EEET ECOLOGICAL ENGINEERING & ENVIRONMENTAL TECHNOLOGY

Ecological Engineering & Environmental Technology 2023, 24(1), 104–115
https://doi.org/10.12912/27197050/154994
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Received: 2022.09.04
Accepted: 2022.10.10
Published: 2022.11.01

Contribution of GIS for the Piezometric Monitoring of the Unconfined Water Table Aquifer of the Fez-Meknes Basin

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ABSTRACT

The Fez-Meknes basin consists geomorphologically of the Meknes plateau to the west and the saïss plain to the east, separated by the Ain Taoujtat flexure. It is characterized by a semi-arid climate. Hydrogeologically, the basin contains two important aquifer reservoirs, a free and a captive water table. The first one circulates in the Plio-Villafranchian formations, while the second one is deep in the dolomitic limestone of the Lias. These two aquifers communicate with each other in some places, either directly through flexures and faults or indirectly through upward drainage. They are the main sources of drinking water and irrigation. These two aquifers have been overexploited due to successive years of drought and agricultural use. Thus, this work aims to monitor the piezometric level of the free water table through several field trips, technical data sheets of the drillings, geological and topographical maps. The analysis of rainfall data in the stations located around the piezometers in the study area allowed to distinguish a low water period (June, July, August and September) and a high-water period (March, April and May). The piezometric maps were made on the basis of the comparison between kriging and TIN during the low and high-water period. The TIN method has been recommended as the most reliable one.

Keywords: upward drainage, Fez-Meknes basin, piezometry, aquifer reservoir, overexploitation.

INTRODUCTION

The aquifer of the Fez-Meknes basin belongs to a semi-arid region with a high agricultural production potential and an undeniable industrial activity. It constitutes an important source of drinking water and irrigation (surface area of about 49 725 ha). After the long periods of droughts that have classified Morocco in the category of countries with chronic water stress, the hydrodynamics of the free water table of the Fez-Meknes basin has experienced an overexploitation of these groundwater. In order to obtain reliable and representative information on the evolution of these resources, we resorted to a temporal piezometric monitoring through the realization of inter-seasonal piezometric maps, in particular during the low (June, July, August and September) and high waters (March, April and May). They provide a vision on the state of the water table at a given time. These maps provide important information on the functions of the reservoir (exchanges at the edges of the aquifers or between them and the leakage of irrigation canals, discharge and recharge areas, the gradient of the water table...) (Castany, 1982). After the collection of piezometric data, the realization of piezometric maps relies on spatial modelling integrated by GIS software such as ArcGIS, through its extension Geostatistical Analyst. The latter suggests several functions that are used for geostatistical interpolation of different data values (Johnston, 2004). Depending on the desired objectives of the expected representativeness of the results (Renard and Comby, 2006), several considerations are taken into account when choosing an appropriate technique

(Rogers, 2003; Martin and Schwartz). According to previous work by several authors (Annen et al., 2008; Aboufirassi and Mario, 1983; Kumar and Ahmed, 2003; Pucci and Murashige, 1987; Sun et al., 2009; Kumar, 2007) the universal kriging and intrinsic kriging method for interpolating piezometric data is the most suitable. The objective of this study is to test the TIN method, which is considered as old and frequently used by hydrogeologists, with the kriging method, to choose the most reliable and the most adapted to the free water table of the Fez-Meknes basin.

Geomorphology and geology of the study area

The Meknes-Fez basin is a syncline that occupies the median part of the southern Rifian sillon. Its northern part is bordered by the prefectural wrinkles, its southern part by the middle Atlas causse, its eastern part by the valley of the Oued Sebou and the western part by the Oued Beht and its tributaries (Figure 1).

The regional synthetic log of the basin (Figure 2) begins with shales and flysch of the Palaeozoic and passes to formations of the Triassic translated by an alternation of red clays and basalts. These formations are surmounted by limestones and dolomites of the Lower Jurassic. On these deposits comes to settle the cover with its Neogene filling. The lower Pliocene is constituted by sands with a carbonate matrix, which surmounts the grey marls of the Mesinian (Boumir, 1990; Brahim, 1991) and passes to the upper Pliocene to sands which will constitute the future tawny sands (Taltasse, 1953). Nevertheless, the roof of the series is composed of Quaternary age deposits known by their heterogeneity (Amraoui, 2005), materialized by tawny silts, oncolytic limestones, and oncolytic sands (Chamayou et al, 1975).

HYDROGEOLOGY

The Fez-Meknes basin is composed of two important aquifer reservoirs. It is the free surface water table that circulates in the Plio-Villafranchian formations (Chamayou et al., 1975) and the water table that circulates in the dolomitic limestone of the Lias. The latter is free at the level of the Middle Atlas Causse and then sinks under the thick series of impermeable Miocene marls, which put it in charge under the plain and constitutes the captive water table. These two aquifers intercommunicate in places either directly through flexures and faults, or indirectly through upward drainage. The free water table which will be the subject of our study is fed mainly by rainfall infiltration, by the return of irrigation water and by the contributions by direct abouchements of the free part of the Liasic water table (Belkhirri, 2007; Benaabidate, 2010; Bahaj et al., 2004).

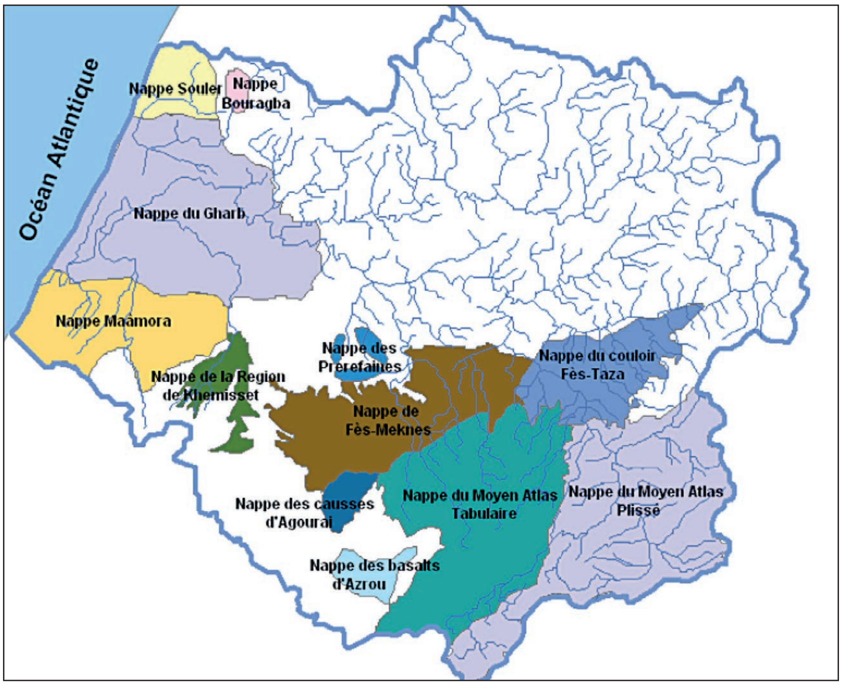

Figure 1. Situation of the Fez-Meknes aquifer in the Sebou basin (ABHS, 2008)

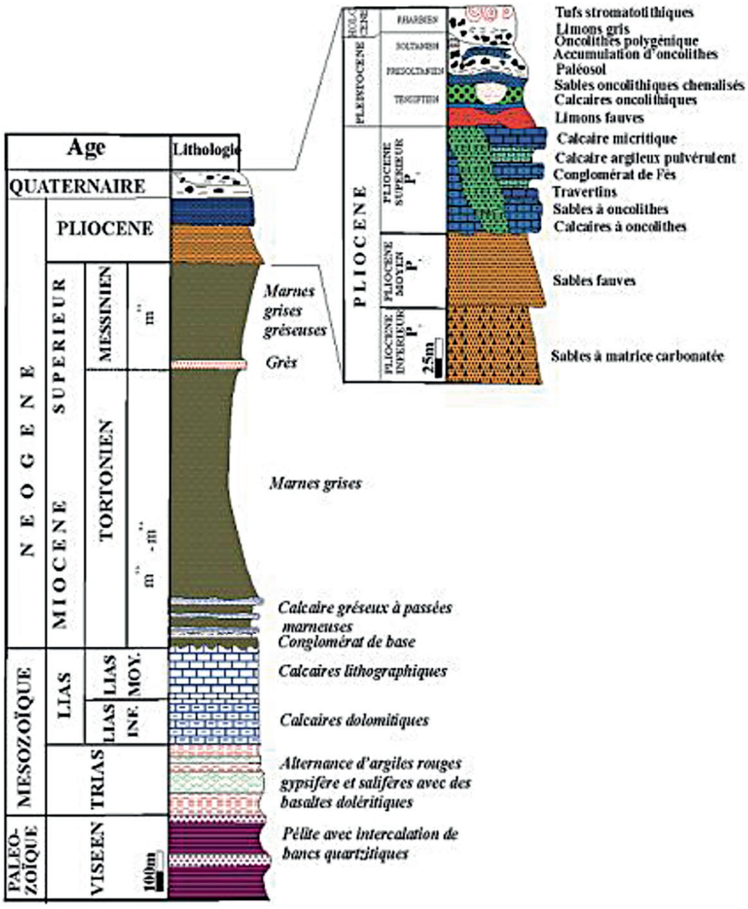

Figure 2. Synthetic lithostratigraphic log of the Fez-Meknes basin (Essahlaoui, 2000).

MATERIALS AND METHODS

To achieve the objectives of this study, and for the representation of the hydrodynamics of the Fez-Meknes aquifer, rainfall and piezometric data were collected from each of the monitoring piezometers (693/14; 3362/15; 2763/15; 290/22; 2366/15; 3362/15) considered as the closest to the rainfall stations. Measurements of the piezometric level of the free water table of the Fez-Meknes basin were carried out on 15 piezometers dispersed in such a way as to cover the entire study area (Figure 3). Two field surveys were organized, one during the low water period, and the other during the high-water period. These periods have been determined beforehand, after the analysis of the historical rainfall data from 2005 to 2019 of 7 stations: Ain Jemaa, Fez-saïss, Meknes, ABHS, Doyiet, Bouderbala and Agouray. This is to realize the representative map of each period. The piezometric maps are fundamental documents on which are based the conductive and captive functions of aquifers and their hydrodynamic behaviour (Castany, 1982). They represent the distribution of potentials and hydraulic loads at a given date. The special interpolation presented by the Geostatistical analyst has been used. This option allows to map the measurements at positions on the whole study area where no measurements are available from the field (Gratton, 2002). In our study, we will be interested in representing and interpolating the piezometric surface which corresponds to the tracing of iso-value curves designated by isopiezes or hydrosohypses. Among the different interpolation methods presented, the kriging and the TIN interpolation methods were chosen. This last approach is the oldest and simplest spatial interpolation technique used by hydrogeologists. It is based on the creation of a network of non-overlapping triangles whose vertices correspond to the measured values. Kriging is considered the most accurate interpolation method for piezometric surfaces (Kumar, 2007; Annen et al., 2008; Pucci and Murashige, 1987; Kumar and Ahmed, 2003). It is based on the assumption that two points close to each other have similar characteristics. After the triangles are constructed in the case of the TIN method, they are

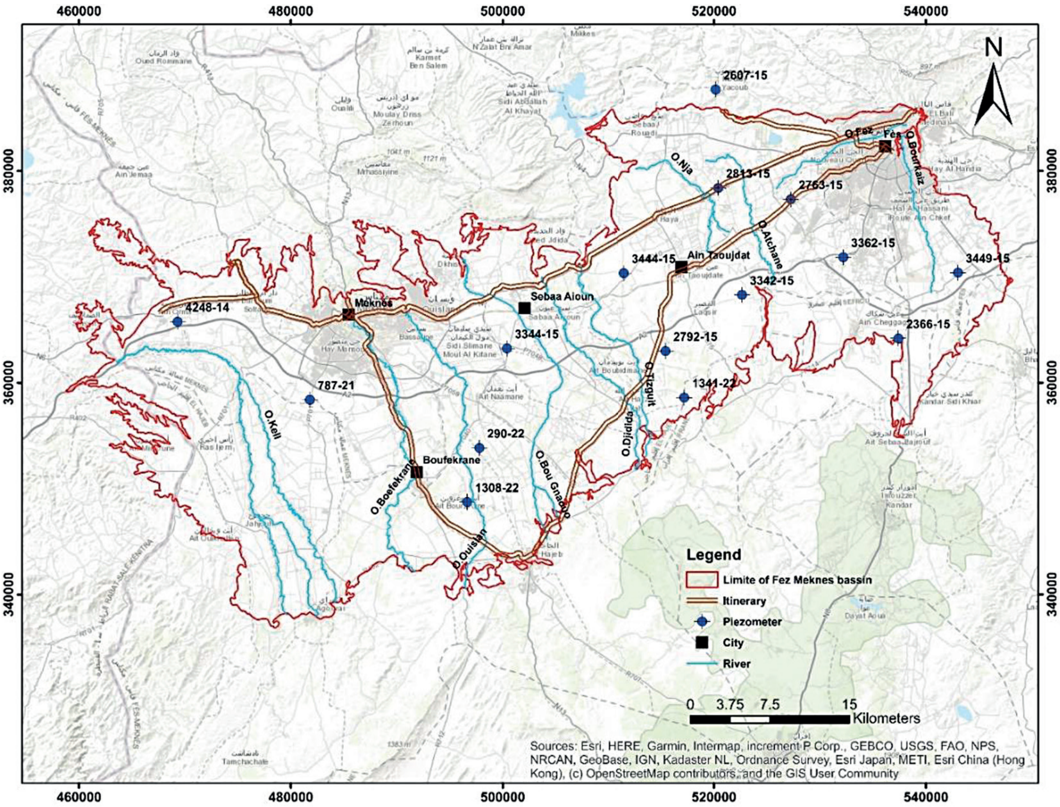

Figure 3. Distribution map of piezometers in the Fez-Meknes basin

converted to a raster image where the isopiez can be displayed. They will be used to interpolate the piezometric surface.

RESULTS AND DISCUSSIONS

The rainfall data were organized in the form of graphs (Figure 4), in order to determine the period of low and high water of the free water table. These data will be used to generate piezometric maps for each period. The analysis of these graphs shows the evolution of the piezometric level as a function of the rainfall. Indeed, an increase in rainfall is followed by an increase in the piezometric level especially during the months of March, April and May forming the high-water period. While a decrease in rainfall is followed by a regression of the piezometric level especially during the months of June, July, August and September qualified as low water.

In ArcGIS, the first step in creating a piezometric map before processing the data is to explore the data through a histogram (Figure 5) to present the distribution of the piezometric altitude of the water table. The analysis of the histogram indicates a normal distribution of the data, centred around the mean, which proves that a statistical study can be used to interpolate the piezometric data by kriging.

Then, we proceed to compare the piezometric measurements according to their inter-distance by drawing the semivariogram (Figure 6) of the piezometric elevation of the free water table. The analysis of the latter shows a good correlation between the points near each other, with a distribution that approaches a spherical curve.

A test of the reliability and representativeness of the model is necessary. In fact, the comparison between the experimental piezometric measurements and the interpolated values (Figure 7) showed a good correlation with a conformity factor of 0.99 for both the summer and winter periods. This step allowed us to notice that there are no aberrant points resulting from a typing error during the numerical data entry. Therefore, the variogram model chosen previously is validated, and on which is based the realization of the piezometric maps for the periods of low and high water by kriging.

The last step is the creation of high and low water piezometric maps (Figure 8 and 9) from a kriging with the semivariogram model chosen previously. They represent several pieces of

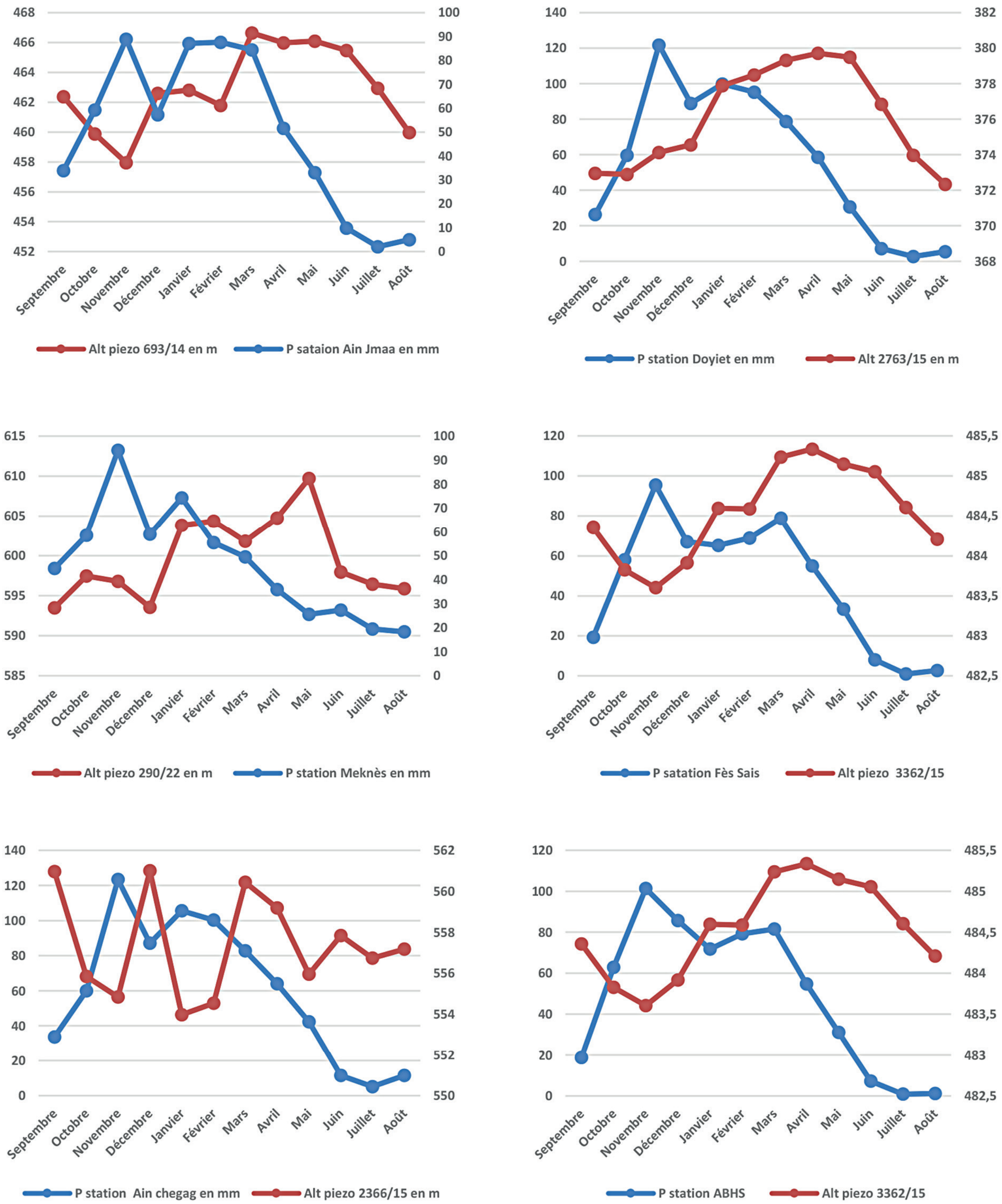

Figure 4. Piezometric and rainfall evolution from 2005 to 2019

information that will be used to determine the direction and sense of groundwater flow. To facilitate their interpretation, the streamlines are traced. They are straight lines perpendicular to each isopiez, therefore with greater slopes. They translate the average direction of the flow. Then their arrows indicate the direction of the flow.

As for the TIN interpolation method, after creating the triangles and correcting them by deleting the triangles drawn between two widely spaced measurement points, we transform them into a raster image (Figure 10 and 11). This step will be used to display and smooth the contours with an equidistance between the isopiez of 20 m.

The result of the superposition of the isopiez of the two maps obtained by the kriging and by TIN during the periods of the low and high-waters (Figure 12 and 13), shows a certain shift of

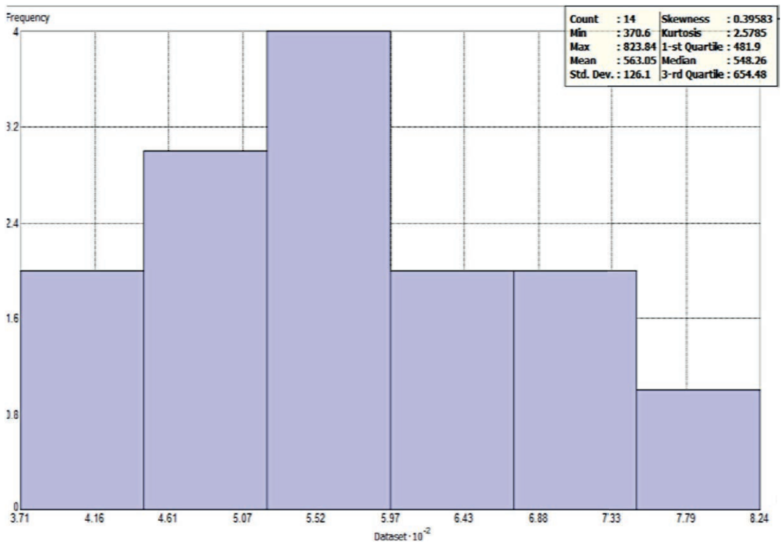

Figure 5. Frequency histogram of piezometric level elevations

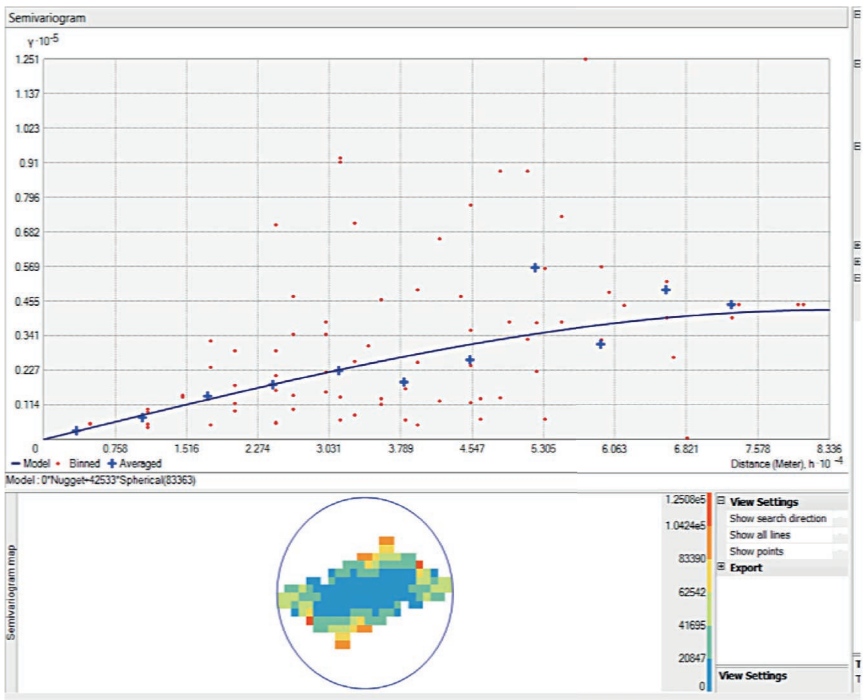

Figure 6. Semivariogram model of piezometric level elevations

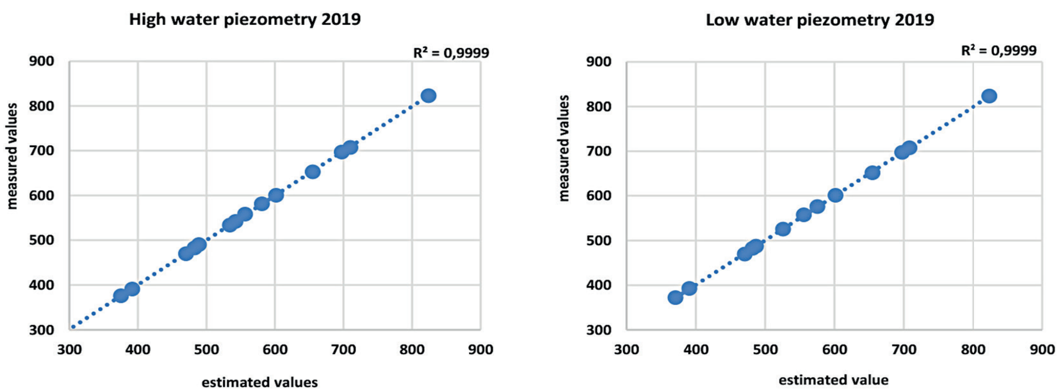

Figure 7. Correlation between measured and estimated values

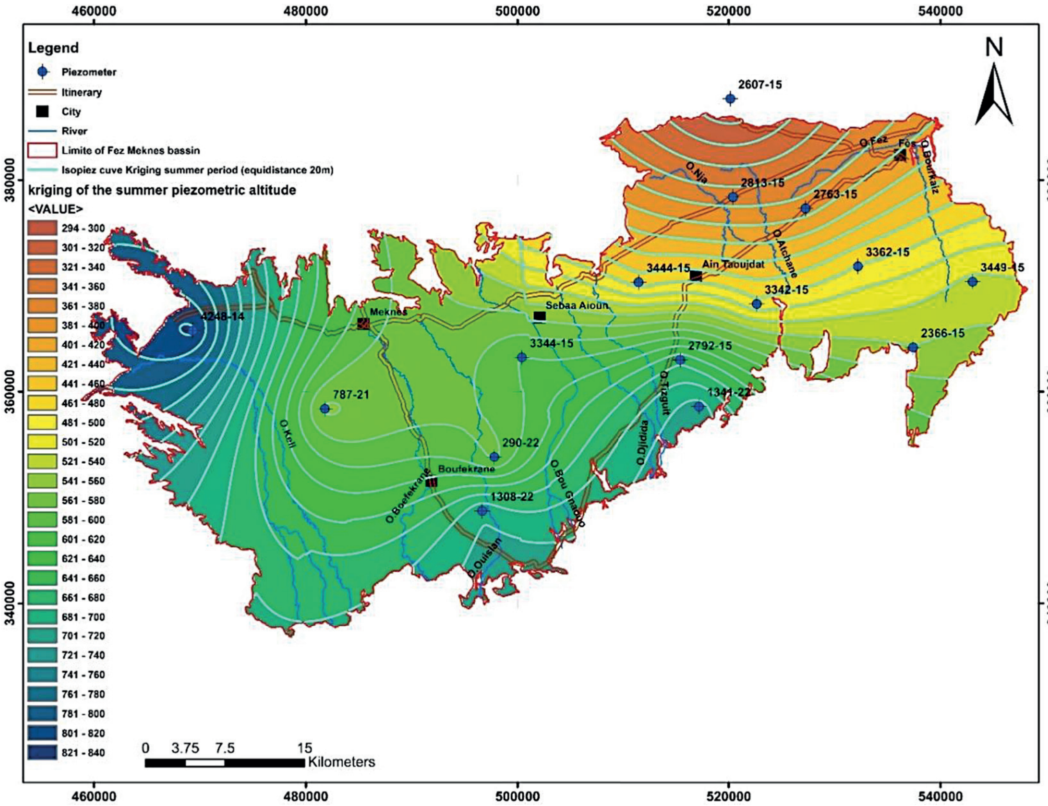

Figure 8. Piezometric map obtained by kriging (low water period: June, July, August, and September 2019)

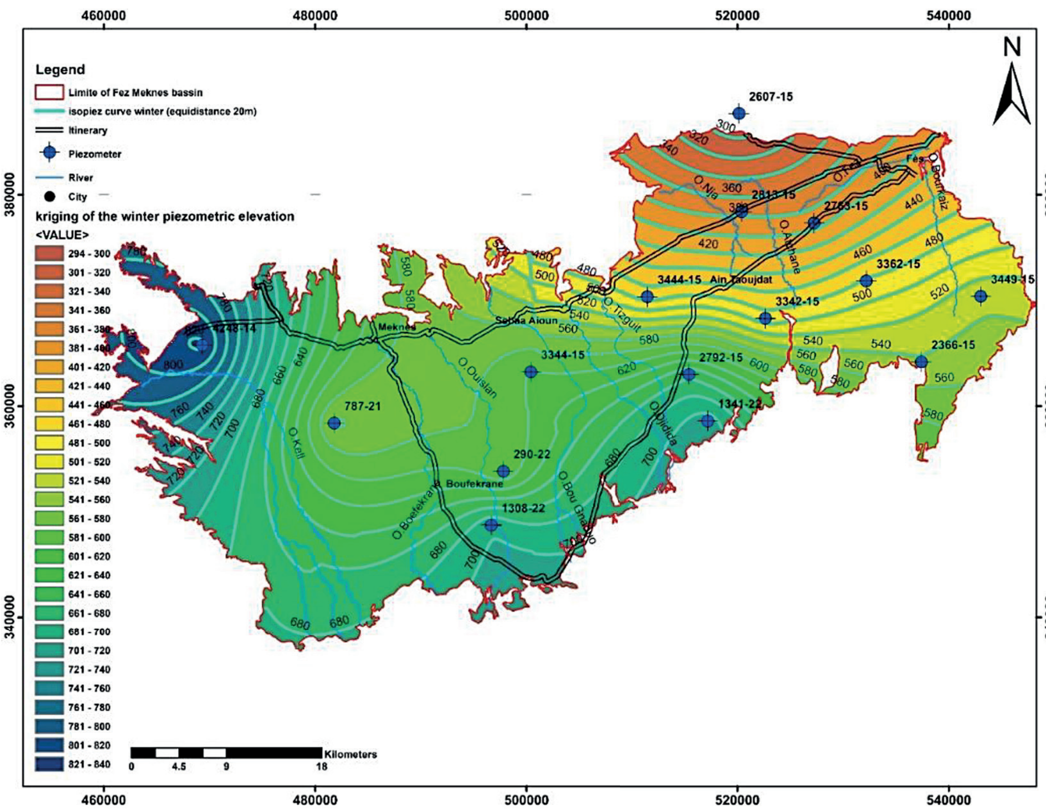

Figure 9. Piezometric map obtained by kriging (high water period: March, April and May 2019)

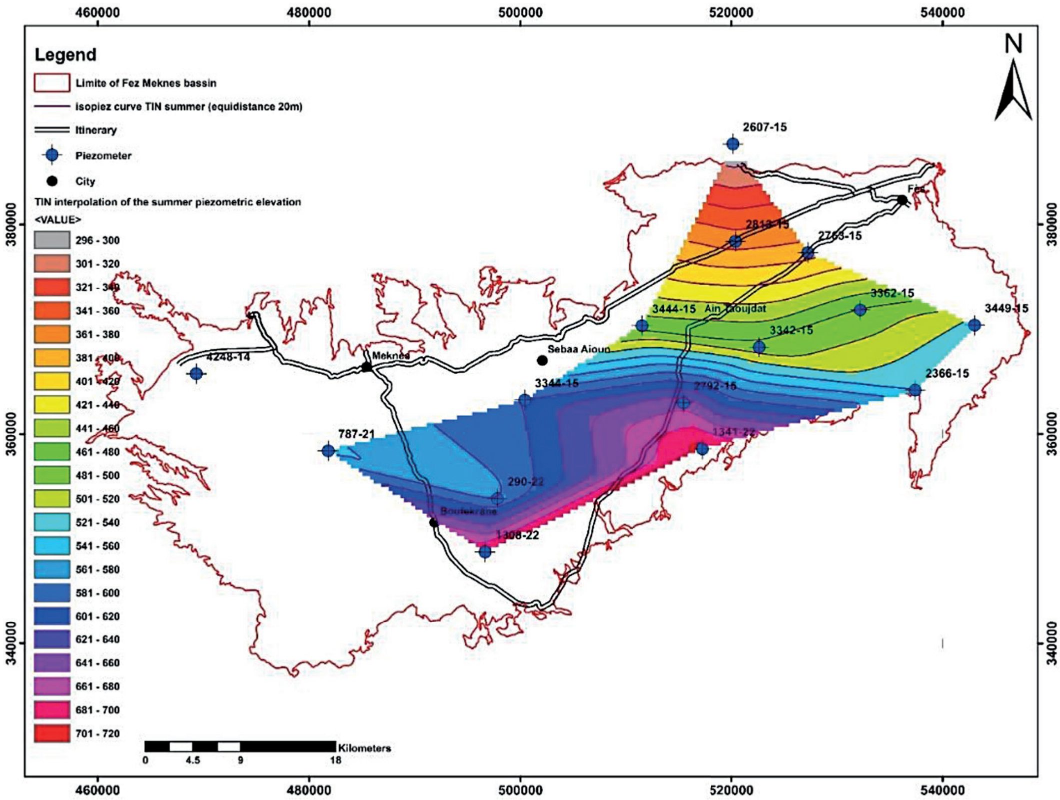

Figure 10. Piezometric map obtained by TIN (low water period: June, July, August, and September 2019)

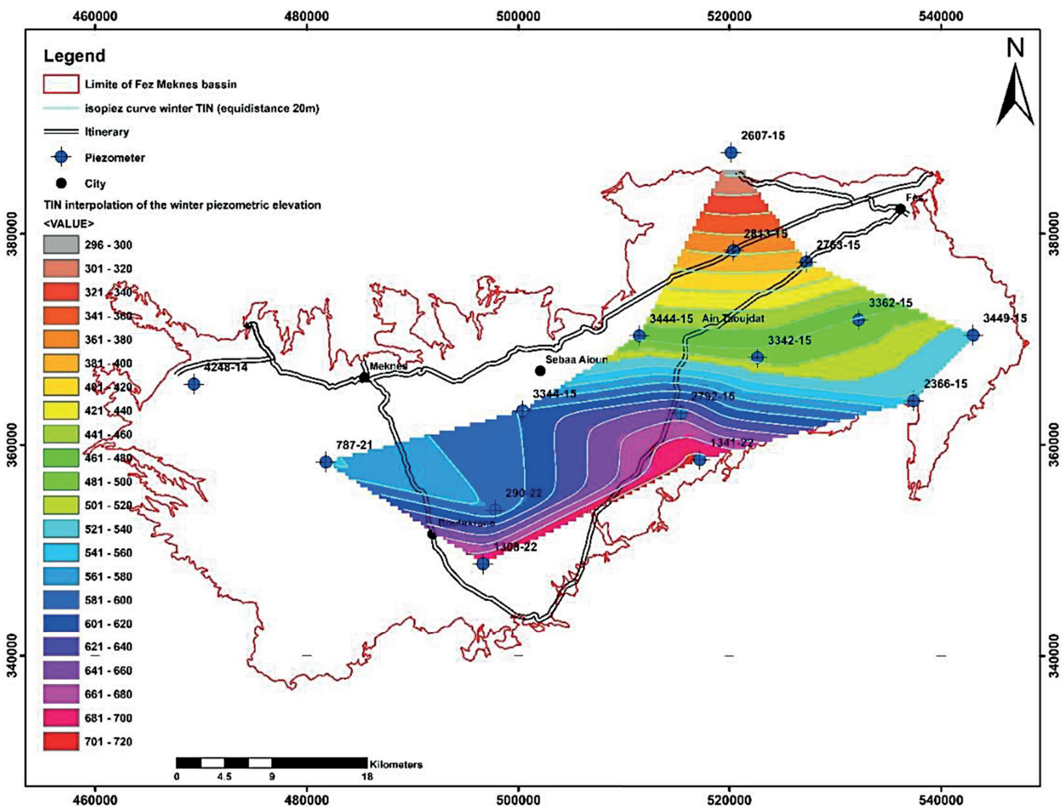

Figure 11. Piezometric map obtained by TIN (high water period: March, April and May 2019)

these last ones in relation to the others. This led us to verify the certainty of the TIN method, taking the example of triangle number 21. The TIN interpolation obtained by manually tracing the isopiez curves in this triangle gives a result consistent with that given by the TIN method of ArcMap. The calculation of the average margin of error between the isopiez curves showed that the piezometric map obtained by kriging is shifted by 2.76 m during the low water period, and by 2.12 m during the high-water period compared to the one obtained by the TIN interpolation. This makes it possible to recommend this method of interpolation as the most reliable, while pointing out that it is necessary to increase the number of piezometric measurement points, so as to cover the maximum of the study area. In fact, the TIN method does not extrapolate beyond the water points.

The final piezometric maps obtained (Figure 14 and 15) are interpolated by the TIN method recommended previously as the most reliable. On the other hand, since it does not allow an extrapolation outside the measurement points, we have continued the interpolation by the kriging method, taking into consideration that it presents a margin of error. Consequently, the final maps correspond to the combination of TIN and kriging. Their morphological analysis shows a general flow of the free water table from S to N. This analysis can also be confronted with geology. This gives a qualitative idea about the boundary conditions of the aquifer. Therefore, along the southern boundary of the study area, we note that the isopiez curves are generally parallel and locally oblique to the southern border of the aquifer, with a direction of flow oriented towards its internal part. This allows to assign to this edge an imposed flow that feeds the aquifer in large part from the free Liasic water table of the Middle Atlasic Causse. As for the northern, eastern and western boundaries, we notice that the isopiezes appear perpendicular. This signifies that the conditions at the level of these edges constitute a tight limit with zero flow. On the other hand, a certain irregularity of the flow direction is reported at the passage of the Ain Taoujtat flexure. Indeed, it is deviated towards the NE in the direction of the saïss plain, and towards the NW on the Meknes plateau. The western part of the latter also knows a change of direction which is explained by the effect of the Toulal flexure. As for the direction of the flow which goes from NW to SE is explained by an overexploitation of the water table in this

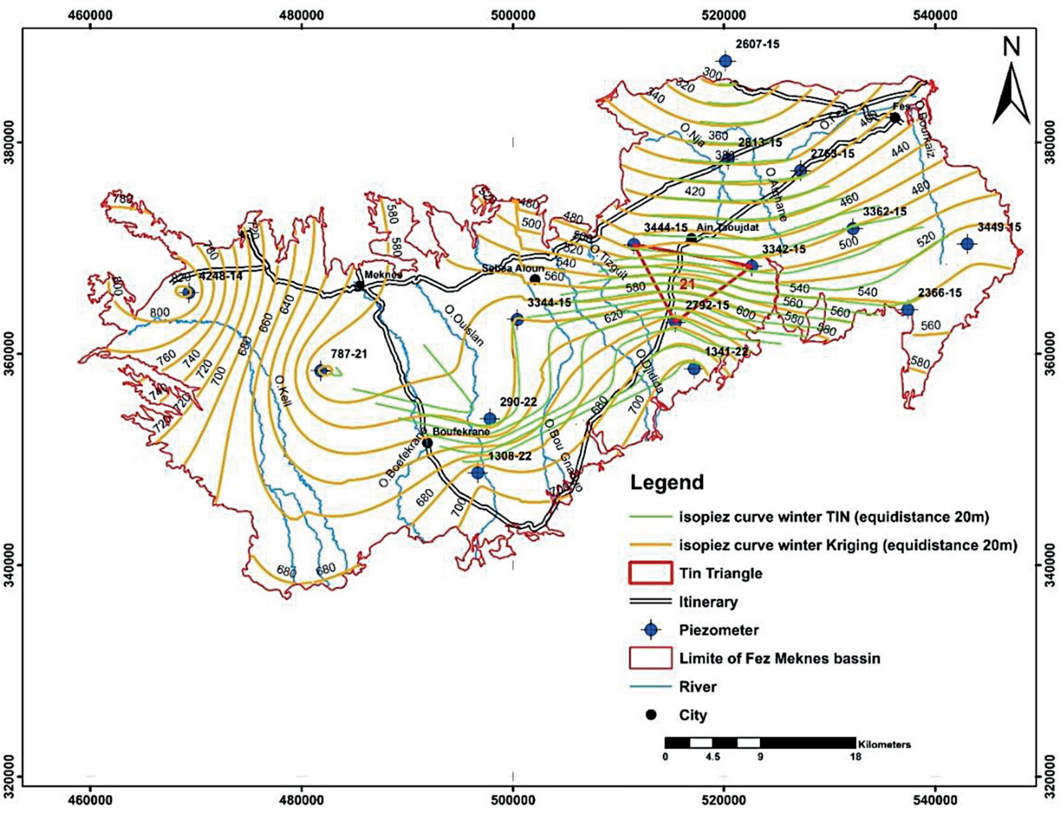

Figure 12. Superposition of high-water period isopiez obtained by kriging and TIN

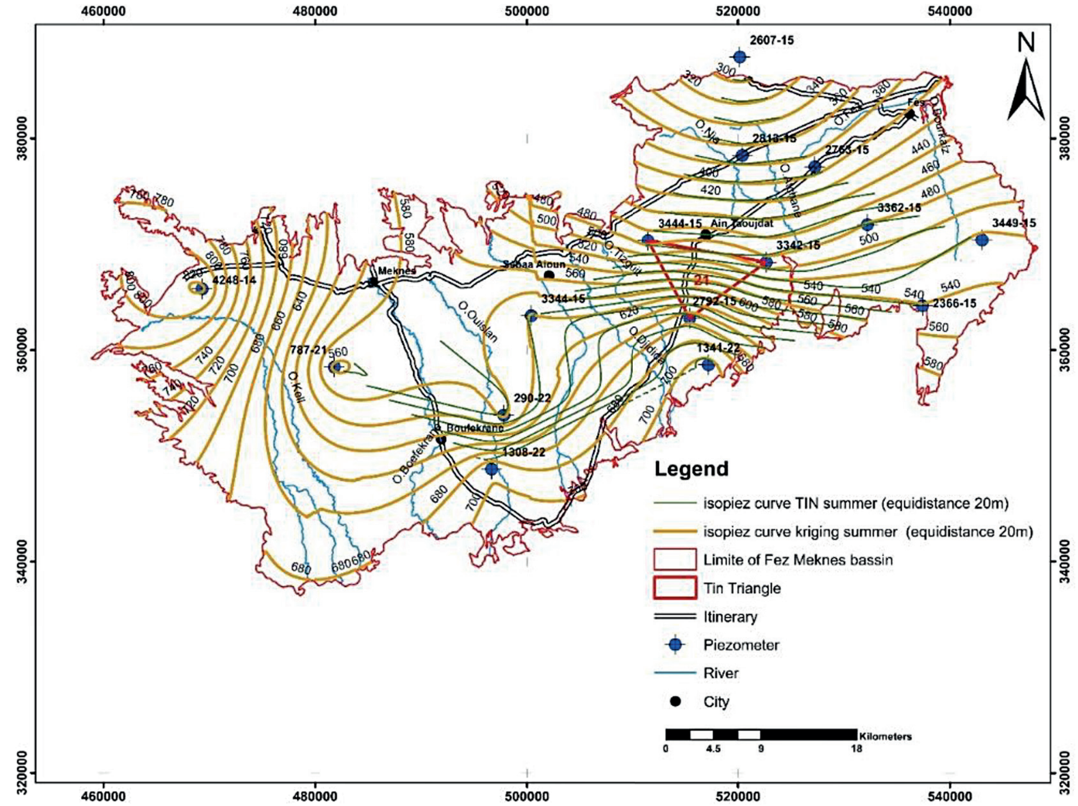

Figure 13. Superposition of low water period isopiez obtained by Kriging and TIN

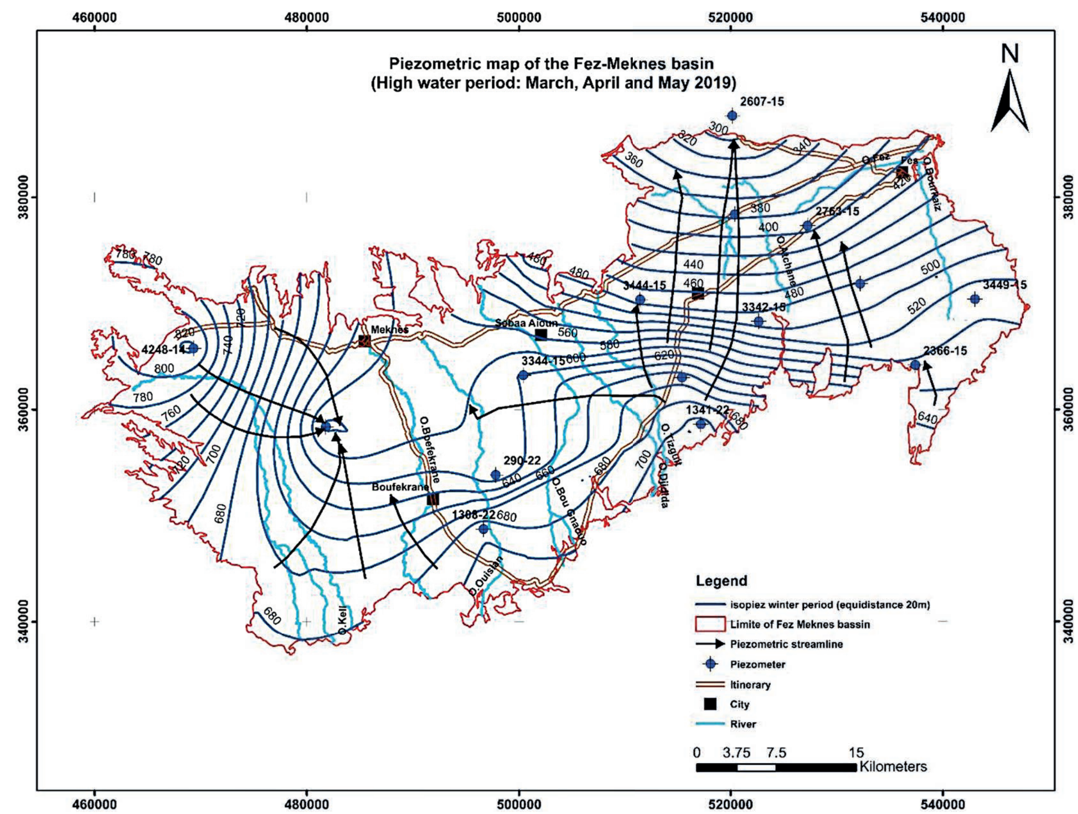

Figure 14. Piezometric map of the low water period

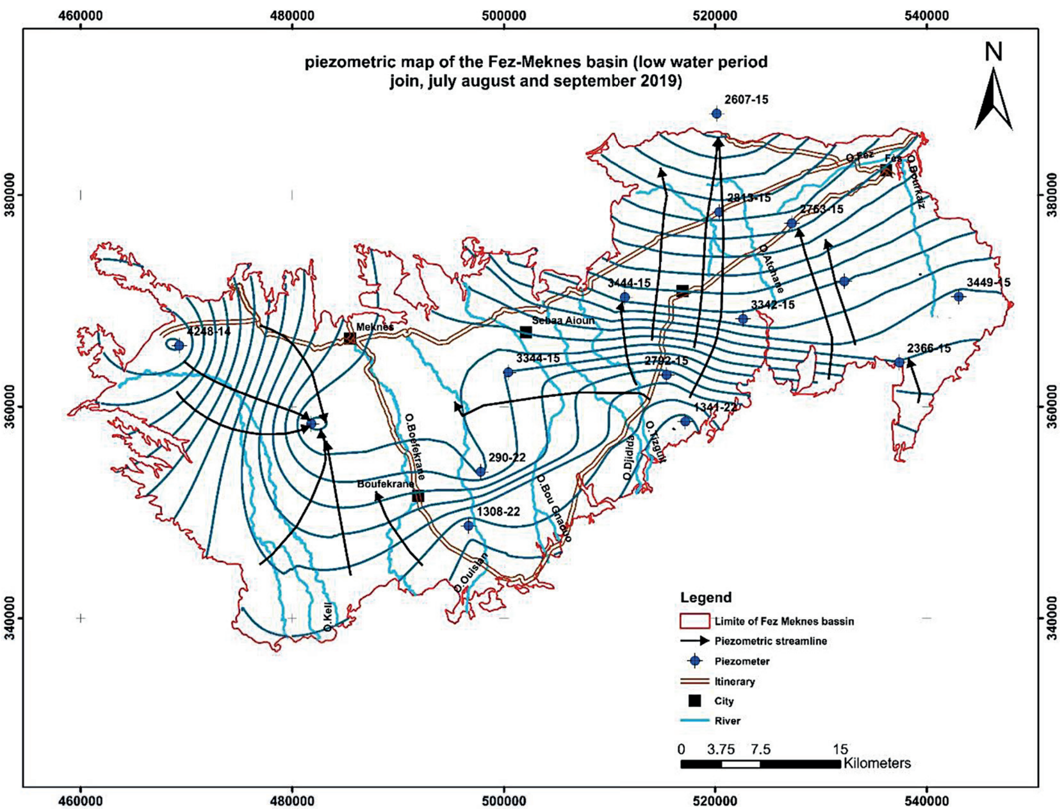

Figure 15. Piezometric map of the high-water period

area. Generally, and beyond the areas affected by the effect of the flexures, the concavity of the isopiezes is oriented downstream of the free water table, in relation to the direction of the flow, which means that we are in the case of a convergent water table.

CONCLUSIONS

The interpolation functionalities of the Geostatistical analyst extension offer many possibilities for the interpolation of a piezometric situation. The joint use of TIN and kriging geostatistical methods shows that geostatistical interpolation by TIN allows to produce a more realistic map. In fact, the resulting maps respect well the spatial comportment of the piezometry. Except that this method has geostatistical interpolation limitations when extrapolating. Thus, the addition of auxiliary measurements should allow to further improve the accuracy of the results, especially in areas without measurements. The morphological analysis of the piezometric map shows a general flow of the water table from S to N with some irregularity at the level of the Ain Taoujtat flexure and the Toulal flexure.

Acknowledgements

The authors would like to thank the Thematic Project 4 on Integrated Water Resources Management of the Institutional University Cooperation Program (CUI, VLIR-UOS) for the equipment used in this study. Thanks, are also due to the anonymous reviewers for their valuable comments on this paper, which allowed us to improve the scientific quality of this research.

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