

Assessing the Environmental Impacts of Treated Wastewater Reuse on Water-Soil-Plant Ecosystems in Oued Bou Naim, Eastern Morocco

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ABSTRACT

As climate change continues to present daunting obstacles in the eastern region of Morocco, the reuse of treated wastewater has emerged as a vital solution for combating water scarcity, particularly for irrigation purposes. This investigation delves into the implications of reusing treated wastewater along the seasonal Isly River, with a specific focus on its downstream area, commonly referred to as “Oued Bou Naim”. A comprehensive campaign was conducted in 2023 to analyse the physicochemical quality of 12 water samples from Oued Bou Naim and 13 soil samples from nearby agricultural plots. The findings from the water analysis show a marginal increase in temperature downstream from the wastewater treatment plant (WWTP) in Oujda, ranging from 19.0 °C to 24.8 °C. The pH varied between 7.08 and 8.33 and generally remained within acceptable limits. However, the electrical conductivity levels, ranging from 2154 to 2898 $\mu\text{S}\cdot\text{cm}^{-1}$, exceeded WHO standards, indicating potential risks to the soil–plant–health ecosystem. Additionally, the total dissolved solids increased significantly downstream from the WWTP, reaching 1437 $\text{mg}\cdot\text{l}^{-1}$. For the nitrites, a level exceeding the limits, especially upstream, had an average of 2.03 and a maximum of 5.48 $\text{mg}\cdot\text{l}^{-1}$. Upon studying the soil samples, a substantial increase in orthophosphates, nitrites, and nitrates was observed downstream. Orthophosphate levels increased significantly downstream, with an average of 361.25 $\text{mg}\cdot\text{kg}^{-1}$, indicating the contribution of treated wastewater. The nitrite concentration (average of 11.61 $\text{mg}\cdot\text{kg}^{-1}$) and nitrate level (average of 60 $\text{mg}\cdot\text{kg}^{-1}$) raise concerns regarding contamination through irrigation with treated wastewater. This research highlights the critical need for responsible irrigation practices to safeguard the delicate balance of the “Water-Soil-Plant” ecosystem and the well-being of humans. Although wastewater treatment plants play an important role, the presence of high levels of harmful pollutants downstream emphasizes the urgent need to carefully manage this treatment combined with the reasonable use of agrochemical inputs to prevent their leaching into nearby ecosystems. By doing so, we can effectively reduce the risks to both the ecosystem and human health in the study region.

Keywords: wastewater reuse, water quality, soil contamination, environmental impact assessment, agroecosystems, health risks, Isly River.

INTRODUCTION

Water, the essence of life, faces unprecedented challenges globally, accentuated by the proliferation of a transnational water market that deepens societal disparities and threatens both the environment and public health (DaSilva Augusto et al., 2012). This pressing issue is exacerbated by mounting pressure on the world's water supply, raising concerns about its impact on biodiversity and underscoring the urgent need for conservation efforts and improved water-use efficiency (Pimentel et al., 2004). The intricate challenges posed by water scarcity, ecosystem degradation, and deteriorating water quality have been eloquently outlined by Bogardi et al. (2012), who emphasize the necessity for sustainable solutions and enhanced governance in the face of these complexities. Disparities in global water access have given rise to a transnational water market, amplifying societal divisions and posing significant threats to both the environment and public health (DaSilva Augusto et al., 2012). These challenges are particularly pertinent in Morocco, where water scarcity, droughts, floods, and the overexploitation of groundwater have become paramount concerns (Bzioui 2011). The government's ongoing efforts to balance water supply and demand reflect the gravity of the situation, especially concerning its implications for agriculture and food security (Falkenmark 1990). Insufficient access to clean water not only hampers human health but also constrains economic development, particularly in rural areas (Cosgrove and Loucks 2015). The interconnection between water availability, climate change-induced crop yield fluctuations, and economic ramifications necessitates the consistent consideration of various policies, such as climate, energy, trade, and agricultural strategies (Hoff 2009; Taheripour et al., 2020).

Surface water pollution, which stems from diverse sources, such as anthropogenic activities, landfills, wastewater treatment plants (WWTPs), industrial discharge, and agricultural runoff, poses a significant threat to the environment and human health (Haseena et al., 2017; Pedrazzani et al., 2019). Both organic and inorganic pollutants present in wastewater challenge water quality, making it essential to meticulously address this issue (Pimentel et al., 2004). Pollutants, including heavy metals and pathogens, infiltrate surface water bodies, leading to environmental degradation and potential health hazards (Schwarzenbach et

al., 2010; Khan et al., 2021). These contaminants, which arise from natural processes and anthropogenic activities, require rigorous investigation into their transmission mechanisms and impacts on aquatic and soil ecosystems (Breida et al., 2019).

The reuse of wastewaters for agricultural purposes is a promising approach for addressing water scarcity. Nonetheless, they have their own set of obstacles and potential hazards. As noted by Fito and Van Hulle (2020), sophisticated treatment techniques and diligent monitoring are essential for overcoming these obstacles effectively. Aziz and Farissi (2014) and Navarro et al. (2015) highlighted the numerous benefits of wastewater reuse, including augmenting water sources and enhancing soil quality. However, they stressed the critical importance of adhering to safe and appropriate procedures to ensure the success of such challenging practices. Treated wastewater is suitable for irrigation after toxic elements are significantly reduced (Kanwar et Sandha 2000), and untreated or poorly treated wastewater introduces harmful substances into waterways, posing threats to both aquatic biodiversity and human health (Guasmi et al., 2010; Perrin et al., 2014).

Wastewater, though a potential resource, is a vector of contamination that carries various organic and inorganic solids, pathogens, and toxic elements (Faour-Klingbeil and Todd 2018). Consequently, the continuous and uncontrolled reuse of wastewater may result in severe environmental and health risks, necessitating stringent monitoring and meticulous surveys of both soil and groundwater quality in irrigated areas (Baumont 2004).

In the context of Oujda, Eastern Morocco, the reuse of treated wastewater for irrigation introduces complex challenges. Since 2010, the WWTP in Oujda city has played a pivotal role in the city's water management strategy (Rassam et al., 2012). However, despite the initial success in terms of purification efficiency, concerns remain regarding the quality of the treated wastewater discharged into Oued Bou Naim (Kajeiou et al., 2023). The illegal agricultural use of untreated wastewater prior to the operation of WWTPs has had a lasting impact, contributing to nitrate concentrations exceeding permissible levels (Es-sousy et al., 2019). The prospect of expanding treated wastewater irrigation in Oujda necessitates a thorough understanding of the potential risks, emphasizing the importance of adhering to stringent standards (NQEDI 2002).

This study investigated the synergistic impacts of agrochemical inputs and treated wastewater

reuse for irrigation on water–soil–plant ecosystems in Oued Bou Naim, Eastern Morocco. Through a thorough analysis of water and soil sample quality, the aim is to enhance our understanding of pollutant dynamics. This deeper comprehension will address vital environmental concerns, offering insights into sustainable resource management for arid environments. This study sought to contribute to the protection of human health and agroecosystems and to inform effective strategies for mitigating environmental risks and promoting sustainable practices in the context of water and soil interactions in Oued Bou Naim.

MATERIALS AND METHODS

Presentation of the study area

The Angads plain (460 km²), located north of the city of Oujda (Figure 1), borders the southern region by the Horst range, the northern region by the Bni Znassen range, the western region by Jbel Megrez and the eastern region by the Algerian-Moroccan border (Boughriba et al., 2010). The Angads Aquifer System is a “transboundary aquifer” extending across the Angads and Maghnia plains. This system is characterized by bending (the Isly River), separating the northern part of the Angads River (200 km²) from its southern part (260 km²) (Boughriba et al., 2010). The city of

Oujda, with a population of 580000, has a semi-arid climate with an average annual rainfall of approximately 335 mm and average minimum/maximum temperatures of 10.3/23.9 °C. It is important to note that the current study presents qualitative results for the surface waters of the Angad Plain (Isly River and Oued Bou Naim).

An in-depth study of surface water quality in the Angad Plain was conducted across four distinct sections (Figure 1). In section 1, 15 km from the Beni Oukil commune to the upstream outskirts of Oujda’s city center, diverse pollutant inputs are applied, including geochemical releases and industrial activities in the Beni Oukil quarries, as well as runoff from nonafforested areas. Section 2, crossing Oujda city for 8 km along the Isly River, raises concerns about multiple water pollution factors, including illicit clandestine sewer connections, residues of phytosanitary products from car washes, and inappropriate use of toxic construction materials. Section 3, downstream of Oujda and extending approximately 5 km, extends from the Isly River and is named Oued Bou Naim. This section discusses various pollution sources, including the discharge of treated wastewater from the Oujda wastewater treatment plant (WWTP). This section is subdivided into three subsections: traversing agricultural operations and raising suspicion of bidirectional pollution (organic pollution due to waterborne contaminants and agrochemical and phytosanitary inputs). In section 4,

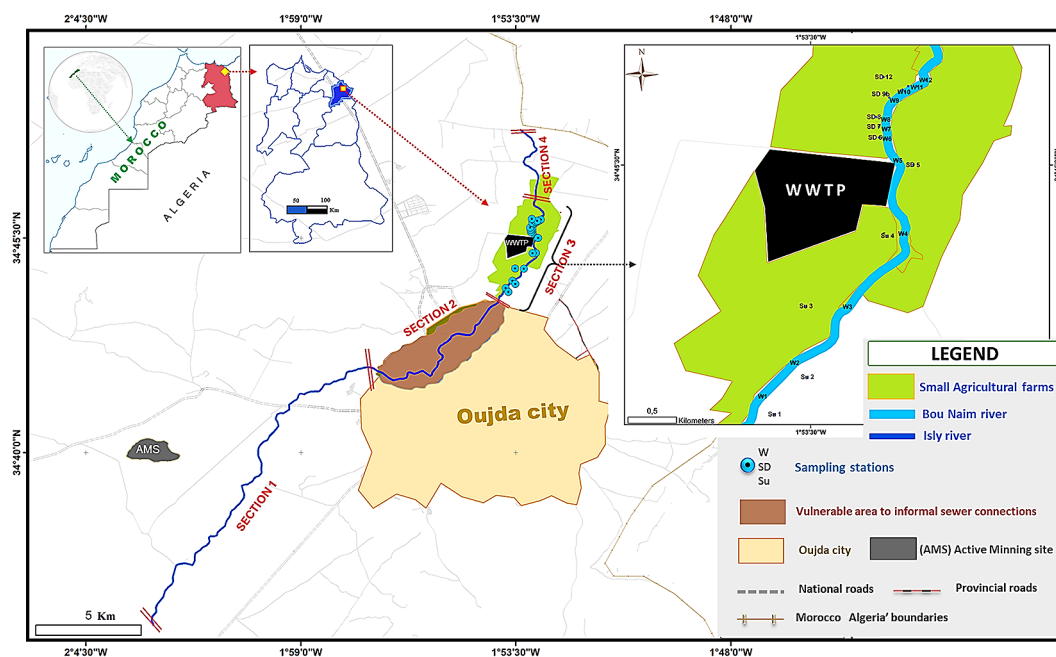


Figure 1. Location map of the study area and sampled stations

section 3 is extended to the Algerian-Moroccan border by 5 km, which is exposed to agronomic influences; thus, an in-depth study of the potential inputs of phytosanitary pollutants and self-purification mechanisms, particularly downstream of the Oujda sanitation spillways, is needed. This study focuses on section 3 because of its strategic location downstream of Oujda, which represents a continuation of the Isly River and encompasses significant aspects of pollution related to agricultural activities and WWTP discharges. Moreover, this section, which is a part of “Oued Bou Naim”, a continuation of the Isly River at the end of Oujda city borders, receives the wastewater treated by this WWTP in Oujda. This section uses an aerated lagoon process and processes approximately 40000 m³ of wastewater daily, equivalent to a population of 850000 inhabitants. This volume is expected to increase to 65000 m³·day⁻¹ by 2030 (RADEEO 2022). In addition, this stream has an average annual flow rate ranging from 0.40 to 0.80 m³·s⁻¹ and is generally supplied with water during flood periods, mainly from October to February (Osrirhi et al., 2007). It is important to note that these waters are often pumped directly from the watercourse and reused as sources for the irrigation of food crops, mainly lettuce, mint, parsley, cabbage, and alfalfa. Sections 1, 2, and 4 offer contextual insights into the broader dynamics that influence water quality in the Angad Plain, providing a comprehensive understanding of the unique challenges posed by each section.

Sampling method

To comprehensively investigate the spatial patterns of water quality in section 3 of the Isly River, namely, “Oued Bou Naim”, a sampling campaign was undertaken in 2023. Twelve water samples (Wn) were collected in sanitized polyethylene bottles. To further understand the

potential consequences of using these waters for agricultural purposes, 13 soil samples (Sn) were extracted from nearby agricultural plots near this watercourse. These soil samples are a composite of three subsamples taken from three different irrigated agricultural plots. The distance between each sampling point was maintained at 10 to 15 metres, and samples were collected at a depth of 20 cm. (Figure 2). This method ensures the accuracy and consistency of the sampling process.

These samples were taken at Oued Bou Naim, more precisely, upstream of the water discharge point treated by the WWTP (W1-W4/S1-S4), at the discharge point of these discharges (W5/S5) and downstream of this discharge point (W6-W12/S6-S13). These sampling points were distributed along the Oued Bou Naim as follows (Table 1).

Physicochemical characterization

Water quality assessment

The physicochemical properties of the water were measured on-site using a versatile portable device, known as the WQM-303 Pentype Multi-Parameter 5-in-1 Water Quality Tester. These properties include temperature (T), hydrogen ion concentration (pH), electrical conductivity (EC), total suspended solids (TDS), and salinity, providing comprehensive information about the quality of the water. The concentrations of key components, including nitrate ions (N-NO₃⁻), nitrites (N-NO₂⁻), and orthophosphates (P-PO₄³⁻), in the water were analysed in a controlled laboratory environment following the protocols defined by Rodier et al. (2016).

Soil quality assessment

The preparation of soil samples involved two distinct phases: first, extraction of the targeted ions was performed, and second, the concentrations were measured. To ensure accuracy and adherence

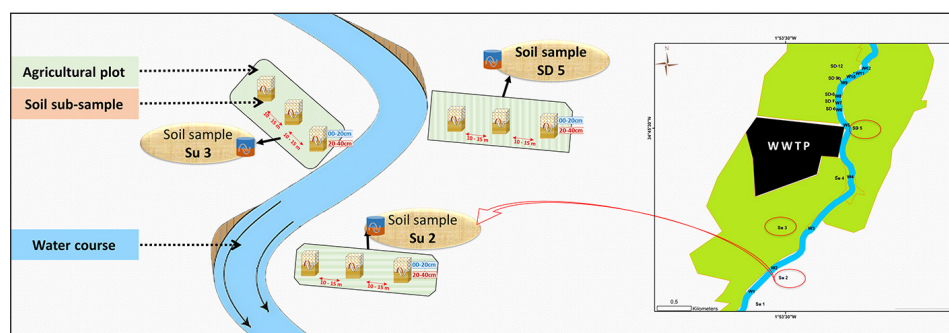


Figure 2. A representative scheme of soil sampling via the “COMPOSITE” method

Table 1. Characteristics of the sampled water stations

| Water stations | Characteristics |
|----------------|---|
| W1 | Located upstream of WWTP wastewater discharge (at a distance of 3 km) |
| W2 | Located upstream of the discharge of wastewater treated by the WWTP (at a distance of 2.5 km) |
| W3 | Located upstream of the discharge of wastewater treated by the WWTP (at a distance of 1.5 km), where there is also the informal deposit of solid waste such as dead animal bodies or livestock excrement, etc.. |
| W4 | Located upstream of WWTP wastewater discharge (800 m distance) |
| W5 | Located at WWTP wastewater discharge point (10 m distance) |
| W6 | Located downstream of WWTP wastewater discharge (70 m) |
| W7 | Located downstream of WWTP wastewater discharge (220 m) |
| W8 | Located downstream of WWTP wastewater discharge (300 m distance) |
| W9 | Located downstream of WWTP wastewater discharge (250 m distance) |
| W10 | Located downstream of WWTP wastewater discharge (450 m) |
| W11 | Located downstream of WWTP wastewater discharge (700 m distance) |
| W12 | Located downstream of WWTP wastewater discharge (1 km) |

to proper protocols, pH was measured according to the ISO-10390 standard (Mathieu and Pieltain 2003), whereas electrical conductivity was evaluated in accordance with the ISO-11265 standards (ISO 1994). Keeney and Bremner (1996) and Keeney and Nelson (1982) used a 2M KCl solution to extract mineral nitrogen in the form of N-NO_3^- and N-NO_2^- ions from the soil, while Olsen and Sommers (1982) employed a 0.5 N sodium bicarbonate solution at pH 8.5 (known as the Olsen-P method) to determine the content of orthophosphate ions. After extraction, the solutions were analysed following the protocols of Rodier et al. (2016) to accurately quantify the concentrations of N-NO_3^- , N-NO_2^- , and P-PO_4^{3-} ions. Hence, the data obtained were processed using MS Excel 2016 software.

RESULTS AND DISCUSSION

Water quality assessment

Upon examining the physical and chemical characteristics of the water collected from Oued Bou Naim (section 3 of the Isly River), located near a wastewater treatment plant, notable discrepancies were revealed throughout the stream. The data recorded for each parameter, encompassing both the lowest and highest values as well as the overall average, provide a comprehensive comprehension of the influence of WWTPs on water quality (Figure 3).

Temperature

Water temperature is a key factor that can have far-reaching effects on the environment, as

observed by Leynaud (1968). It impacts various aspects of aquatic ecosystems, such as the density, viscosity, and solubility of gases; the dissociation of dissolved salts; and the occurrence of chemical and biochemical reactions. Additionally, climate change greatly influences the development and growth of organisms, especially microorganisms, living in aquatic environments (as noted by the WHO (1987). The temperatures recorded in our study ranged from 19.0 °C (W9) to 24.8 °C (W5), with an average of 21.58 °C (Figure 3A). While the measurements generally fall within an acceptable range, there is a slight increase downstream of the WWTP (W5), most likely due to the introduction of treated water. This water may be warmer and still decomposing organic matter, leading to exothermic reactions.

Hydrogen potential (pH) assessment

The pH of water acts as a key indicator of the amount of H^+ ions present, reflecting the balance between different forms of carbonic acid. This measurement is closely linked to the buffering process of carbonates and bicarbonates, as demonstrated by previous studies (Ezzaouaq 1991; El Bliidi et al., 2003; Himmi et al., 2003). Our findings show a range of pH levels, with a low of 7.08 (W7), a high of 8.33 (W2), and an average of 7.73 (Figure 3B), providing valuable insights into water stability. The discharge of organic matter (OM) from the treatment process can impact the pH of the water, potentially leading to acidification reactions. While the pH levels typically fall within the acceptable range of 6.5–8.5, as stated by the WHO (2011), it is still important to monitor their

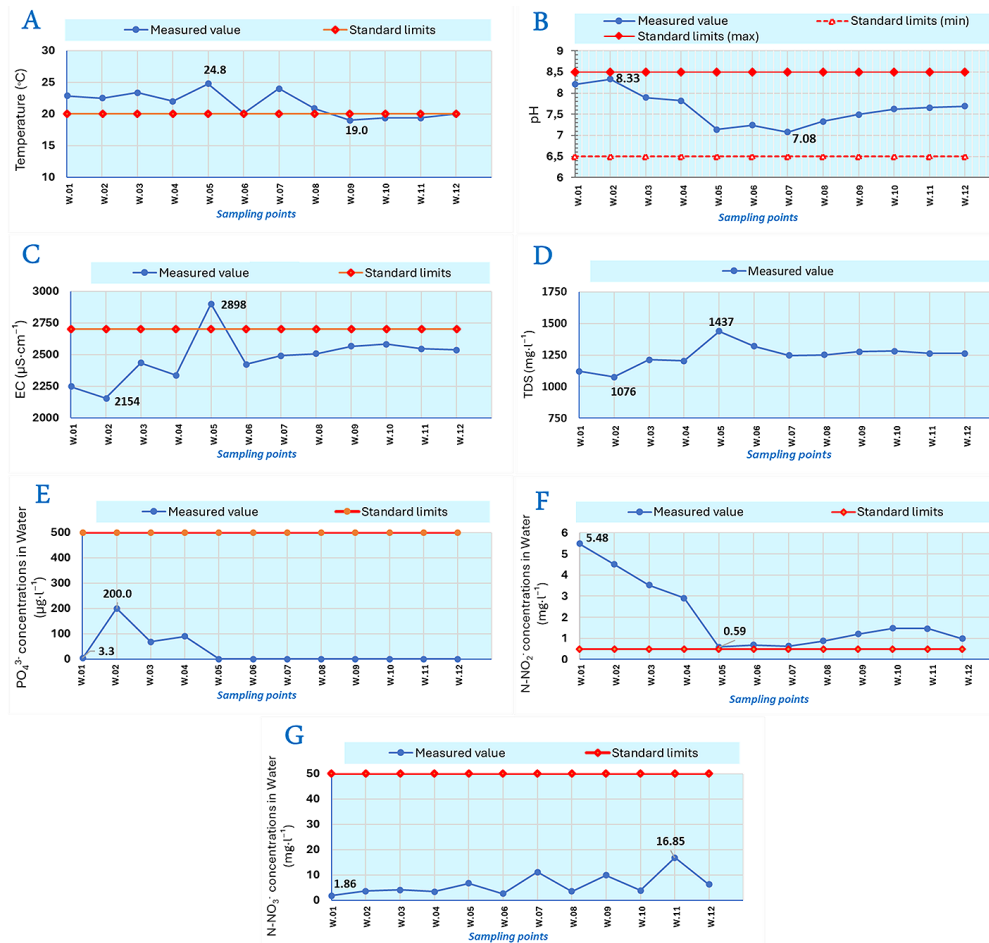


Figure 3. Spatial variation in water quality in Oued Bou Naim: (A) T (°C); (B) pH; (C) EC ($\mu\text{S}\cdot\text{cm}^{-1}$); (D) TDS ($\text{mg}\cdot\text{l}^{-1}$); (E) P- PO_4^{3-} ($\mu\text{g}\cdot\text{l}^{-1}$); (F) N- NO_2^- ($\text{mg}\cdot\text{l}^{-1}$); (G) N- NO_3^- ($\text{mg}\cdot\text{l}^{-1}$)

decrease downstream of WWTPs. This ongoing observation is necessary to ensure the continued health of the water. Overall, most samples had alkaline to slightly alkaline values, which is consistent with the findings of previous studies in which similar streams were treated as Oued Bou Naim (El Halouani 1995; Gharibi et al., 2023).

Electrical conductivity assessment

Measuring water conductivity is an effective way to determine mineralization level, as each ion interacts with its own concentration and specific conductivity (Benyoussef et al., 2022). This assessment is vital for determining the amount of dissolved substances in water, providing valuable insights into the level of inorganic contamination. By measuring the ability of water to conduct electricity, known as electrical conductivity, we can identify the presence of salts and minerals in water. As the concentration of ions, including calcium, magnesium, sodium, and chloride, directly impacts the electrical conductivity of water

(Morrison et al., 2001; Li et al., 2021), the higher the levels of these dissolved substances are, the greater the conductivity will be.

The electrical conductivity levels showed considerable diversity, ranging from $2154 \mu\text{S}\cdot\text{cm}^{-1}$ (W2) to $2898 \mu\text{S}\cdot\text{cm}^{-1}$ (W5), with a mean of $445.67 \mu\text{S}\cdot\text{cm}^{-1}$ (Figure 3C). This trend suggested a greater presence of dissolved ions, likely resulting from the WWTP. Overall, with the exception of W5, all the other measurements fell below the recommended threshold of $2700 \mu\text{S}\cdot\text{cm}^{-1}$ for human drinking water quality (N.M. 2002). Additionally, according to guidelines set by the World Health Organization in 2011, the acceptable level of electrical conductivity in drinking water should not surpass $1000 \mu\text{S}\cdot\text{cm}^{-1}$. However, it appears that all of the studied waters had EC values above this limit. This indicates a clear violation of the WHO's standards. The high electrical conductivity observed in water can have grave consequences for human health, heightening the risk of conditions such as hypertension, cardiovascular disease, and

kidney problems (Fried 1991). Moreover, this issue can also have a significant impact on the overall quality of the water used for various purposes, including irrigation. Furthermore, the samples analysed all exhibited elevated mineralization levels based on the classification system proposed by Detay and Carpenter (1997).

Total dissolved solids assessment

The total dissolved solids levels in the downstream area of W5, which receives WWTP treated water, have shown a noteworthy increase to 1437 mg·l⁻¹. This range is quite significant, varying from 1 076 mg·l⁻¹ at W2 to 1437 mg·l⁻¹ at W5, with an average of 1245.8 mg·l⁻¹ (Figure 3D). Such an increase is a clear indication of the contribution of solids from wastewater treatment. This observation aligns with the high mineralization of Oued Bou Naim's waters, as highlighted in Table 2 according to the Van der Aa (2003) classification. Moreover, the elevated concentrations of mineralization found in the majority of the samples can be linked to salt leaching from the soil along the Wadi. This is likely due to the impact of arid weather conditions, which can induce erosion and transport of minerals. These findings indicate the presence of a natural source of contamination alongside the human-induced source from nearby WWTPs (Dar et al., 2011; Tiwari and Singh 2014).

Assessment of orthophosphates

Phosphorus is a vital nutrient that exists in various oxidized forms (Makhouk et al., 2011). It plays a crucial role in the formation of nucleic acid DNA and RNA and is also involved in the distribution of energy within the human body (Claude et al., 1998). Additionally, BA is essential for the growth of algae as a biogenic element. However, excessive amounts of phosphorus in surface waters can lead to eutrophication. However, they have a beneficial effect by playing a regulatory role: they promote all the phenomena of fertilization, fruit bearing and vegetative organ maturity (Vilain 1989). The

analysis of orthophosphate ions (P-PO₄³⁻) indicated that the highest concentrations were found upstream of the WWTP (W2), where concentrations can reach up to 200.0 µg·l⁻¹ (Figure 3E). However, downstream, these ions are almost nonexistent. In fact, the average concentration of this element was only 31.08 µg·l⁻¹. Although the level of phosphate ions typically stays below the recommended limit of 500 µg·l⁻¹ (as stated by the WHO in 2011) and makes it possible to classify these waters in the “good” class by exposing values below 0.2 mg·l⁻¹ (N.M. 2002), its presence suggests possible contamination from human activities. Specifically, the affected sites are defined by the unauthorized disposal of animal waste or even the remains of household pets (as shown in Table 1). Furthermore, importantly, the presence of orthophosphates may be attributed to urban discharge from nearby cities and the release of phosphorus, which has accumulated in sediments, as suggested by Makhouk et al. (2011). Additionally, Martin (1980) highlights that atmospheric factors such as wind and rain can also serve as sources of phosphates, particularly during periods of low river flow.

Nitrite assessment

At the points upstream of the WWTP, the nitrite ion (N-NO₂⁻) concentration exhibited extremely high values (Figure 3F), with values of 5.48 mg·l⁻¹, 4.5 mg·l⁻¹, 3.52 mg·l⁻¹, and 2.91 mg·l⁻¹ at W1, W2, W3, and W4, respectively. These concentrations far surpass the recommended standard of 0.5 mg·l⁻¹, reaching an alarming 5.48 mg·l⁻¹. However, along the stream from point W1 to W5, the average nitrite concentration gradually decreased to 1.85 mg·l⁻¹. At point W5, a promising level of 0.59 mg·l⁻¹ was recorded, indicating the potential for self-purification. There was a slight increase in concentration afterwards, ranging from 1.0 to 1.6 mg·l⁻¹.

Nitrate assessment

Nitrate pollution is an issue of global significance and has been identified as a significant contaminant

Table 2. Classification of water samples in the study area according to TDS

| TDS (mg·l ⁻¹) | Mineralization | Number of samples | % of samples |
|---------------------------|----------------|-------------------|--------------|
| < 50 | Very low | 00 | 00 |
| 50–500 | Low | 00 | 00 |
| 500–1 000 | Moderate | 00 | 00 |
| 1 000–1 500 | High | 12 | 100 |
| > 1 500 | Very high | 00 | 00 |

in water sources. This is primarily due to the intensive use of agricultural practices, including the application of large quantities of mineral fertilizers, as well as local geological factors (Qin et al., 2013; Zhai et al., 2017). The nitrate ion level (N-NO_3^-) increased after W5, reaching $11.13 \text{ mg}\cdot\text{l}^{-1}$ at W7, $9.88 \text{ mg}\cdot\text{l}^{-1}$ at W9, and $16.85 \text{ mg}\cdot\text{l}^{-1}$ at W11 (Figure 3G). The consensus revealed an average reading of $6.07 \text{ mg}\cdot\text{l}^{-1}$. While these levels fall below the WHO standard of $50 \text{ mg}\cdot\text{l}^{-1}$ (2011), they still suggest the presence of nitrate ions originating from the water processed by the WWTP. This raises the possibility of an abundance of nitrate ions in this specific stream, indicating potential inefficiency in the treatment process for this particular element. In addition, there is a possibility of probable anthropogenic activity, including agricultural activity and the development of habitats not connected to the sewerage system by discharging sanitary discharge directly into the watercourse or via uncontrolled septic tanks (Chafouq et al., 2018). This is why farmers use this water source for the irrigation of vegetable plants located on the edge of this river.

Soil quality assessment

The assessment of soil quality from multiple agricultural plots along the Oued Bou Naim revealed significant variations at different sampling points. The results of key parameter analysis, including orthophosphates (P-PO_4^{3-}), nitrites (N-NO_2^-) and nitrates (N-NO_3^-) (Figure 4), highlight the potential impact of this reuse on the agroecological ecosystem (soil–plant), which is at risk of contamination to consumer health.

Orthophosphate content

The orthophosphate levels in the examined soils showed remarkable variation along the length of the Oued Bou Naim. Before the wastewater treatment plant (WWTP), the points designated S01 to S04 exhibited consistently low levels of P-PO_4^{3-} , averaging $84.42 \text{ mg}\cdot\text{kg}^{-1}$. However, after the treated water is discharged (at points S05–S12), there is a substantial increase in the concentration of orthophosphate ions, with an average of $329.62 \text{ mg}\cdot\text{kg}^{-1}$ and a maximum of $640.0 \text{ mg}\cdot\text{kg}^{-1}$ at S07; these ions are predominantly supplied by water pumped from the WWTP (W7). An increase in phosphate levels in the soil can be attributed to the use of treated water for irrigation, which contains residual phosphate. Particularly at point W7, where the concentration of these ions is low, it is evident that the excess orthophosphate found in plot S07 is a result of farmers utilizing phosphate fertilizers. This is further supported by a survey conducted among these farmers, which revealed their application of corrective measures for crops that demand high levels of phosphate, such as lettuce, spinach, and onion (Ouédraogo et al., 2019).

Nitrite content

The nitrite levels in the tested soil exhibit notable discrepancies. Prior to the WWTP, the values ranged from low (S01–S04), with an average of $3.99 \text{ mg}\cdot\text{kg}^{-1}$. However, beyond the station (S05–S13), the concentrations increase greatly, reaching an average of $11.04 \text{ mg}\cdot\text{kg}^{-1}$, with a peak of $15.36 \text{ mg}\cdot\text{kg}^{-1}$ in the soil sample (S08) located 300 m from the WWTP's outfall. Although irrigation

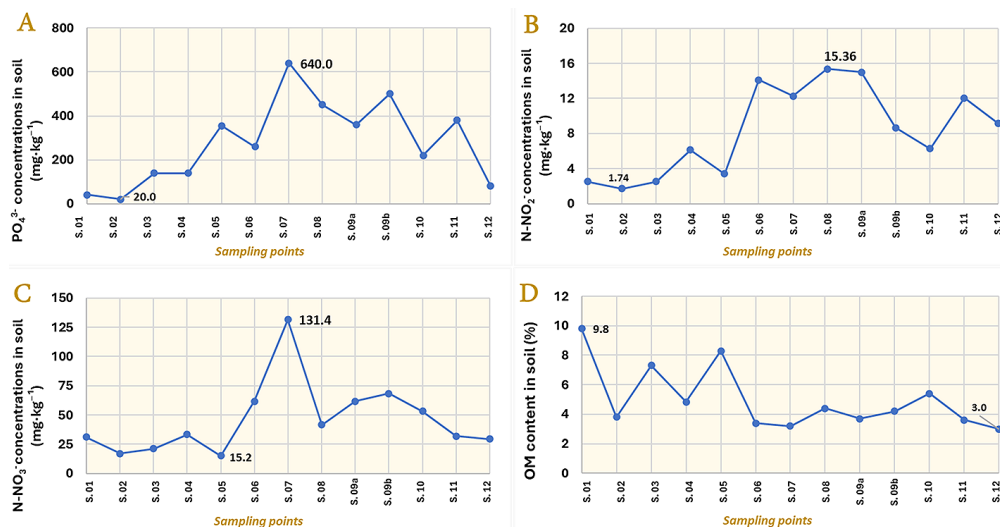


Figure 4. Spatial variation in soil quality in combination with Oued Bou Naim: (A) P-PO_4^{3-} ($\text{mg}\cdot\text{kg}^{-1}$); (B) N-NO_2^- ($\text{mg}\cdot\text{kg}^{-1}$); (C) N-NO_3^- ($\text{mg}\cdot\text{kg}^{-1}$); (D) OM (%)

using treated wastewater may result in the presence of nitrites in the soil, mainly downstream of the WWTP station, these nitrogenous nitrite ions could originate from sources other than reused treated water. For instance, nitrogen fertilizers such as nitrate or urea, which can be converted into nitrites through microbial processes, may also contribute to their presence. Nevertheless, it is crucial to consider that the utilization of recycled effluents for irrigation, as emphasized by Master et al. (2004), could result in high levels of nitrites in the soil, potentially affecting the growth of crops. According to Enduta et al. (2011) and Naghdi et al. (2018), vegetable crops have the ability to remove nitrite ions from recycled wastewater. Enduta's study delves into the utilization of water spinach and mustard in an aquaponic recirculation system, showing promising results in diminishing nitrite levels. Also, Naghdi's study delves into the use of nitrifying bacteria to convert nitrites into nitrates through plant waste, suggesting potential applications for vegetable crops.

Nitrate content

Nitrates, the stable form of nitrogen in oxygenated environments, play a vital role in plant growth and are absorbed by plants from the soil (Tamme et al., 2010). Downstream of the WWTP, nitrate levels significantly increased (from S05 to S13), with an average of 65.46 mg·kg⁻¹ and a maximum of 131.4 mg·kg⁻¹ near the discharge point (S07). This finding underscores the importance of nitrates in maintaining a thriving ecosystem. The concentrations present highlight the potential for contamination from treated water irrigation. This concern is further amplified when considering soils that have been irrigated with both the waters of Oued Bou Naim (which contains nitrogen at even lower levels) and those that have also received fertilization during the growing season, with limited monitoring. Notably, in addition to treated wastewater, nitrogen fertilizers can also contribute to this burden (Olesen and Askegaard 2003). It is undeniable that the leaching of nitrates in organic farming arable crop rotations is a pressing issue, with far-reaching impacts on both the environment and agricultural yield. As highlighted by Olesen and Askegaard (2003), this issue cannot be overlooked. In fact, addressing integrated agricultural systems that operate at high intensity levels is particularly crucial. The risk of excessive nitrogen usage and subsequent leaching is greatly magnified in such systems, underscoring

the urgent need for effective management strategies, as emphasized by Grignani and Zavattaro (2000). As such, the concerns surrounding the potential leaching of agricultural fertilizers into Oued Bou Naim are of utmost importance, calling into question the overall stability of its quality.

Organic matter content

Although many factors may contribute to the variability of organic matter content in agricultural soils, irrigation with treated wastewater can change soil properties and organic matter content. The soil organic matter content in the present study exhibited significant variations. Upstream of the wastewater treatment plant, the values (S01 to S04) remain relatively stable, with an average of 6.42%. However, downstream (S05 to S13), a decrease is observed, reaching an average of 4.08%, with a minimum value of 3.0% near the discharge point (S13). These decreases suggested potential degradation of organic matter due to irrigation with treated water, as confirmed by Jueschke et al. (2008) and Mastro et al. (2009), as indicated by the reduced soil organic carbon after prolonged wastewater irrigation, potentially indicating soil degradation. However, Morugán-Coronado (2011) observed a slight increase in soil organic carbon content in the short term, suggesting that the effects of treated wastewater irrigation may vary over time. This study revealed a significant link between elevated levels of orthophosphates, nitrites, and nitrates in the soil downstream of WWTPs and agricultural activities, potentially attributed to excessive fertilization practices. To gain a better understanding of the extent to which treated wastewater and agricultural practices contribute to this issue, further investigations incorporating isotopic and temporal analyses are necessary. Such research will provide valuable guidance for implementing effective management strategies to safeguard the water quality of Oued Bou Naim.

CONCLUSIONS

In conclusion, the study underscores environmental concerns linked to treated wastewater reuse for irrigation in Eastern Morocco's Isly River region, with a focus on the downstream "Oued Bou Naim" section. Water quality analysis revealed acceptable temperature and pH levels but highlighted potential issues associated with elevated electrical conductivity and dissolved solids

downstream. Soil examination near agricultural plots indicated increased orthophosphates, nitrites, and nitrates, signalling potential contamination through irrigation with treated wastewater combined with the irrational use of agrochemical fertilizers. Despite the purification role of the Oujda WWTP, noteworthy downstream concentrations emphasize the need for meticulous irrigation management. This underscores the importance of careful irrigation practices to avert soil and water contamination, preserving the water–soil–plant ecosystem and human health. A balanced approach to wastewater reuse guided by stringent regulations and sustainable agricultural practices is pivotal in the face of climate-induced water scarcity, ensuring agroecosystem resilience and safeguarding local communities' well-being.

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