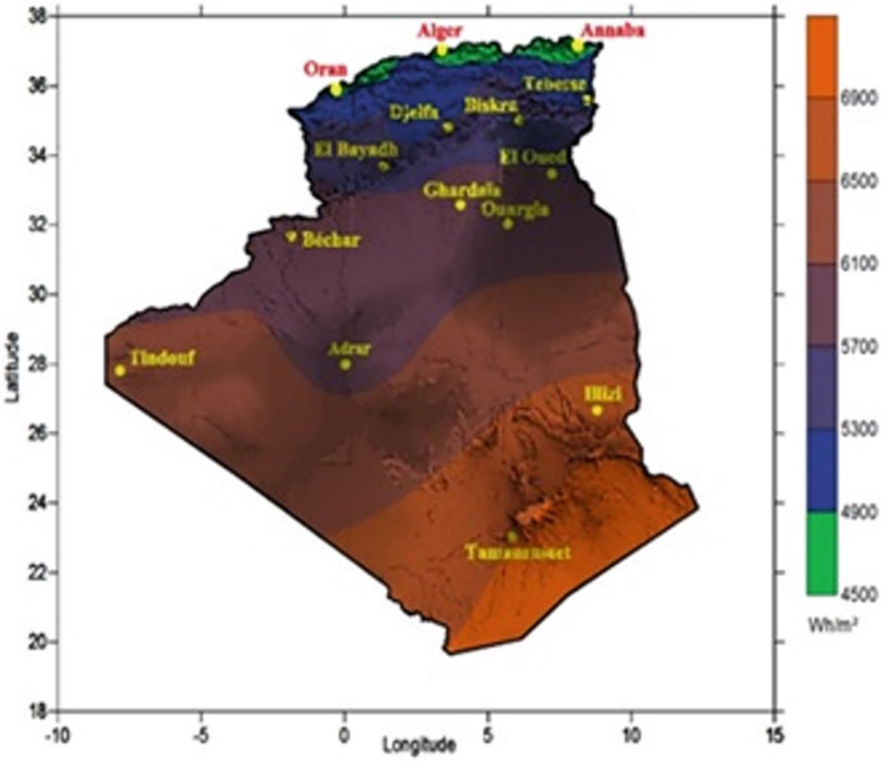


Fig. 4 Average annual irradiation in Algeria [28]

Table 9 Projects 2013–2017

Planned sites	Combined cycle (MW)	Gas turbine (MW)	Total (MW)
West region			
Mostaganem (new site)	800	400	1,200
Naama (new site)	800	400	1,200
Boutlelis (extension)	300	–	300
Total	1,900	800	2,700
Center region			
Hadjret Ennous (new site)	800	400	1,200
Djelfa (new site)	800	400	1,200
Boufarik (MAPNA) (extension)	–	300	300
Total	1,600	1,100	2,700
East region			
Kaïs (new site)	800	400	1,200
Biskra (new site)	800	400	1,200
Ain Djasser (extension)	–	250	250
Total	1,600	1,050	2,650
Total general			
Region	Combined cycle (MW)	Gas turbine (MW)	Total (MW)
West	1,900	800	2,700
Center	1,600	1,100	2,700
East	1,600	1,050	2,650
Total	5,100	2,950	8,050

3.2 Meeting Demand

3.2.1 Meeting Demand for 2013–2017

To meet the demand for electricity, Sonelgaz has programmed an additional power of 8,050 MW by the realization of projects listed in Table 9.

In addition to this power, there are other projects already decided, and their tenders have been launched (See the table below and Fig. 5) [19]:

Site	2013	2014	2015	2016
Labreg (GT)	1 × 171 MW GT	2 × 171 MW GT		
Ain Djasser 2 (GT)	2 × 132 MW GT			
Boutlelis (TG)		2 × 258 MW GT		
Hassi Messaoud (GT)			4 × 150 MW GT	
Hassi R'Mel (GT)			2 × 150 MW GT	
Ras Djinet 2 (CC)				3 × 400 MW CC
Ain Arnat (CC)				3 × 400 MW CC
Total (MW)	435	858	900	4,400

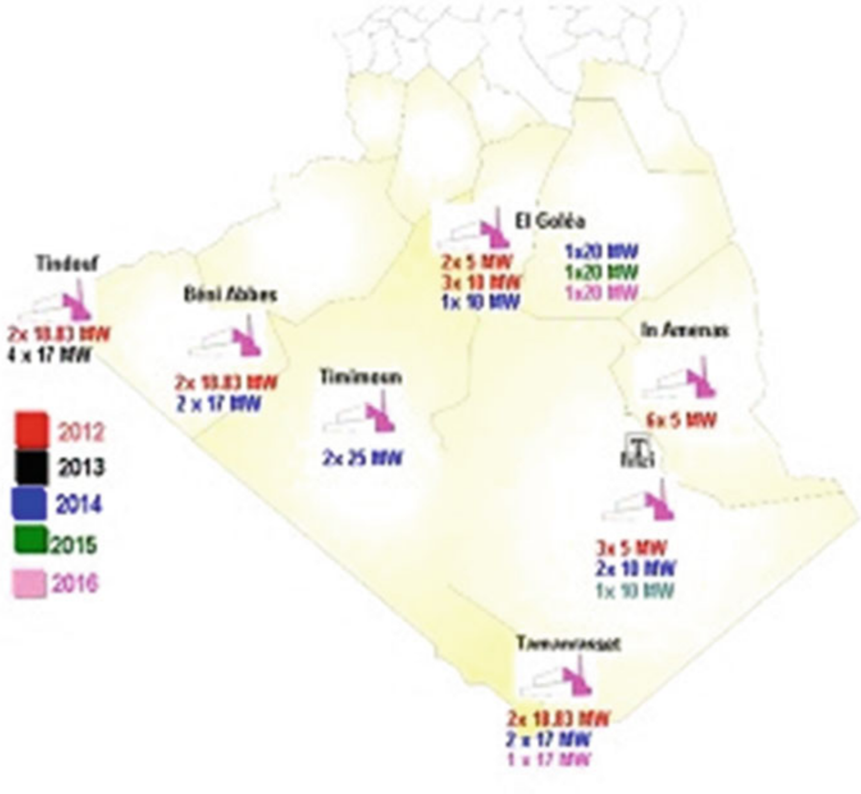


Fig. 5 Sites in progress of realization in the South of Algeria

3.2.2 Meeting Demand Beyond 2018 [11]

The additional capacity planned for the period 2013–2023 will amount to 35,505 MW, of which 21,305 MW are decided and 14,200 MW in project idea (conventional type) [11].

The 21,305 MW already decided consist of:

- 5,539 MW of renewable energy
- 14,370 MW of conventional for the Interconnected Grid of North (IGN)
- 50 MW of the gas turbine to In Salah – Adrar – Timimoun
- 421 MW of gas and diesel turbines for the Isolated Grid of South (IGS)
- 925 MW for strategic mobile reserve

The total development program for the production of electricity 2013–2023 will amount to more than 4,791,391 million dinars (more than 2,664,878 million dinars for renewable).

14,370 MW of additional capacity are under construction on the 2013–2017 period, of which 1,140 MW are of Koudiet Eddraouech site (SKD).

Additive to a conventional park, it is expected the realization by SKTM (Shariket Kahraba wa Taket Moutadjadida, subsidiary of Sonelgaz group) of a renewable energy park of 5,539 MW distributed as follows:

Interconnected Grid of North (IGN): 5,084 MW of renewable energy planned from 2013 to 2023 which can be carried out in collaboration with the SSB (Sahara Solar Breeding) project, for example

Isolated Grid of South (IGS): 167 MW of renewable energy planned from 2013 to 2023

In Salah – Adrar – Timimoun: 288 MW of renewable energy planned from 2013 to 2023

Beyond 2023, the various types of electricity generation will be investigated, and the necessary decisions will be taken at the appropriate time, wind farms, solar farms, natural gas power plants, or even the hydroelectric sites.

For Renewable Energy [12]

Until 2030, it is planned to install a capacity of nearly 12,000 MW with 10,000 MW of export opportunity.

The development of renewable energy is a major component of Algeria's New Energy Strategy, aimed at securing supply, ensuring availability, and reducing the nation's energy dependence.

Algeria has great renewable energy potential. Exploiting it will cover a substantial part of its growing energy needs and help protect the environment by replacing fossil fuels.

As the technologies mature and their production cost becomes more competitive, the contribution of renewable to the energy mix will expand gradually.

3.2.3 International Trend

A favorable world market:

- An environment conducive to the development of renewable energy.
- Technologies in continual development, tending to reduce investment and operating costs and produce competitive kWh or Btu.
- Uncertainty and extreme volatility of fossil fuels.
- Environmental awareness and the fight against global warming.
- A competitive cost per MW for some renewable (including wind) and a downward trend in the medium and long term for others.
- A high-potential market for wind, solar thermal, and photovoltaic.
- More than US$ 60 billion invested in 2007 in renewable energy projects worldwide 5.
- A CO2 emissions market of approximately US$ 233 billion in 2050 (compared to US$ 60 billion in 2007).
- The total installed capacity in late 2007, all segments combined, was estimated at around 240 GW, excluding large-scale hydropower, equivalent to nearly 6% of global electricity capacity.
- Wind farms in 2007 totaled almost 100 GW, with the average annual growth of 25%.
- 50 million households worldwide have solar water heating systems, 65% of which are in China. The annual growth in this market is between 15% and 20%.
- 2 million geothermal heat pumps installed.
- Grid-connected solar photovoltaic is growing constantly.
- Biodiesel generation is under development.

The annual flows of investment in "renewable energy" technology per period in billions of USD are shown in the Table 10.

1. Constraints to developing renewable energy

Current Situation

- Capacities for developing renewable energy projects extremely limited compared to the identified potential
- Marginal contribution of foreign funds
- Limited government incentives

Table 10 Annual flows of investment in renewable energy technologies

	2003–2010	2010–2020	2020–2030	2030–2040	2040–2050
Hydro	41.7	34.1	24.7	24.1	20.6
Wind	19.8	79.4	84	36.7	41.6
Photovoltaic	11	35.2	79.4	78.3	77.3
Thermal solar	0.7	11.3	43.6	49	49.7
Marine	1.1	2.8	2.7	3.1	2.7
Total	74.3	162.8	234.4	191.2	191.9

Constraints

- Lack of legislative and regulatory framework concerning the development of renewable energy
- Renewable energy low on the priority lists of national infrastructure development programs
- Competition from subsidized energy sources: e.g., butane and fuel oil
- Low level of information and awareness among the general public
- Lack of research and development that could lead to innovation and technological adaptations
- "Project" approach not creating visibility for potential investors or deployment of suitable financial mechanisms
- Budget allocations and financial incentives insufficient for real development of the economic, social, and environmental added value of renewable energy

2. Renewable energy development strategy
   The new energy vision is structured around the following points:
   - Renewable energy: a major aim of the New Energy Strategy
   - A diversified national energy mix aimed at developing renewable energy on a market basis using four strategies:
     – Progressive development of power purchase agreements (PPA)
     – Promotion and development of large-scale projects for exporting green power
     – Development of self-production
     – Strengthening the capacity of the grid
   - Contribution to reducing energy dependence
   - Controlled expansion of energy resources to support economic development
   - Positioning Morocco in regional and international renewable energy and energy efficiency markets
   - Development of renewable energy equipment and facilities industry
3. The objectives of the new strategy
   - Contribution to diversifying and securing supplies
   - Sustainable human development: widespread access to energy and creation of income-generating activities
   - Control of energy costs to ensure the competitiveness of domestic production
   - Optimization of the electric load curve
   - Environmental protection: control of growth in greenhouse gas emissions, 60% of which is from energy production
   - Conservation of natural resources: water, forest cover, biodiversity, combating desertification
   - Economic development and investments
   - The industrial rise of a new sector, regional positioning to win
   - Increased mobilization of international cooperation and strengthening regional partnerships (Euro-Mediterranean, African, Arab)

4 Energy Needs for Water

Electrical energy is used mainly for the operation of pump and injection stations for drinking, industrial and irrigation water, drinking water treatment plants, and activated sludge wastewater treatment plants. It is also used for lighting and for pumping in marine outfalls (See Fig. 6).

Overall, the water sector in 2011 consumed around 4,983 GWh. This consumption is set to rise to 16,090 GWh by 2030 (0.7–0.8 kWh/m^3), more than three times the consumption of 2011. This predicted increase is mainly due to:

- The use of energy-intensive solutions – e.g., seawater desalination and the water transfer project.
- Use of conventional, high energy-consuming resources to meet water demand. This is the case of water pipes for drinking water supplying the cities.
- Development of sanitation and wastewater treatment activities (See Table 11).

4.1 Current Need

These needs, collected from water users, seem to be in the region of 4,983 GWh, or 0.44 kWh/m^3.

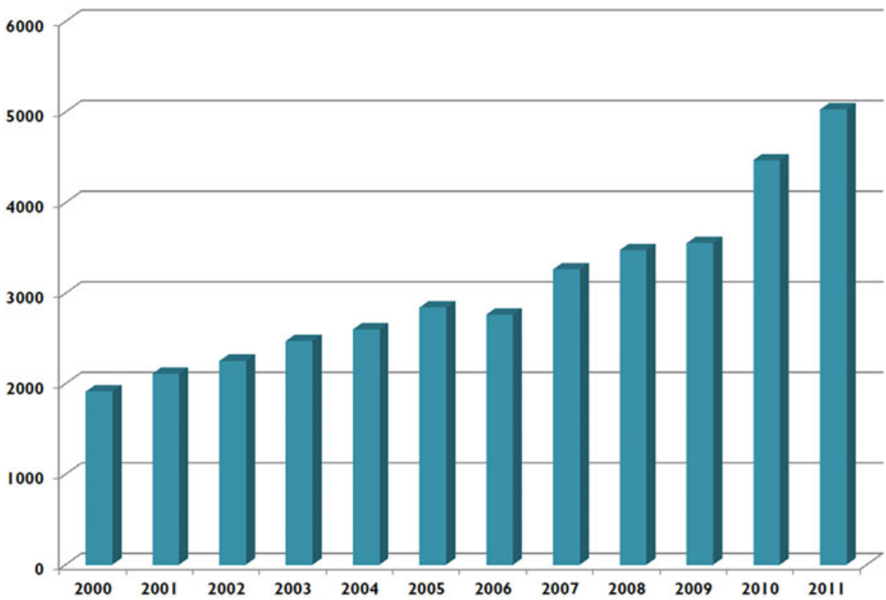


Fig. 6 The evolution of consumption in GWh (International Symposium of the 9th edition SIEE-Pollutec 2013)

Table 11 Evolution of energy consumption in the water sector

Sector	2011		2030	
	Water (Mm^3)	Energy (GWh)	Water (Mm^3)	Energy (GWh)
Drinking and industrial water (with desalination)	2,900	2,606	3,500	5,700
Irrigation	8,600	1,513	15,400	9,193
Sanitation	1,000	331	1,200	397
Wastewater reuse	800	533	1,200	800
Total	12,300	4,983	20,100	16,090

4.2 *Energy Needs by 2030*

These energy requirements were evaluated on the basis of current needs and the provisions adopted regarding usage of conventional and unconventional water resources, water saving programs, drinking water generation programs, sanitation and wastewater reuse programs, and programs aimed at water conservation and expansion of irrigation.

4.2.1 Drinking Water

Energy requirements were estimated on the basis of current needs and drinking water supply projects adopted in connection with planning studies. These energy needs are estimated at around 2,606 GWh, or 0.90 kWh/m^3:

- Seawater desalination, These needs are estimated at approximately 1,642 GWh, or 3.7 kWh/m^3.
- Use of energy-consuming drinking water supply systems.

4.2.2 Sanitation

Electrical energy is used mainly for the operation of activated sludge wastewater treatment plants (in lagoon-based wastewater treatment plants (WWTPs), it is used for pumping and sometimes for treatment), for network pumping, and for lighting. It is also used for pumping in marine outfalls.

The electrical energy estimate is based on the following assumptions:

- The activated sludge purification process was adopted for WWTPs serving more than 100,000 inhabitants. The power consumption for these WWTPs was calculated on the basis of 1 kWh/kg BOD5 eliminated.

- The lagoon-based purification process was adopted for all other towns and cities. The power consumption for these WWTPs is negligible. The National Sanitation Plan has estimated this consumption at around 10% of the consumption of WWTPs that use activated sludge.

On this basis, the National Water Plan estimated the energy requirements for sanitation and wastewater treatment at 397 Gwh by 2030.

This data does not take into account energy needed for wastewater reuse (additional treatment, pumping water to the place of use, etc.).

4.2.3 Irrigation

Overall, the water needs of the agricultural sector are estimated at around 9,193 GWh per year. The assumptions used in estimating these water needs can be summarized as follows:

- Current (2011) energy needs of agricultural areas are estimated at 1,513 GWh per year [31].
- The energy requirements of extensions to agricultural areas.

4.2.4 Wastewater Reuse

Overall, the energy requirements of wastewater reuse projects are estimated at around 800 GWh, or 0.7kWh/m^3.

The assumption used to estimate this need is:

- Reusing a volume of treated wastewater in the region of 1,200 Mm^3 per year for watering golf courses and green spaces as well as for irrigation of those crops that are suited to it

5 Desalination Station of El Magtaa (TMM) of Oran as a Case Study of Photovoltaic Power Plant

TMM which stands for “Tahlyat Myah Magtaa” is a project of stock company established for the desalination of seawater by reverse osmosis on the site of Marsat El Hadjadj plant in Oran [25] (See Table 12).

The principal shareholders of TMM are Hyflux Singaporean Society with 49% of the social capital and AEC Algerian Energy Company with 51% of the capital.

Table 12 Datasheet of TMM [7]

Location	District MARSAT El Hadjadj common Magtaa, Oran
Project owner	Tahlyat Myah Magtaa stock company
Constructor	Hyflux (Singapore)
Operator	Hyflux OMA
Treatment process	Reverse osmosis with energy exchanger
Production capacity	500,000 m^3/day
Power consumption	3.2 kWh/m^3
Amount of project	492 M$ ≈ 368.4 M €
Component of the station	25 modules of 21,000 m^3/day unit production, 24 modules in production, and 1 on standby 288 units PX energy interchanges
Quality of the water produced	Complies to the OMS standards
Start of operation	Commissioned in 2015
The associated	Hyflux: Singaporean company 49%. AEC: Algerian Energy Company 51%
Clients	Contract of sale and purchase of water: TMM – Sonatrach – SIOR (jointly)

Funding for the project was carried according to the “Project Financing” principle, whereby the debt repayment is made from income from the sale of produced water.

The choice of El Magtaa Oran station was made for his large consumption of electric power and its strategic location, next to one of the largest industrial areas in Algeria (Arzew), which is itself a major consumer of water and electricity, in addition to current disturbance of the electrical grid in this region.

6 Photovoltaic Generator

Photovoltaic conversion occurs by submitting the photovoltaic cell to sunlight. The energy received causes a chaotic motion of electrons within the material of the cell. The latter are connected in series and encapsulated in modules and watertight panels which protect them from moisture, shock, and nuisances [13].

The installation for TMM Oran consists mainly of photovoltaic generators placed on metal supports and a connection to the MV grid (30 KV) of Sonelgaz. The source selection is made such that the system can continuously provide the energy needed by the station (See Fig. 7).

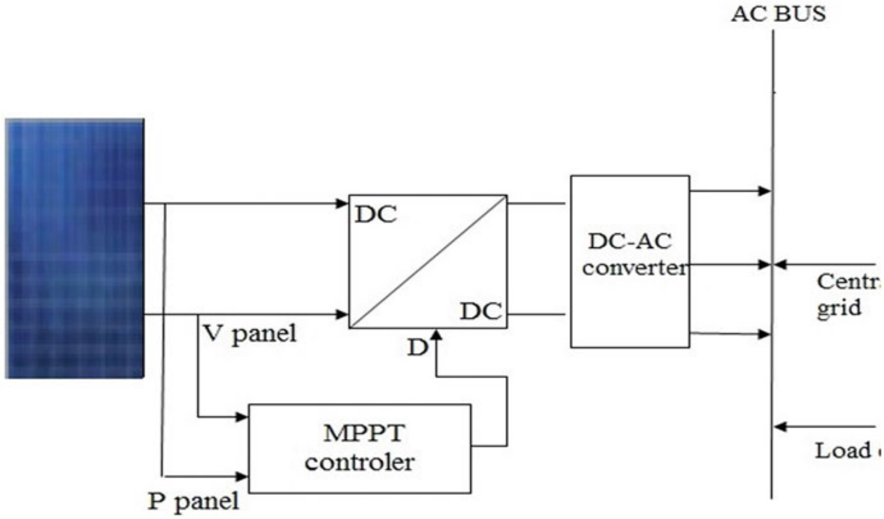


Fig. 7 Block diagram of a hybrid photovoltaic system [29, 30]

7 Simulation and Results

Our application is made on one module of 21,000 m^3 from the 25 identical of the station of TMM.

Each module has a connection to the grid of Sonelgaz (30 KV).

A feasibility study was conducted and allowed to provide all the technical and financial elements to the project owner and the person who commissions (a funding agency, bank, credit company, etc.) allowing the realization of the plant.

This study has:

1. Estimated the expected production is taking into account environmental constraints
2. Evaluated the possible constraints of the connection to the grid due to the location of the site (end of the line, bad grid, etc.)

This has led to the following results.

- The geographical coordinates of the site are [14]:
  - Latitude: 35° 47.2 min North
  - Longitude: 0° 9 min West
- The minimum irradiance at 45° of the site of TMM according to data from NASA was that of December, it was 2.40 kWh/m^2/day (RETSCREEN [15]).
- Energy consumed per month for each module (Sonelgaz billing during the test period) (Billing of Sonelgaz) was Ec = 67,423,479 kWh/day

7.1 Sizing

The dimensioning calculations [16] led for each module of TMM to a generator with the following features [17]:

Pc = 46,824 MW

- Number of panel = 164,295
- Type of connection
- Parallel branches = 1,217
- Serial panel = 135
- Panel selected

Condor CEM285P-72 type poly-crystalline 30,010.50 DA:

- UPS chosen: Condor 50 KW Solar Inverter.
- Total area of the panels is 25 × 31.8724 = 796.81 hectares.
- Total approximate investment cost is 25 × 140.76 € = 3519M€ [32, 33].

Storage:

After a metrological study, the storage should be provided for at least one-half day by large tanks of water of 250,000 m^3 while the station currently has only 40,000 m^3.

7.2 Results and Interpretation

The simulation was carried out under MATLAB/Simulink shown in Appendix 2.

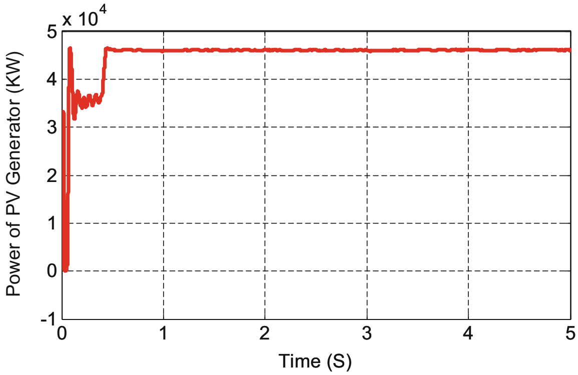
As our study is composed of two parts, the first supports the photovoltaic generator; the second supports the cost of m^3 of water produced.

The analysis begins with a presentation of the results of our photovoltaic generator outputs and voltages delivered to the load to ensure the smooth functioning of our PVG (photovoltaic generator).

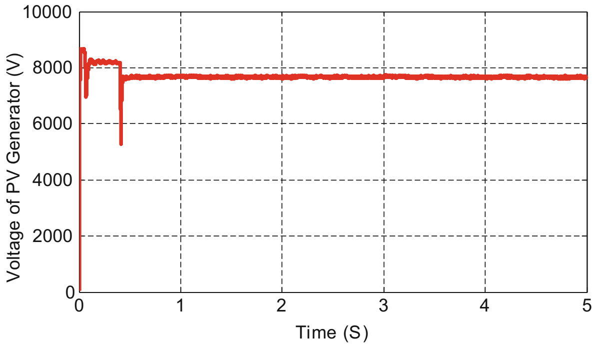
On the results of Fig. 8, we see the effectiveness of our generator. The time of responses of the transitional regimes is very acceptable especially for the application for which we are interested (desalination of El Magtaa) because the maximum of power is reached in 0.4 s (Fig. 9).

Figure 10 presents the results of the injection of power to Alternative bus (AC bus), and they are very acceptable especially at steady state (permanent) where the frequency of 50 Hz is respected and the *rms* values of the voltage and current are 6 KV and 5.16 KA, respectively, with the perfect sinusoidal waveforms realized with the adjustment of the filter of connection.

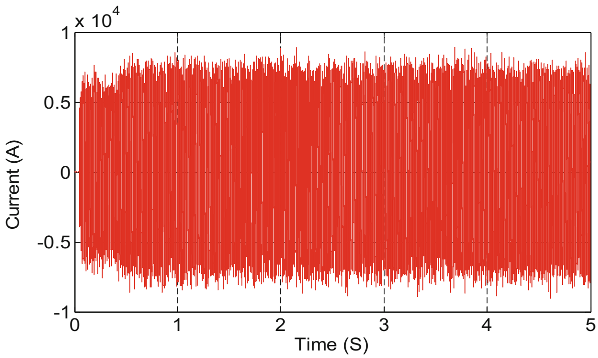
Fig. 8 Simulation results of (PVG) with MPPT for the irradiance of 1,000 w/m^2
To validate our model, we tested our generator for various irradiance values.



Power of PVG versus time



Voltage of PVG versus time



Alternative current (AC bus)

Fig. 9 Simulation results for different irradiance values
Simulation results obtained show again the effectiveness of our generator to produce the maximum power and that it follows the command regardless of the irradiance changes, 46.55 $\times$ 10^3 kWh for the irradiance of 1,000 w/m^2 and 36.88 $\times$ 10^3 kWh for 800 w/m^2 of irradiance. These results are acceptable from the standpoint of system stability. The form of the signals delivered by the PVG confirms the effectiveness.
The AC (Alternative) simulation results are given by the curves of Fig. 10.

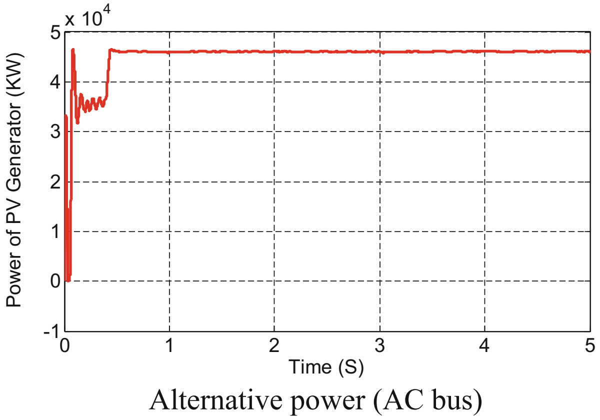
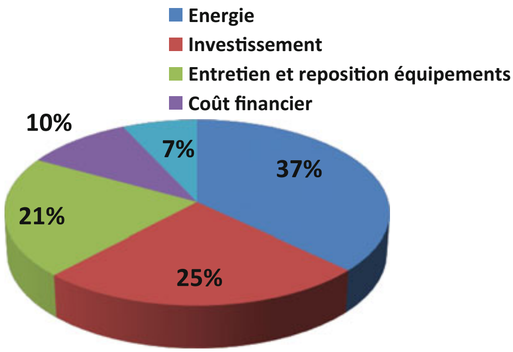


Fig. 10 Simulation results of the injection to the Alternative bus (AC bus)

Fig. 11 Decomposition of the production cost per item of expenditure
It should be noted that the contractual price of m^3 of water of the project with the connection to the grid of Sonelgaz is 45 DA/m^3 the equivalent of 0.43 €/m^3 [18].



8 Cost of Desalination

The estimation of the cost of desalination to this day and for the future is very important to know the feasibility of solution of desalination compared to other solution of augmentation of drinking water like surface water, groundwater, transfer, recycling of wastewater, and water conservation (See Fig. 11).

The decomposition of the production cost per item of expenditure is shown in the following figure [7].

8.1 Estimation of the Cost of Water with the PV Generator

So the new cost of m^3 is estimated at 374 DA.

Table 13 Estimation of the cost of water with the PV generator

Global investment (€ 3887 million) € 368 million (initial investment) + 25 × 140.76 M € (Photovoltaic investment)		
Estimated cost per m^3 of freshwater €/m^3		
Investment 7,774 €/m^3/day 20 years at 5% 95% of availability	(7,774 × 0.08)/(365 × 0.95) = 1.79 €/m^3	51.07%
Electric power	0 €/m^3	0%
Operating and maintenance 5% of the investment	(7,774 × 0.05)/(365 × 0.95) = 1.12 €/m^3	31.95%
Personnel	0.245 €/m^3	7%
Total cost	3.505 €/m^3	100%

From the results, we note that the investment is colossal 3.5 billion euros, and the price of m^3 of water is very expensive, making the subvention a compulsory thing (See Table 13).

Finally another aspect that intrigues me is that all the arguments are based on the cost of kWh or Wc provided by a photovoltaic cell.

Is this the correct variable to consider?

Of course the "money" is an encompassing variable to take into account the hidden settings and often indistinguishable, whereas if we imagine that the unrestrained race for superfluous is deadly, it is necessary to take time to equip a part of our country by solar panels.

It is also essential to use which is the better at each stage and not which is less expensive. The installations will have a greater lifespan and maintenance costs will be reduced. The gradual installation lets also to size the production plants at reasonable size: they will provide only the replacement of old equipment when the PV array is finished.

9 Conclusion

To cope with population growth and economic development, energy and electricity demand in Algeria will increase substantially between now and 2030.

In the absence of a rigorous energy efficiency policy, the energy sector's water requirements will be also envisaged in terms of electricity generation in hydroelectric plants (dams), as make-up water for cooling in classic thermal power stations, and cleaning for the hybrids stations (solar-stream) particularly for those located in the country's interior (Sahara).

Solar photovoltaic is used very widely and since a long time for pumping water. For example, the site of El Hamrawin in Egypt commissioned in 1981. This station used the mechanical energy of a thermodynamic solar pump (SOFRETES), now replaced by a photovoltaic generator.

On the other hand, for desalination, there are quite of few realizations in photovoltaic, probably due to *high costs*. However, we can mention in our country the unit of Hassi Khebi with reverse osmosis associated with a PV generator.

Solar thermal energy is economically more competitive; there are already a significant number of achievements. In the Mediterranean, there are solar stills particularly hothouse type in Greece and Spain. Tunisia provides for the use of solar energy in 45 new desalination plants in areas of the South whose Medenine, Tataouine, Kébili, and Ksar Ghilane.

Finally, Tahlyat Myah Magtaa Spa is in front of a very promising project of technology watch which can be combined with other projects such as the SSB (Sahara Solar Breeding) project in order to optimize the investment and its damping as quickly as possible.

Appendix 1

See Table 14.

Table 14 Trend scenario of water and energy sectors

	2011	2030
Water demand (Mm^3)	12,300	20,100
Electricity demand for water (GWh)	4,983	16,090
Total electricity demand (GWh)	48,860	146,900
Natural gas reserves (years)	52	33
Oil reserves (years)	15	0

Appendix 2

See Fig. 12.

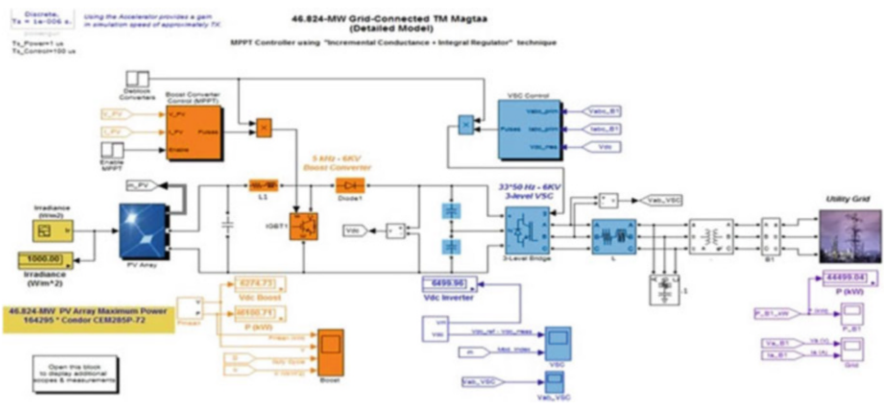


Fig. 12 PV generator of Magtaa desalination (MATLAB/Simulink)

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Part V
Conclusions

Update, Conclusions, and Recommendations for Water Resources in Algeria: Water Quality, Treatment, Protection, and Development

Abdelazim Negm, El-Sayed Ewis Omran, and Damia Barcelo

Contents

Abstract Water quality, treatment, protection, and development in Algeria are framed by problems related to water sustainability. Natural resources are at the core of Algeria's sustainable development and are critical to socioeconomic growth. This chapter captures the water quality, treatment, protection, and development in Algeria (in terms of findings and suggestions) and provides ideas extracted from the

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Abdelazim M. Negm, Abdelkader Bouderbala, Haroun Chenchouni, and Damià Barceló (eds.), *Water Resources in Algeria - Part II: Water Quality, Treatment, Protection and Development*,
Hdb Env Chem (2020) 98: 319–334, DOI 10.1007/698_2020_564,

volume cases. In addition, topics were covered by some (updated) results from a few lately published study works linked to water resources. This chapter offers a number of suggestions for protecting resources for Algeria's current problems.

Keywords Assessment, Egypt, Environment, Protection and development, Sustainability, Treatment, Water quality

1 Introduction

Water is one of the most important raw materials in Algeria. In the context of sustainable management of invaluable water resources for the future, Algeria has taken quantitative and qualitative adaptive steps. By implementing a domestic water plan, Algeria aspires to safeguard its water resources and provide a sustainable response to water supply and management problems. This program is consistent with all projects adopted by the Algerian government to improve the quality of its water sector.

This book explores up-to-date information on water quality, water treatment, and water resource protection and development in Algeria. This book addresses the question of how science and technology can be mobilized to make that promise come true. Therefore, the intention of the book is to improve and address the following main theme.

– Water quality
– Treatment and protection
– Water resources modeling
– Development and future of water resources

The next section offers a brief overview of some of the most recent (updated) water resource studies in Algeria's important outcomes. Then, the key results of the book chapters are summarized as the primary suggestions for researchers and decision-makers. The update, conclusions, and recommendations presented in this chapter come from the data presented in this book.

2 Update

The following are the major updates for the book project based on the main book theme.

2.1 Water Quality and Modeling

One potential practice for water resource modeling is identified: the Kalman filter for spatiotemporal modeling and prediction of Algerian water resource variability. The chapter is an overview of water resource modeling for ends of prediction in Algeria. It focuses on a particularly interesting type of model that can support not only the stochastic nature of the hydrological processes but also their temporal variability as well as the nonlinear character of the hydrological system. Such models are mostly required in water resource design and management because they provide a helpful tool for decision- and policy-makers in Algeria. The objective is to showcase some of the recent results regarding the extent of applicability of discrete Kalman filter (KF) to the modeling and prediction of water resources in Algeria. For this end, two important hydrological variables have been investigated: rainfalls in the Chéliff watershed and stream flows in northern Algeria. KF is one of the most popular filters in this area. It relies on the recursive least squares concept. It is well-known in many other fields than hydrology that the KF optimality provided the assumptions of linearity and white Gaussian noise. The major advantage of KF is to provide the prediction error covariance an indicator of the filter accuracy. In addition, its calculation algorithm works in the temporal domain with a recursive nature and has an optimal estimator in the least squares concept. Another aspect of its optimality is the incorporation of all the available information on the system, measurements and errors in an adaptive operator, which is reset each time a new measurement becomes available.

Additionally under this theme, two chapters are identified in the book connected to the current status of water quality. The first study predicting water quality indicators from conventional and nonconventional water resources in the country of Algeria is "adaptive neuro-fuzzy inference systems versus artificial neural networks." Monitoring water quality is of great importance and mainly adopted for water pollution control of conventional and nonconventional water resources. Monitoring wastewater treatment plant (WWTP) using online sensors has become an essential and crucial task to handle rapid and seasonal variations that occur during all the months of years [1]. Consequently, real-time supervision of the process of WWTP is nowadays a challenge [2]. To deal with these challenges, WWTP must be highly efficient [3]. Evaluation of the WWTP performances is mainly based on the measure of water quality indicators (WQI), which are generally hard to measure regularly. In the last few years, soft computing models have been largely employed for modeling and forecasting WQI in several water ecosystems. Chemical oxygen demand (COD), biochemical oxygen demand (BOD), and dissolved oxygen concentrations (DO) were the most important WQI that have received great importance, and modeling chemical oxygen demand in WWTP is broadly discussed in the literature [4].

The second study is linked to the organic chemical characterization of water of the northwestern Algerian dams. To ensure its independence and guarantee its water resource needs, Algeria has already taken this problem very seriously. Surface water collected in dams may be polluted and contain important levels of salts, toxic ions, heavy metals, and organic residues. Accumulation of these pollutants when in water and soils may cause a threat to agricultural production and the environment. Organic matter content in water generally comes from crop wreckage, food waste, other degradable solid wastes, and fecal matters. Algal and phytoplankton growth is enhanced by nutrients that are supplemented by fertilizers which finally results in eutrophication [5]. Many studies have been published concerning the assessment of water quality in rivers [6] and dams [7–9] using physical, chemical, and biological parameters.

2.2 Treatment and Protection

Four approaches related to treatment and protection are identified in this book. The first approach identified is the wastewater reuse for irrigation purposes: the case of the Aïn Témouchent region. Anthropogenic effects like municipal waste discharge and agricultural and industrial activities play a major role in determining the surface water quality in a given region. Nowadays, existing treatments can reduce the pollutant concentrations to non-hazardous levels and make it possible to obtain water of better quality from wastewater. The treatment and disposal of wastewater do not only minimize environmental impacts but also allow uses for irrigation purposes and those that do not require drinking water (e.g., recreational activities, industrial uses, aquifer recharge, firefighting, aquaculture, domestic uses, etc.). In wastewater, phosphorus can come from human metabolism, washing and cleaning products, and orthophosphates from the hydrolysis of inorganic phosphate. Phosphorus released from wastewaters into watercourses can cause undesirable effects, such as eutrophication and its related effects [10] which leads to profuse algal blooms, excessive growth of aquatic plants, deoxygenation, and water purification problems [11]. The purpose of measuring EC is to control the quality of the wastewater; it reflects the degree of overall mineralization and tells us about the water salinity [12]. Its measurements can be used to monitor the processes in wastewater treatment that cause changes in conductivity such as biological phosphorus and nitrogen removal.

The second study identified is the protection of water resources in mining sites in northeast of Algeria. Mining is a sector of activity essential for global economic development. Metals and minerals extracted by the mining industry are integrated into several consumer goods. Given the increase in the population and the demand for these goods, the mining industry is growing globally for a few decades. This type of industry is responsible for several impacts during each phase of the mining process. In particular, it is during the exploitation phase that the natural ecosystems, located above the deposits, are destroyed by the elimination of soil and vegetation and the establishment of storage sites for discharge mining. Thus, the extraction of mineral resources has a definite duration, whereas the associated environmental impacts can be visible indefinitely if no corrective measures are taken.

The third method identified is the physicochemical and bacteriological quality of surface water resources receiving common wastewater effluents in the drylands of Algeria. The assessment of water quality and pollution of surface water resources is crucial to maintain the integrity of aquatic environments. Nature and living beings are increasingly suffering the consequences of pollution generated from industrial development and population growth. Water pollution affecting rivers, seas, groundwater, and lakes is the result of the discharge of wastewater in nature without or with insufficient treatment, thus causing degradation of habitat and disturbance of ecosystem balance. Water pollution is one of the serious problems of modern civilization as it continuously concerns people and governments. Increasing pollution is spreading and threatening development efforts and the health of humans and their environment, mainly water resources [13]. On the other hand, the reuse of wastewater in crop irrigation [14] and its by-products such as sewage sludge in land fertilization [15], provided adequate treatments and pollutant removal are made [16], may solve partially issues related to water shortage in arid agriculture and food insecurity at drylands [17]. Another study focuses on the physicochemical and biological quality of the surface water of Wadis of Biskra (Algeria's No. 1 agricultural hub [18]).

The last approach identified is the valorization of oily sludge in the Arzew refinery. The environment is one of the pillars of sustainable development. For a long time, it was forsaken with the profit of the economic and social one. It is obvious today that the company and the economic activities will have to be built on a better balance of these three realities closely dependent. It is about a new and considerable challenge, which is carrying opportunities and innovations [19]. Other sources contribute to the pollution of the natural environment; one is the sanitary and domestic waters conveyed in underground networks separating toward sea [20]. The sludge treatment is a difficult phase in the fight against pollution. Moreover, the economic importance of this problem is illustrated by the importance of the cost. Both in investment and operating, it can represent oily sludge with a significant calorific value, which represents 90% of methane that can be considered as an interesting fuel. The impact related to its combustion in poor conditions can be important.

2.3 Development and Future of Water Resources

Four methodologies related to the development and future of water resources are identified. The first study is an overview of water resources in steppe regions in Algeria. Water resource management is an essential step in the national water resource planning. However, the overexploitation of groundwater as a result of population growth and industrial and agricultural emergent activities makes the planning operation more complicated. In the field, two questions appear in the mind: What are the Algerian water resources' potentialities? Moreover, what are the procedures to avoid the rapid depletion of these resources? Because of many reasons, the answer to these questions is not dependent only on the actual and the available statistics on water resources. The answer is dependent on the actual climate situation, the actual population growth, and the actual availability of water. The Algerian steppes have seriously faced more episodes of drought in the last decade. The lack of water is the principal source of this drought (meteorological drought). Furthermore, the Algerian steppes have great importance in the national strategy of development (higher plate development program). The rapid demographic growth applies high pressure on water resources [21]. Since the last few decades, the region's water resources were limited in terms of quantitative availability and quality.

The second study acknowledged is water resources, state of play, and development prospects in the steppe region of Naâma (Western Algeria). The issue of water resources is vital. It is at the center of a large number of interests: food security, agriculture, biological diversity, desertification, land use planning, poverty, health, peace, conflict, etc. However, the risks of degradation of agro-ecological resources, including water resources, are still persistent, and levels of agricultural and pastoral production are still rather modest compared to the significant needs of a growing region. The Naâma region contains significant underground water potential that has been little exploited, especially in the steppe plains around the chotts (El Chergui and El Gharbi), in the Naâma syncline. Geographically, the department of Naâma is a vast territory with stratified reliefs consisting of three large geographical units [22]. It has relatively large water resources and indeed benefits from many natural assets: heavy rains, a mountain water tower with large infiltration areas and snow-capped peaks, perennial rivers, and large underground aquifers of continental intercalary (Albien). The integrated water management approach will contribute to sound planning taking into account the various social, economic, and environmental interests. It emphasizes the participation of stakeholders at all levels in the development of legal texts and emphasizes good governance and effective institutional and regulatory arrangements to promote more equitable and sustainable decisions. The approach must be implemented using the economic, institutional, and technical tools to increase the efficiency of irrigation, improve the operation and maintenance of perimeters, improve drainage, and reduce soil salinity.

The third study recognized is desalination in Algeria: photovoltaic power plant for TMM (Tahlyat Myah Magtaa) of Oran as a case study. The future development of water resources depends on solutions characterized by high energy consumption, for example, seawater desalination, the reuse of wastewater, and the introduction of drip irrigation. The development of the water sector will, therefore, be closely tied to the development of the energy sector. This sector must conduct a large-scale program of studies to understand the current and future impact of climate change, identify and quantify associated costs and its interactions with water and energy, and specify adequate solutions for adaptation. Mobilization of nonconventional water resources (desalination and wastewater reuse) will be a strategic component of future water policy. The development of unconventional resources and the management of water demand will increase more the energy consumption of the water sector. The production of electricity using a photovoltaic system connected to the grid is of great interest to developing countries, especially for countries suffering these last years from the quality of their central grid. Photovoltaic can have undeniable advantages, particularly for its cleanliness and durability. Also, it can be used in various applications such as agriculture and desalination, etc.

The last study known is flood hydrograph forecasting in the catchment of the middle Cheliff. Algeria is among the Mediterranean countries which are the most vulnerable to floods caused by overflowing of streams crossing towns and suburban. The impact of climate change on flood peaks was the subject of several studies. However, a flood is not characterized only by its peak but also by the time, duration of the tip, as well as the rise time and shape of the flood hydrograph according to geographical distribution, leading to an understanding of these extreme hydrological hydrographs and to detect areas vulnerable to flood hazards. The Flood-duration-Frequency observed chronic Q(t) rate offers a theoretical definition of multi-term flood quantiles, explicitly fulfilling the needs of the catchment's integrated hydrological modeling. Although some studies had to be devoted to F-d-F models, this approach remains not much used. In Algeria, this method was successfully applied in some basins [23]. Many studies on the genesis and the dangerosity of the flood have been carried out for a few years in the world [24, 25] and in Algeria [26]. Finally, the study also went on the determination of the peak output of floods. For that, the F-d-F analysis was requested to define mono-frequency synthetic hydrographs (MFSH) able to characterize the behavior of a flood for a given period of return.

3 Conclusions

Several results taken from this book were obtained by the editorial teams. The chapter draws significant lessons from the book cases in relation to methodological concepts, specifically the covered topics of water quality, treatment, protection, and development in Algeria. This chapter provides the present problems faced by the water resources in Algeria. These outcomes are vital to Algeria's improvement of water resources. Based on the materials listed in all areas of this volume, the following findings could be reported:

1. MLPNN, MLR, and three ANFIS models, namely, ANFIS_GP, ANFIS_SC, and ANFIS_FC, were developed to model two water quality indicators: (1) *chemical oxygen demand* (*COD*) and (2) dissolved oxygen concentration (DO). The models were developed using several water quality variables measured at daily time step at WWTP and DWTP, respectively. Some conclusions can be drawn and are summarized as follows: by comparing several combinations of the input variables for modeling DO concentration, the best results were obtained by the ANFIS_SC with TE, pH, SC, and TU inputs, followed by the ANFIS_FC in the second order, ANFIS_GP ranking third, MLPNN ranking fourth, and the MLR model in the last place. In regard to modeling COD, the results showed that the ANFIS_SC with TE, pH, SC, and SS as inputs had the best results, and it can be used to estimate COD with very acceptable accuracy,

followed by the MLPNN, ANFIS_GP, ANFIS_FC, and MLR, respectively. Another *conclusion we can draw is that the accuracy of the proposed models is mainly dependent to the selection of the input variables. To obtain good* prediction *accuracy,* it is necessary that all the variables be included for the models.

2. Surface water quality data for 14 parameters collected from the monitoring of 10 dams located within 2 northwestern Algerian watersheds (Macta and Tafna) were analyzed monthly. The waters of all dams were alkaline, with pH values ranging between 7.01 and 8.97. The highest DR contents were found at Macta watershed. The maximum yearly average (3,161.7 mg L^{-1}) was recorded at Sarno dam located upstream of the confluence of Mekerra and Sarno wadis. In the other Macta dams, yearly averages were between 1,101.7 and 1,858.3 mg L^{-1}. Tafna watershed registered lesser contents varying between 279.2 mg L^{-1} at Meffrouch dam and 1,081.7 mg L^{-1} at HB. The calculated organic pollution index values during the study period evidenced the pollution state of the dams. They indicated moderate to very strong pollution in the water of the two watersheds. In Tafna dams, OPI averages of SA, Meffrouch, and BB dams exhibited moderate organic pollution. As for Sikkak, pollution is considered to be moderate from January to April and strong during the remainder of the year. The water of HB was strong to very strongly polluted. Waters of Fergoug, Ouizert, Cheurfa, and Bouhanifia dams were generally strongly polluted except that of Sarno dam, which indicated strong pollution only during May and December months. Indeed, the water of the two watersheds was more or less difficult to biodegrade.
3. Temperatures and pH values at the inlet and outlet of the WWTP show no significant differences and are generally in compliance with wastewater discharge in receiving mediums and reuse standards for irrigation use. Wastewater conductivity values are between 1,240 and 2.730 μS cm^{-1}. They vary after purification to reach values ranging from 1,460 to 2,730 μS cm^{-1} and can, therefore, be used for crop irrigation according to the standard recommended by WHO. The values of the COD/BOD_5 ratios for approximating the biodegradability of organic matter in a given effluent indicate that this wastewater is domestically dominant and, in general, easily biodegradable. This biodegradability is well evidenced by the values of the COD/BOD_5 ratios which vary between 1.08 and 2.70. The analyses also revealed significant decreases in BOD_5 and COD. In treating water, they are between 2 and 8 mg L^{-1} and 18.7 and 43 mg L^{-1}, respectively. We note, however, an increase in the dissolved oxygen concentration of treated water (6.49–9.63 mg L^{-1}) compared to that of wastewater (0.46–4.46 mg L^{-1}). Elevated suspended matter content in wastewater (84–464 mg L^{-1}) decreases in low concentrations in treating water. The analyses also revealed significant nitrogen pollution. The high Kjeldahl nitrogen concentrations in raw water (31.81–79.42 mg L^{-1}) decrease after treatment to reach values between 3.01 and 11.6 mg $L^{-1}$and are therefore within the standards of discharge in the environment and that of wastewater reuse in crop irrigation. Phosphorus is present in treating water with concentrations ranging

from 1.09 to 4.86 mg L^{-1}. These values are in line with the JORA effluent discharge standards and the FAO and WHO standards for irrigation use.

4. The management of waste from mining activities and tailings and waste rock usually represents an undesirable financial burden for operators. Generally, the mine and ore processing plant is designed to extract as many marketable products as possible, and tailings and environmental management as a whole is then designed as a consequence of the mining stages. The choice of tailings and/or waste rock management method to be applied depends mainly on an assessment of three factors: cost, environmental performance, and the risk of accidents.
5. It is also determined the water quality of arid wadis receiving wastewater in the region of Biskra. The results of water physicochemical and bacteriological analyses revealed that the values of several parameters exceed the standards established by FAO and WHO, which indicates large fecal pollution. In effect, the high level of bacterial loads indicates fecal pollution of all the study wadis. The findings show that wastewater effluents pose serious environmental contamination issues and health risks that can affect human communities, agricultural lands, crop products, and aquatic life forms that rely on water of the wadi system. The main risk is associated with exposure to pathogenic biological agents, including pathogenic bacteria, helminths, protozoa, and enteric viruses. High fecal contamination induces drastic changes and deterioration in water characteristics that cause the collapse of aquatic ecosystems.
6. At the time of the realization of our memory of the end of the study, we became aware of the importance of the purification plant, with the objective of purifying oily water so that they are not directly rejected. They can generate serious environmental problems and handles the public. The exact composition of muds varies according to the origin of oily water. Muds are very rich in organic matter (between 50 and 70% of matter dries), which supports the proliferation of microorganisms which multiply and break up the organic matter. In the absence of sufficient ventilation, decomposition of organic matter releases greenhouse gases (carbonic gas. methane. etc.). This situation illustrates clearly that an action plan became necessary to rehabilitate a system allowing adequate exploitation of muds by respecting the standards of environmental protection. The calorific values of organic matter of dried mud are high. The use of alternative fuels makes it possible to diversify energy resources and to reduce these costs. The organic components which will be exposed to heat treatment with temperatures of 200°C and 600°C will be burned completely, while the mineral components which will undergo a chemical conversion will integrate into clinker without deteriorating their excellent quality.
7. Due to the important socioeconomic development in recent years, the new sustainable development strategy in Algeria is a real challenge that is fundamentally based on rigorous management of water resource potential to cope with all forms of water demand for domestic, agricultural, industrial, and environmental needs. The present chapter is presenting some of the recent results in the context of the stochastic hydrological process modeling and prediction in the

case of time-varying linear systems. It concerns water resources in the northern part of Algeria, where discrete Kalman filter technique has been applied to the modeling and prediction of stream flows and rainfalls in a number of sites simultaneously (multisite) for each of the monthly and annual scales. The developed operators have the particularity of automatic self-adaptation as soon as a new measure becomes available. This is an advantage of the KF algorithm recursive character that can be used in real-time predictions. As a result, optimal stream flow and rainfall predictions are obtained considering time variations of the underlying hydrological generating processes, as well as their stochastic character. The obtained predictions can be appreciated from a temporal point of view, where observations and predictions in a single site are obtained during a period of time, but can also be extended to any further step where observation is available. These predictions can also be appreciated from a spatial point of view, where observations and predictions in all considered sites are obtained during a period of time, but can also be extended to any other site where observation is available. One of the most important advantages of the developed operators is to provide the error prediction covariance matrix with certainty at each calculation step. This is of great interest because it constitutes a measure of the prediction accuracy at each step calculation. The accuracy of the predictions, and consequently the suitability of the operators, has also been checked by the prediction relative error in percent whose overall average value is less than 10% which is highly acceptable. A slight tendency for operators to overestimation for rainfalls and underestimation for stream flows has been observed. Another advantage of the developed operators is that the algorithm may be initiated with very little objective information and the prediction is obtained in time domain. This is of great interest because it offers a real-time forecasting possibility. The developed operators are interesting because they can help policy- and decision-makers in water resources in Algeria acting efficiently for better management and sustainable development of such resources in the country.

8. On the other hand, a simulation of the situation of groundwater resources in the next 10 years by introducing an actual parameter of exploitation was conducted. Two scenarios have been implemented to show the evolution of water demand and water deficit during the simulation period. The results show that the water deficit in the coming years is about 13% by taking a water demand reference for a population of 100 L/capita/day. The situation may be complicated in the future years by groundwater quality degradation and reducing the mobilized water from dams. An emergency plan must be implemented to secure the population of such kind of regions from water shortage in the medium and long range. Some of these projects propose [7] the transfer of desalinated water from the north [16], water reuses [14], reduction of the loss of water in distribution networks [22], and optimization of water distribution by using the remote control of water production facilities to avoid leakage in the distribution network.
9. The department of Naâma is a region with a pastoral and agro-pastoral vocation that has considerable pastoral and underground water resources. With an arid

climate and the absence of structures for mobilizing surface water, the department of Naâma is mainly supplied with groundwater. The water resources of the department are appreciable but require to be evaluated in a precise way to ensure their use in a rational and sustainable way. The situation in the department of Naâma is worrying where water must be at the center of the concerns of local authorities, management bodies, users, and all citizens. Faced with this situation, and in order to avoid potential conflicts, we must involve all those involved in water, where individual practices must become more aware and more respectful. The major concern for the sustainable safeguarding of the water resource in these arid regions is to implement a strategy of safeguarding and exploitation rationally by resorting to planning based on short-, medium-, and long-term forecasting models for detecting trends and future patterns of water use, socio-economic development, and population growth.

10. To cope with population growth and economic development, energy and electricity demand in Algeria will increase substantially between now and 2030. In the absence of a rigorous energy efficiency policy, the energy sector's water requirements will be also envisaged in terms of electricity generation in hydro-electric plants (dams) and as makeup water for cooling in classic thermal power stations and cleaning for the hybrids stations (solar stream) particularly for those located in the country's interior (Sahara). Solar photovoltaic is used very widely and for a long time for pumping water, for example, the site of El Hamrawin in Egypt commissioned in 1981. This station used the mechanical energy of a thermodynamic solar pump (SOFRETES), now replaced by a photovoltaic generator. For desalination, there are quite a few realizations in photovoltaic, probably due to high costs. However, we can mention in Algeria the unit of Hassi Khebi with reverse osmosis associated with a PV generator. Solar thermal energy is economically more competitive. There are already a significant number of achievements. In the Mediterranean, there are solar stills particularly hothouse types in Greece and Spain. Tunisia provides for the use of solar energy in 45 new desalination plants in areas of the South which are Medenine, Tataouine, Kébili, and Ksar Ghilane. Finally, Tahiyat Myah Magtaa Spa is in front of a very promising project of technology watch which can be combined with other projects such as the SSB (Sahara Solar Breeding) project in order to optimize the investment and its damping as quickly as possible.
11. The flood regime modeling has been established according to quantiles of threshold flows coming from the statistic adjustment, which is compared with flood regime characteristics of the watershed *(QIXA10 and D),* to different counterparts quantiles from F-d-F models. The relative quantiles with low flows are better reconstituted than equivalent or superior quantiles to *QIXA10*. The converging model applied to tested basins constitutes equivalent values to those which could be obtained by adjustment on each duration taken separately. In general terms, using F-d-F approach seems to be well-adapted, and it is able to take into account duration, which is the essential notion when we are speaking about flood; it, therefore, considers "variable time step." So the description in flow-duration-frequency, whatever be the formulation, has several uses:

estimation of flood quantiles in middle flows or threshold flows to estimate hydraulic works, insertion in a flood regime typology, definition of hydrologic reference scenarios for flood risk estimation, validation of hydrologic model outputs, and characterization of the regime evolution of high water level. The knowledge of the flow threshold made it possible to trace the mono-frequency synthetic hydrographs, which are essential components of hydrodynamic model entry in order to determine the risk of a flood characterized by a return period. The station of Sidi Akkacha (Allala) is characterized by a very important quantile for the longer return periods, which follow the station Bir Ouled Tahar (Rouina-Zeddine).

4 Recommendations

A key component of Algeria's water resources is the ability to adapt to future issues. We argue that water resources need integrated flexibility to achieve this goal. The editorial teams observed certain aspects that could be explored for further enhancement throughout this book project. Based on the contributors' results and findings, this chapter provides several recommendations for future scientists to go beyond the scope of this book.

1. Results obtained in the present study highlighted many points that need to be addressed in the future. Firstly, the quality of data must be improved and the list of variables measured should be extended to other variables, notably to include chemical and physical variables that can be good predictors for COD. Secondly, the proposed models should be applied to other WWTP for further comparison of the models' performances.
2. To ensure good water quality in order to preserve dams against pollution, several measures must be taken. Following the observations made during the processing of the acquired information, it is important to frequently analyze other water parameters at watershed and dams, such as heavy metals, to get more information and to identify the emerging water quality issues and the extent to which existing criteria and recommendations can address these problems. More accurate monitoring is recommended for watercourses, and setting up mandatory regulations for polluters by requiring them to clean their wastewater by sewage treatment plants before pouring them into streams is needed. Necessary measures must be taken to avoid the eutrophication of the dams which is the consequence of the poor quality of water and the presence of pollution. It is also important to create treatment plants for each dam inlet regardless of the destination of these waters, as it is necessary to adjust the treatment in relation to the water quality and according to their uses.
3. It is well-known that wastewater should be disposed of in a manner that it should not be harmful to the environment and human health. Currently, although implemented devices allow the elimination of pollutants contained within this effluent, reuse of wastewater from WWTP could cause unhealthy problems. It is

necessary to ensure the performance of the treatment techniques used by performing complete physical, chemical, and bacteriological analyses of the treated water. As for reuse for irrigation, monitoring and frequent testing of the clean water should be made to ensure the international standards and maximum safety levels. An increase of awareness at all levels with particular emphasis on WWTPs and among farmers is required to mitigate the risks that may be incurred by the population. Farmers should use appropriate crops with treated water and suitable irrigation techniques.

4. Mining operations generate wastes that can be harmful to the environment if they are disposed of without adequate treatment. The monitoring of an abandoned or active mine site is mandatory. This monitoring is aimed at preserving the environment and especially natural ecosystems. Therefore, studies must be carried out, whether ad hoc and local or recurrent and national, to measure the levels of metal deposits. These studies measure the deposition either directly (by placing collectors close to the ground) or indirectly (by accumulation in soils, sediments, living organisms). The implementation of a program allows an estimate, in background situations, of metal deposits (iron, mercury, nickel, lead, arsenic, zinc, etc.). This program has the following objectives: monitor the variations of metal deposits in the natural environment; evaluate the extent of contaminated areas by using the ArcMap application; identify the local origin of the sources of emissions; set up a rehabilitation plan for closed or abandoned sites; and monitor improvements resulting from the application of rehabilitation plans to reduce the impact of metal emissions.
5. In perspective, in order to limit the risks of water pollution in wadis, it is recommended to (1) install wastewater treatment plants before releasing it into the environment in order to preserve water quality in the natural environment and thus sustain life forms and ecosystem integrity; (2) divert sewage collectors and discharges sites away from agricultural lands to reduce the risk of soil contamination and thus produce healthy agricultural products; and (3) periodically monitor water quality to prevent events of high contamination of hydrosystems receiving polluted water. Under conditions of water scarcity in drylands, a wise water management policy needs to promote the increase in agricultural production with less water. This can be achieved through the rationalization of irrigation and drinking water use and the improvement of irrigation systems with cutting-edge techniques of water saving. The reuse of the adequately treated wastewater in agriculture irrigation is a promoting practice to save natural water resources for other healthy uses. Since arid agriculture is often associated with land degradation and soil salinization, biosolids produced by wastewater treatment plants are indicated to increase soil fertility with organic matter and improve several soil proprieties and also alleviate the negative effects of soil salinity and water stresses on the crop plant.
6. As an example, the substitution of 13% of the raw material by ashes enables us to eliminate a quantity of 65,000 t/year knowing that annual production of cement in a cement factory (e.g., cement factory of Saida) is estimated at 500,000 t/year cement with ashes obtained at 900°C, which will be used preferably in the

nonexposed works. Finally, it can be completely said that the study of valorization of muds eliminates this waste in an exemplary industrial process on the ecological and economic level.

7. The recommendations to be considered should focus on the following areas: Undertake the necessary studies (hydrogeological, hydrological, and bacteriological analyses) to determine with precision the real water potential across the department.

   Estimating the volumes stored and not yet exploited, notably the synclines of Naâma and Ain Sefra, the Ksour Mountains, as well as Chott-Gharbi and northeast of Mecheria.

   Learning how to manage the water resource in the perspective of sustainable development is learning to control its scarcity but also its excesses, to ensure the supply of drinking, agricultural, and industrial water.

   Water development and management should be based on a participatory approach, involving users, managers, planners, and policy-makers at all levels.

   Quantitative and qualitative assessment of water resources and the planning of the development of hydraulic infrastructures.

   Implement measures to minimize network losses (supply, storage, and distribution) by modernizing and expanding infrastructure.

   Rehabilitation and optimization of infrastructure by better management of pumping stations with a policy of preservation, and effective and continuous maintenance of the equipment of dewatering is supervised by qualified personnel with the ability to provide for any failure.

   Improve the water economy by adapting agricultural practices to local climatic conditions and by using new irrigation techniques.

   Promote water purification technologies, which aim to find the mechanisms for the extension of the rational exploitation of water and the recycling of wastewater and their exploitation in the agricultural or industrial fields.

   Integrating climate change into water resource management strategies – adoption of a strategy to increase the storage of water by the construction of hydraulic structures.

   Adaptation of the legal and institutional framework of water.

   Develop and improve public information and specialized education and training for integrated and sustainable water management.

8. The mono-frequency synthetic hydrograph is not observed hydrograph. They have the characteristic of being single frequency; regardless of the length considered, the flow continuously overwhelmed by the hydrograph, which is a quantile debit same frequency threshold. This property ensures consistency between hydrograph and the average flow rate corresponding quantile. The observed flood events in the river could not be described in terms of frequency or return period for the reason that they vary according to the period over which we analyze the phenomenon observed. For this reason, it seems irrelevant to analyze the flood risk on the basis of an actual flood that can be pessimistic and optimistic peak volume or vice versa. The contributions to the hydraulic model will be calculated simply from QdF models. If working steady, reading the

maximum instantaneous flow rates obtained for different return periods gives the rates corresponding to the inputs of hydrodynamic models (such as Saint-Venant). If working in a transient state, it is first necessary to build a single-frequency synthetic hydrograph. Another common use of a single-frequency synthetic hydrograph is in flood routing in order to determine the height poured through a spillway of a dam because this hydrograph is also a hydrometric characteristic of the watershed.

9. In Algeria as well as in other countries (e.g., European countries), monitoring programs are needed to check the quality of wastewaters and to evaluate wastewater treatment processes. This will need to be done in order to achieve high water quality standards of Algeria's treated wastewaters and surface waters. In addition and considering future agricultural uses of water, reuse of a good quality of wastewaters is needed to avoid plant uptake of the contaminants present in wastewaters and to keep food crops and population in good health particularly for pollutants such as pharmaceuticals, personal care products, and surfactants that are present in wastewaters.

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