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Impact Of Sidi Yakoub And Ouled Mellouk Dam Releases On The Artificial Recharge Of The Alluvial Aquifer In Northern Algeria

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Abstract
Artificial recharge of aquifers is a particularly suitable approach for water resources management, especially in arid and semi-arid regions where groundwater is overexploited as the primary source of water supply. Various techniques have been applied worldwide to enhance aquifer recharge. This study focuses on examining the dam release technique and its impact on the artificial recharge of the alluvial aquifer of the Middle Cheliff region (Northern Algeria). Two case studies were considered: the Sidi Yakoub and Ouled Mellouk dams. To achieve this objective, piezometric level data from wells located downstream of each dam, collected by the National Water Resources Agency during the high-water period (April) and the low-water period (September), were analyzed. The Water Table Fluctuation (WTF) method, combined with the creation of piezometric maps and monitoring of groundwater reserve variations, was employed to assess recharge efficiency. The findings demonstrate the effectiveness of dam releases in sustaining groundwater recharge. After each release operation, groundwater levels in wells rise, indicating that the alluvial aquifer benefits from dam water contributions and is regularly replenished following releases.
Keywords: *Dam Releases, Alluvial Aquifer, Artificial Recharge, Groundwater Recharge, Water Table Level.*

1. INTRODUCTION

The recurrence of drought years, overexploitation of groundwater, the growing number of groundwater extraction structures, and the rising water demand associated with demographic growth in semi-arid regions have led to a marked decline in groundwater levels, reduced well yields, and deterioration of water quality [1-4]. In these regions, domestic supply, industry, and agriculture rely primarily on groundwater. Shortages or degradation of this resource may cause significant damage to these sectors, including reduced farmers' income, decreased food security, and adverse health outcomes [5]. To address these challenges, integrated management of surface and groundwater resources, particularly through artificial recharge operations, has proven to be an effective strategy [6]. Artificial recharge is defined as the process of transferring water from periods of availability to periods of demand by modifying the natural movement of surface water, using techniques adapted to local topographic and geological conditions [7-10]. This approach involves deliberate human intervention to facilitate aquifer replenishment [11, 12]. In practice, surface water is introduced into aquifers to minimize evaporation losses from lakes, avoid siltation of large reservoirs, and secure water availability during droughts.

Artificial recharge has been applied in numerous countries over the past decades to mitigate projected water shortages, particularly in the United States, Germany, Spain, the Netherlands, France, Tunisia, and Morocco. Some countries have even explored the reuse of treated wastewater for shallow aquifer recharge [13-15]. This water management strategy encompasses various methods designed to enhance aquifer recharge and is increasingly applied to preserve, improve, and protect groundwater systems under stress [16,17]. The selection of a suitable method depends on local topography, geology, and soil conditions, the availability and quality of recharge water, as well as the technical, economic, and social feasibility of the program [18]. Recharge can be achieved using surface infiltration structures in permeable soils (e.g., basins, furrows, and ditches) or through injection wells where permeable soils and/or sufficient infiltration areas are absent [19]. Among these methods, infiltration basins in highly permeable aquifers are preferred due to their efficient land use and minimal maintenance requirements [20]. Numerous studies have demonstrated the effectiveness of different artificial recharge systems using diverse water sources [21-30].

Artificial recharge through dam releases into riverbeds in the form of flood waves is one of the most widely adopted techniques over the last fifty years, owing to its technical efficiency, economic viability, and seasonal water availability, particularly in arid regions. This approach has been notably studied in the Walnut Gulch Experimental Watershed in Arizona and in the Kairouan Plain in Tunisia [31]. Positive impacts of dam release recharge have also been reported, including rises in groundwater levels and improvements in water quality [32-35]. However, its effectiveness depends on the volume and quality of water mobilized, storage capacity, and aquifer characteristics. Thus, a comprehensive understanding of hydrology, geology, and ecology is essential for conceptualizing surface–groundwater interactions related to recharge [36-38].

Despite the global development of artificial recharge practices, their application in Algeria has remained limited. Early experiments were conducted on three basins along the upper Oued El Harrach, and subsequently by diverting water from Oued Hammam Melouane into five infiltration basins to recharge the Mitidja aquifer.

The Cheliff region, like many parts of Algeria, is primarily agricultural, with irrigation relying heavily on groundwater due to its relative ease of extraction. However, continuous exploitation has resulted in significant declines in piezometric levels. The present study investigates the impact of controlled releases from the Sidi Yakoub Dam on Oued Sly (280 hm^3 capacity) and the Ouled Mellouk Dam on Oued Rouina (127 hm^3 capacity) on the recovery of groundwater levels in the alluvial aquifer of the Middle Cheliff downstream of these dams.

2. MATERIALS AND METHODS

2.1. Study Areas

2.1.1. Sidi Yakoub Dam – Western Middle Cheliff Plain

The study area corresponding to the Western Middle Cheliff Plain (WMC) is located in northwestern Algeria, approximately 200 km west of Algiers and 30 km from the Mediterranean coast. It covers an area of about 300 km^2 within the Western Middle Cheliff Basin, composed of three sub-catchments: Oued Ras Ouahrane (0122), Oued Sly (0123), and Oued Cheliff Ouarizane (0124) (Fig. 1), part of the larger Cheliff-Zahrez hydrographic basin.

The area extends along the Cheliff Valley from 6 km upstream of Oum Drou to 3 km downstream of Boukadir, reaching Ouled Fares in the valley of the Oued Ouahrane tributary. It is bounded to the north by the southern slopes of the Dahra Mountains and to the south by the Ouarsenis massif. The hydrographic network is well developed, totaling 1967 km, including 1321 km of intermittent streams and 646 km of perennial streams. Five main tributaries contribute to the main watercourse, Oued Cheliff: Oued Ouahrane and Oued Ras on the right bank, and Oued Tsighaout, Oued Sly, and Oued Tafelout on the left bank.

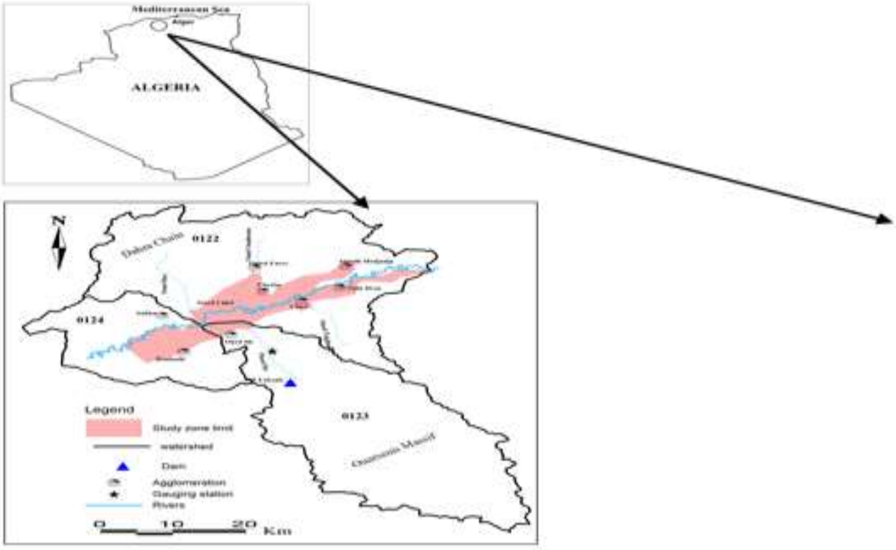


Fig. 1. Location of the study area.

The climate is semi-arid (aridity index 10 < I < 20) with very hot summers and cold winters. The region receives an average annual rainfall of 364 mm (1972–2011), with temperatures ranging from 10.4 °C in January to 30.6 °C in July. Potential evapotranspiration, calculated using the Thornthwaite method (1980–2011), is estimated at 961 mm, approximately 53% of which occurs between July and September. Both study areas belong to the sublittoral sedimentary basin of northern Algeria [39]. Structurally, they form synclines, with substrates outcropping in Cretaceous–Oligocene blocks [40]. The Middle Cheliff plains' intramontane trough is filled with Neogene deposits, including Quaternary sediments up to 300 m thick, along with Miocene and Pliocene layers [41].

The southern slopes feature exposed Upper Miocene limestones underlying alluvial deposits, while more recent Quaternary formations cover Pliocene sandstones. The valley mainly comprises Pleistocene and Quaternary alluvial deposits, consisting of clays, marls, sand, gravel, and conglomerates. Three aquifer horizons exist in both plains: Lithothamnium-bearing limestones**,** outcropping at valley edges and underlying alluvium. Astian marine sandstones and dune sands. Quaternary alluvial deposits**,** forming the primary aquifer.The exploitable groundwater potential of the alluvial aquifer is estimated at 11 hm³ [42].

2.1.2. Ouled Mellouk Dam – Eastern Middle Cheliff Plain

The Eastern Middle Cheliff Plain is part of the larger Cheliff watershed, covering approximately 360 km^2. It is located about 150 km southwest of Algiers, at the junction of the Wilaya of Ain Defla (east) and the Wilaya of Chlef (west). The sub-basins included are Arib-Ebda (0118), Rouina (0119), Tikezal (0120), and Oued Fodda (0121) (Fig. 2). The area is bounded to the north by the Dahra Mountains, to the south by the Cheliff massifs, to the east by the Djebel Doui threshold, and to the west by the Ponteba gorge.

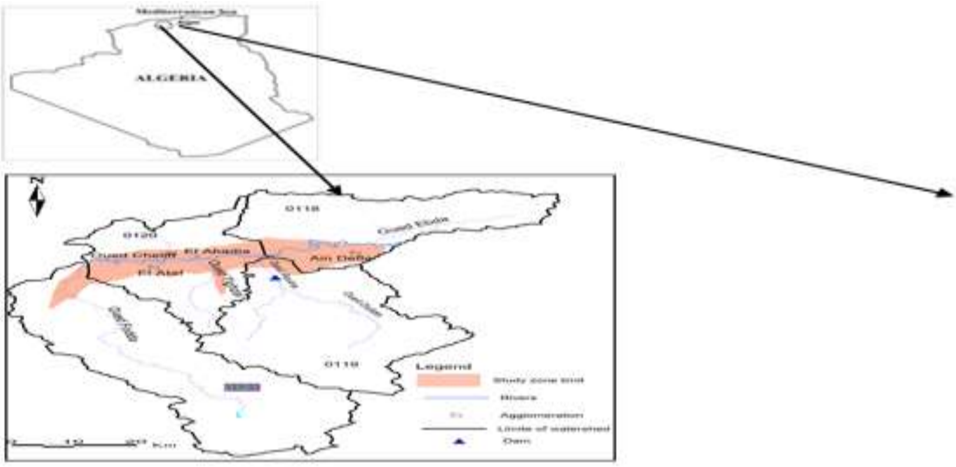


Fig. 2. Location of the study area.

The climate is semi-arid Mediterranean, characterized by irregular rainfall, hot, dry summers, and mild, humid winters. Temperatures range between 8 °C in January and 27 °C in July. Annual precipitation measured over 40 years varies from 260 mm to 610 mm, with an interannual average of 447 mm, indicating significant variability and alternating wet and dry years.

The lithological framework of the Middle Cheliff Oriental plain is composed primarily of Neogene and Mio-Plio-Quaternary formations. The substratum, largely of Secondary age, is exposed along the margins of the basin. This plain is bounded by the Ouarsenis Mountains to the south, the Dahra Range to the north, and, to the east, the epimetamorphic schistose massifs of Doui, Rouina, and Temoulga. Within this structural setting, three main aquifer horizons have been identified: Quaternary alluvial deposits, Astian sands and sandstones, and Lower Tortonian sandstones and calcareous sandstones. These units collectively form the principal groundwater reservoirs of the region, playing a critical role in its hydrogeological system.

2.2. Methodology:

Artificial recharge assessment was conducted on the alluvial aquifers of both Western and Eastern Middle Cheliff plains, the largest and most exploited aquifers in the region. The Water Table Fluctuation (WTF) method [43-45] was employed to estimate groundwater recharge by analyzing water-level fluctuations in observation wells.

For the Sidi Yakoub Dam, 58 measurement points were considered, while for the Eastern Middle Cheliff alluvial aquifer (Ouled Mellouk Dam), 37 observation points, including wells and boreholes, were used. Measurements were conducted twice annually: during the high-water period in April and the low-water period in September. The WTF method is based on the assumption that any observed rise in the water table in shallow wells is caused by additional recharge to the aquifer.

3. RESULTS AND DISCUSSION

3.1 Monitoring of Piezometry Downstream of the Sidi Yakoub Dam

At boreholes 105-2 and 105-1, located 17 and 18 km downstream of the dam, the piezometric level fluctuated between 70 m and 79 m during the period 1986–2013. A sharp decline was observed from the low-water period of 2009, with an average drop of 40 m. This marked decrease could be attributed to a low storage coefficient. In addition, reduced rainfall likely limited natural recharge, compounded by intensive pumping for irrigation.

Well 105-19 showed a clear correlation between water level fluctuations and dam releases, reflecting low-water periods except in cases of continuous exploitation during drought to meet irrigation demand. Recovery of piezometric levels in the three wells during the 2011 low-water period, despite sharp declines during the high-water season of the same year, is clearly linked to dam releases, as shown in Figure 3.

The influence of releases is further demonstrated by differences between the three wells, separated by 3.6 km (105-2 and 105-19) and 1 km (105-2 and 105-1).

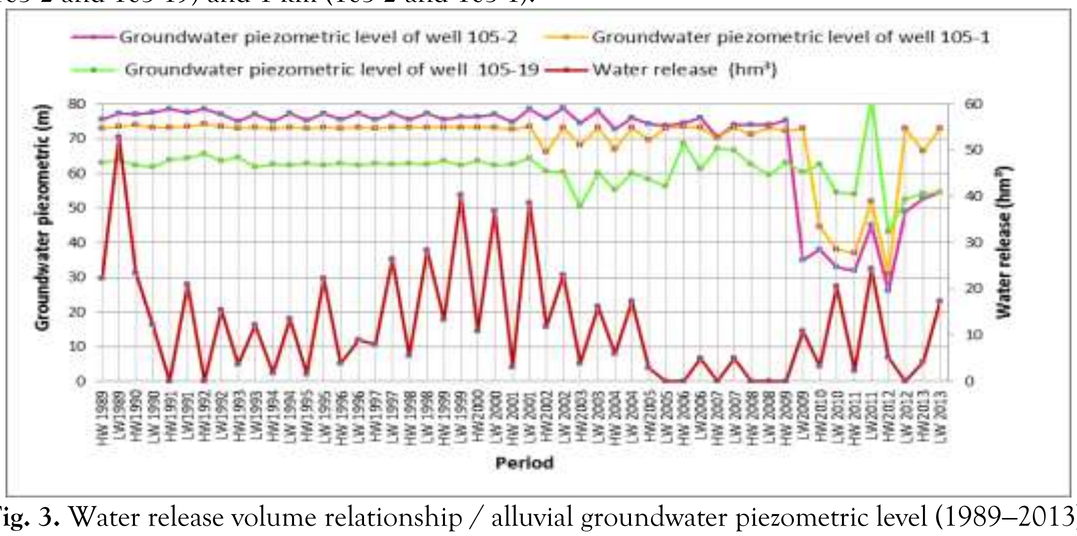
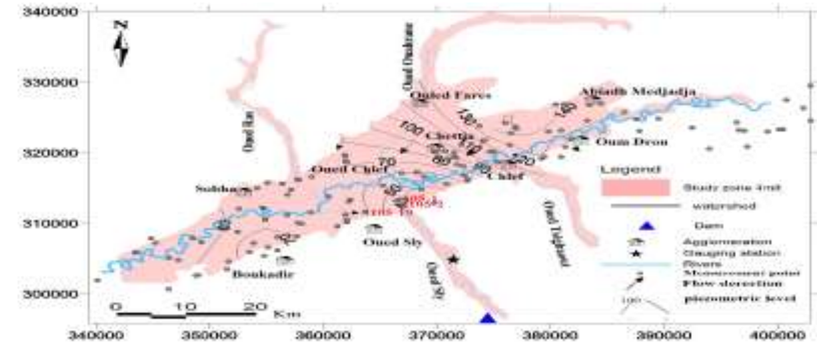


Fig. 3. Water release volume relationship / alluvial groundwater piezometric level (1989–2013).

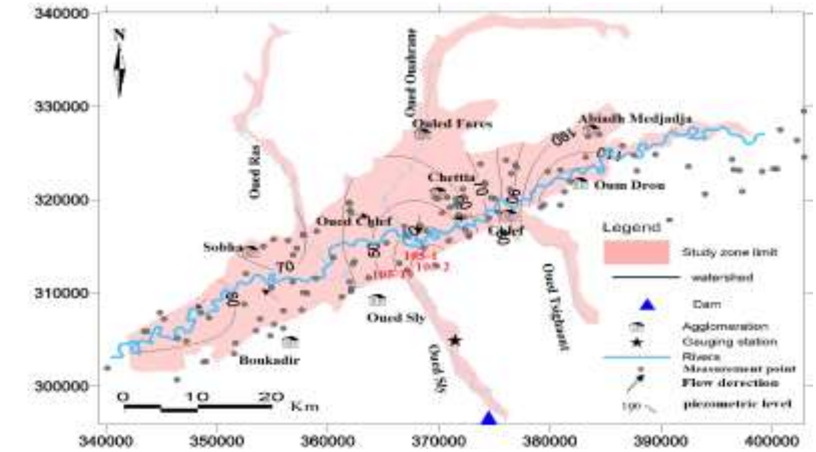
Piezometric maps constructed to characterize groundwater flow and to track changes in the alluvial aquifer of the Western Middle Cheliff (2010, 2011, 2016, 2017; for both high- and low-water periods) show isopiezometric lines perpendicular to the northeastern boundary (Ouled Fares), indicating impermeable limits and absence of external recharge. In contrast, in the southwest (Boukadir and Oued Sly), the lines become parallel to the boundary, suggesting inflow to the aquifer.

The piezometric contours intersect the Oued axis perpendicularly, with slight convergence toward it, indicating groundwater inflow to the Oued Cheliff. According to the National Water Resources Agency and the Chlef Irrigation Directorate, 13 springs have been identified across the plain, with a combined capacity of 49,365 m^3, all exploited for domestic, livestock, and small-scale agricultural use.
Groundwater flow is directed toward the center of the alluvial plain due to its basin-like morphology, bordered by mountain ranges where groundwater heads are high and naturally flow downslope. Assuming transmissivity values are relatively constant, the primary hydrological factor is the hydraulic gradient, which decreases east to west and is weakest at the center. Variations in gradient are likely due to changes in flow cross-section and recharge. Gradient increases upstream and at the aquifer margins correspond to highly recharged zones. Flow generally proceeds from the southern margins toward the central valley axis, then westward along basin morphology.
Depressions observed in 2010 and 2017 resulted from intensive pumping for agriculture. Recovery of piezometric levels in 2011 and 2016 low-water periods, along with the appearance of a piezometric dome near point 105-19 during the 2011 low-water period (Fig. 4d), confirm recharge from dam releases.

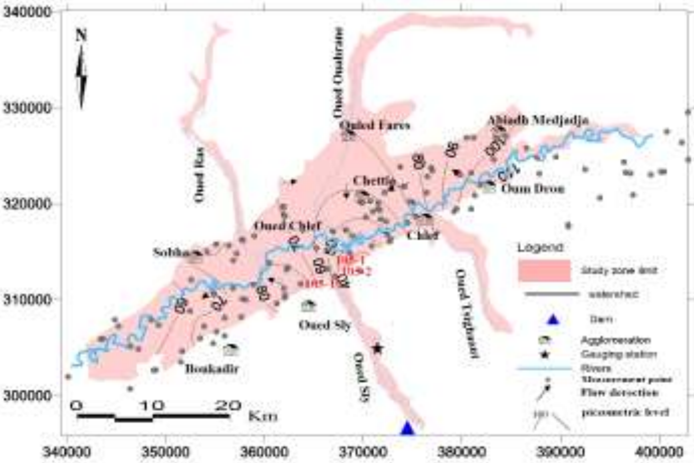


(a) High water 2010

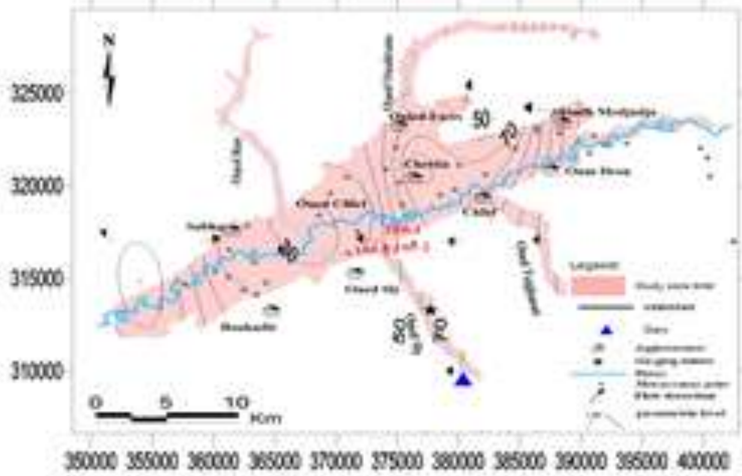
(b) Low water 2010



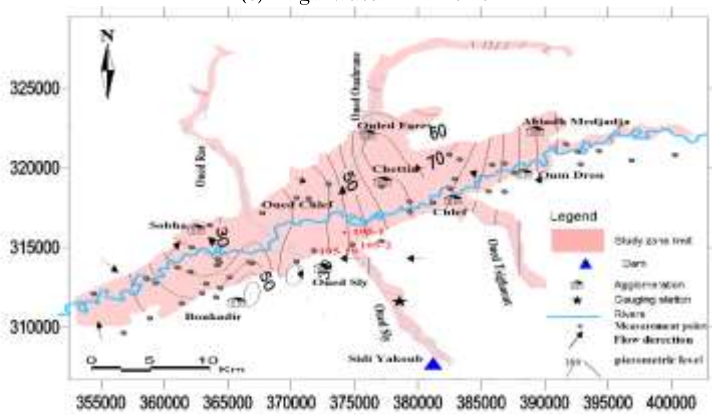
(c) High water 2011



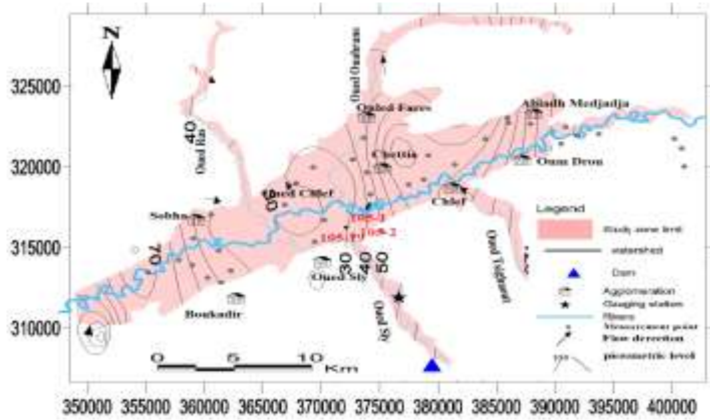
(d) Low water 2011



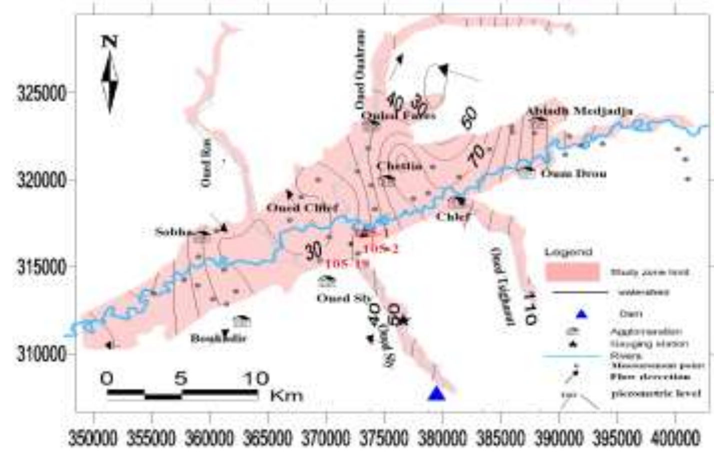
(e) High water 2016



(f) Low water 2016



(g) High water 2017



(h) Low water 2017

Fig. 4. Piezometric fluctuation of the water table of the western middle cheliff.

A notable divergence zone in the central valley is attributed to aquifer recharge from tributaries or liminitic limestone formations. Due to insufficient data for a complete water balance, aquifer reserve evolution was tracked using a graphical method, applying the formula:

$\mathrm{Re} = s.S.\Delta h$ Where:

Re is reserve of a water table in m^3.

s is storage coefficient.

S is drawdown surface in *m*.

Δh is drawdown in *m*.

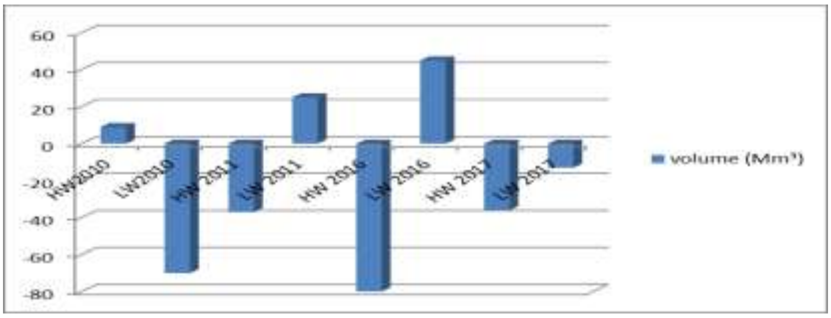


Fig. 5. Variation in the reserve of the alluvial aquifer of the middle western cheliff.

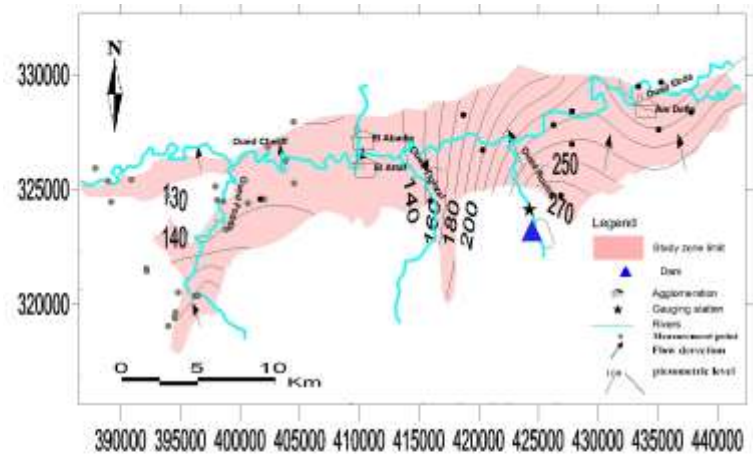
The obtained results indicated in Fig. 5 show that in 2010 the aquifer increased by 9 Mm^3 during floods, indicating rainfall recharge. However, 70 Mm^3 was lost during droughts due to intensive pumping. In 2011, 2016, and 2017, recharge during high-water periods did not compensate for extraction. Increases of 25 Mm^3 (2011) and 45 Mm^3 (2016) during low-water periods indicate aquifer replenishment from dam releases. Conversely, a loss of 13 Mm^3 in 2017 highlights intensive groundwater pumping.

3.2 Monitoring of Piezometry Downstream of the Ouled Mellouk Dam

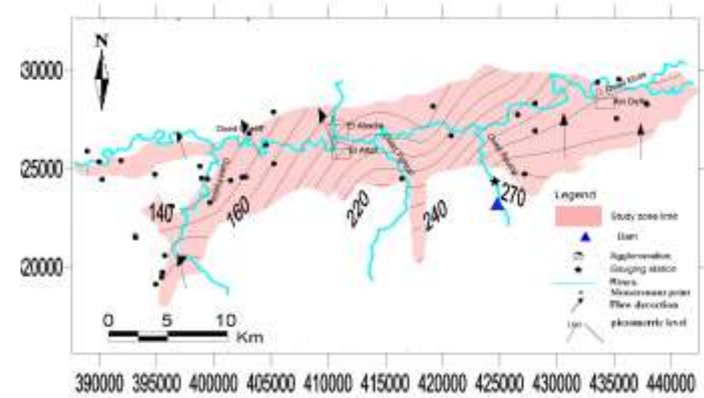
Piezometric maps for 2010, 2011, and 2012 show a general east-to-west decline in groundwater levels, consistent with surface water flow (Fig. 6). Contours reveal lateral recharge converging toward Oued Cheliff. Tight contours between Rouina–Ain Defla and Rouina–El Attaf indicate steep gradients caused by Miocene clay substratum uplift. The piezometric regime remained stable across years, reflecting consistent flow patterns.

Low-water piezometric maps show surfaces nearly identical to high-water periods, as in 2011. Differences are minimal, reflecting intensive aquifer exploitation for irrigation. Flow direction remained unchanged (east–west), but contour spacing widened under low gradient. Divergences in 2010 high-water and 2012 low-water maps suggest recharge zones.

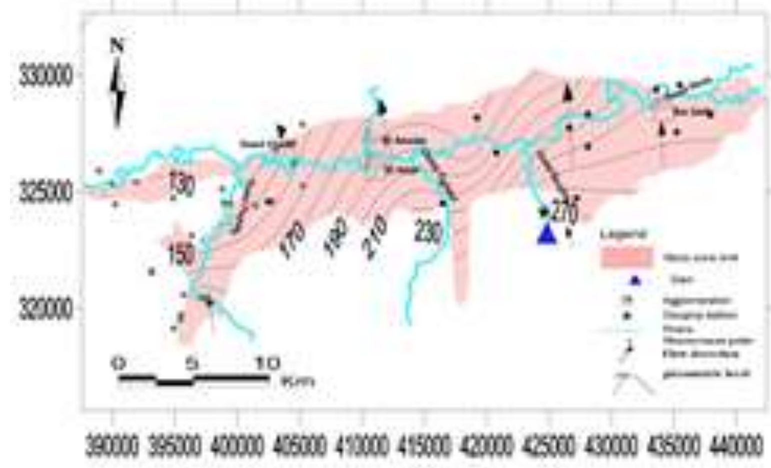
Using the same groundwater reserve calculation as in the western aquifer (Fig. 7), results show recharge since 2009, with 3 Mm^3 gained initially. By the 2010 low-water period, 56 Mm^3 was infiltrated, contrasting with a 1 Mm^3 decline during 2011 high-water (low rainfall). Groundwater reserves continued increasing from both rainfall (high-water periods) and dam releases (low-water periods), reaching 132 Mm^3 in 2012. Notably, Ouled Mellouk Dam released 16 hm^3 in 2010, 12 hm^3 in 2011,



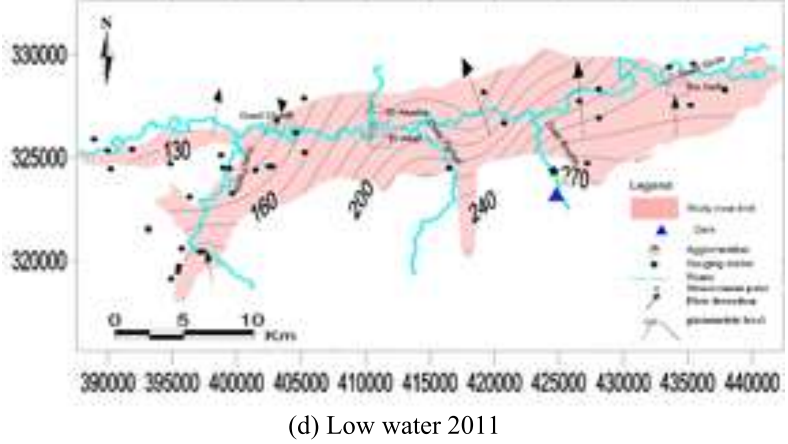
(a) High water 2010



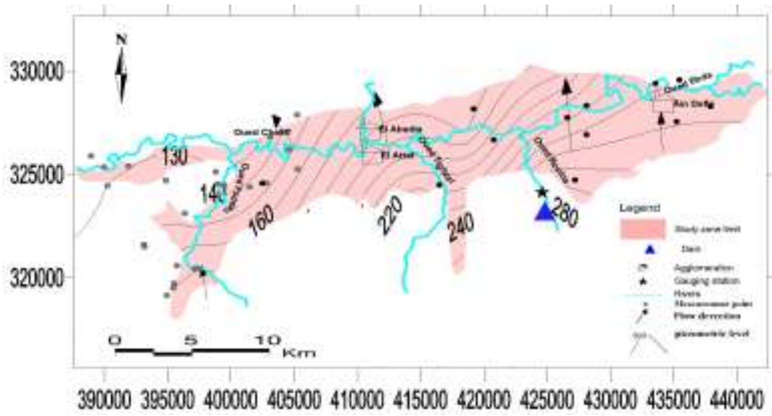
(b) Low water 2010



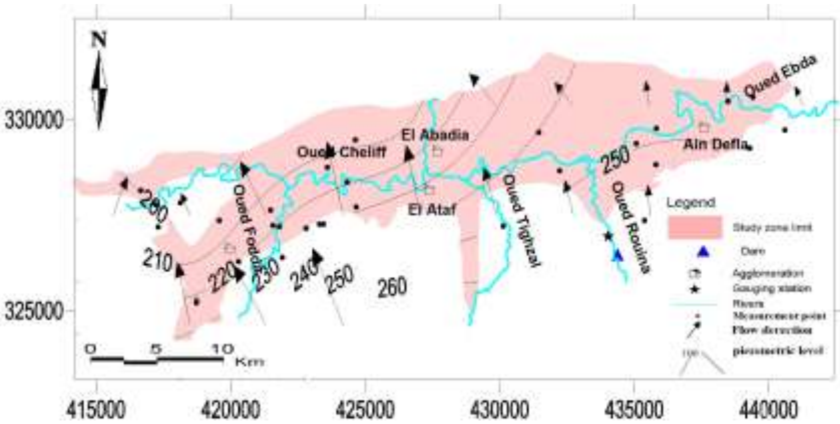
(c) High water 2011



(d) Low water 2011



(e) High water 2012



(f) Low water 2012

Fig. 6. Piezometric fluctuation of the water table of Middle Eastern Chellif.

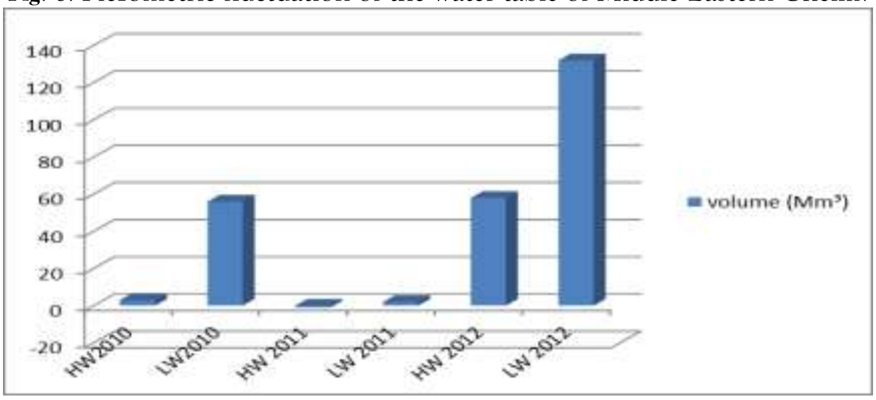


Fig. 7. Variation in the reserve of the alluvial aquifer of the Middle Easterne Cheliff.

4. CONCLUSION

This study demonstrates that artificial recharge of aquifers through controlled dam releases in the form of flood waves is an effective method to counteract groundwater depletion in the Middle Cheliff alluvial aquifer. Depletion arises from both natural factors (rainfall scarcity) and human factors (excessive irrigation pumping).

From piezometric maps and groundwater reserve variations, the following findings were established:

Groundwater generally flows from the southern margins toward the central valley axis, then shifts east–west along basin morphology. Hydraulic gradient decreases from east to west, influenced mainly by lithological heterogeneity.

Low-water piezometric maps mirror those of high-water periods, showing both aquifers are replenished by dam releases.

Controlled releases restore piezometric levels of wells and boreholes, particularly near the junctions of Oued Sly and Oued Rouina with the aquifer, and in areas closest to the dams. This also improves groundwater quality.

Thus, this technique is particularly suitable for arid and semi-arid regions, as it minimizes evaporation losses compared to surface reservoirs, ensuring sustainable groundwater availability.

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