

Identification of suitable sites for aquifer recharge in Moura region (southern Portugal)

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Abstract Recent research found a decrease in the recharge of the karstic Moura-Ficalho (MF) aquifer and called for further research on appropriate mitigation strategies to reverse desertification. This research identifies areas where natural recharge has occurred within the MF aquifer and where recharge could be increased through Managed Aquifer Recharge (MAR) techniques. Topographic maps and hydraulic heads were constructed using Geographic Information System (Arc GIS) software to identify sites with sufficient ground storage space for artificial recharges. Data analysis found the northern, western, and eastern margins of the Moura region unsuitable for recharge due to impermeable layers, insufficient groundwater storage space, and insufficient water resources. The central region of the MF was also unsuitable as the groundwater and hydraulic potential throughout the aquifer could not be increased. The southern margin was shown to be most suitable for groundwater recharge as it had adequate groundwater storage space and an available water supply.

Key words Moura-Ficalho (MF) aquifer system; sink holes; natural recharge; Managed Aquifer Recharge (MAR); Geographic Information System (Arc GIS)

INTRODUCTION

The Moura-Ficalho (MF) region in Portugal is a semi-arid area with the greatest water scarcity in the country. According to climate change predictions, the Alentejo region will be subject to increases in average annual temperature (Costa, 2008). In addition, according to the Instituto Nacional de Estatística (2006) decreases in mean annual precipitation and changes in the seasonal distribution of these climatic parameters are also predicted. As a consequence, natural recharge of the aquifer system will be reduced. Furthermore, the MF aquifer system is currently subject to various pressures and constraints. For example, several villages in the municipalities of Moura and Serpa use this aquifer for their public water supply. This aquifer is also being used for private use, human consumption and to supply agriculture and industry in this region (Costa, 1999).

As result of recent increased stress on this aquifer system the purpose of this research was to evaluate the feasibility of artificial recharge using runoff in the Ribeira de Brenhas basin. To reach this aim, MAR techniques were considered to increase natural recharge. Recharge wells were used for where the aquifer was confined and an infiltration basin was constructed for the unconfined aquifer. Arc GIS was used in order to detect proper places for recharge techniques.

MANAGED AQUIFER RECHARGE TECHNIQUES APPLIED TO THE MOURA FICALHO AQUIFER

The benefits of using groundwater in the Moura have been clearly indicated (Costa, 2008); the MF aquifer provides water storage which, if utilized and managed effectively, can play a vital role in this region. Hence, to increase groundwater recharge in the Moura, a MAR technique was considered. MAR is the infiltration or injection of water into an aquifer for the purposeful recharge of water for subsequent recovery or environmental benefits (Dillon, 2009). This study only focused on the managed input (rather than the unintentional or unmanaged kinds of input for aquifers) (Dillon, 2005) and considered water from runoff and rainwater. According to decreases in groundwater level and increased water demands in this area, increased natural recharge within MAR methods can be considered as one of the best options for impeding the depletion of groundwater in the MF aquifer. Concerning recharge in the MF, the following advantages can be considered:

- Boost water storage for beneficial use without evaporative losses (Gale, 2005); The Alentejo region has high mean temperatures which cause elevated levels of evaporation. MAR methods

can decrease the influence of evaporation by as much as 90% and is considered a great benefit (Tuinhof & Piet-Heederik, 2002).

- The Alentejo includes several villages needing enough water for consumption and for crop irrigation; MAR can save water during the wet season and reserve it for later use. This would prevent the displacement of these local populations (Kumar & Aiyagari, 1997).
- The Alentejo is an area with much arable land and gardens for producing grapes and olives, which makes the land a valuable resource in this region. With the use of MAR, no large storage structures are needed to store water. Required structures are small and cost effective.
- A significant benefit to the Moura in using methods of MAR would also be flood mitigation (Devine, 1995; Bouwer, 2002).

PRESENTATION OF OVERALL METHODOLOGY

Selection of recharge methods in the Moura

The identification of suitable sites for groundwater recharge is very important and must be done with enough accuracy and timeliness to assure the overall efficiency of any recharge project (Saravi *et al.*, 2006). A region's suitability for MAR is critically dependent on the native soil, aquifer varieties, rainfall, evaporation rates and land elevation, etc. The criteria for aquifer selection are extensive but, as a starting point for a successful MAR project, the following elements must be addressed: a sufficient demand for recovered water, an adequate source of water for recharge, a suitable aquifer in which to store and recover the water, sufficient land, and capability to effectively manage a project (Gale, 2005).

The Moura region met all these essential elements for performing an MAR project. Therefore the next step was to utilize the recharge well method for areas where the aquifer was confined and the infiltration basins for unconfined areas.

To employ these two methods, two fundamental factors were considered (Sharma *et al.*, 2000):

- Identification of suitable hydrogeological environments and sites for creating a subsurface reservoir.
- Assessing the availability of water resources for appropriate space and time for recharge.

The available underground storage space was evaluated by examining the merge between the topographic model and the hydraulic head simulations (designed with Arc GIS software). Also, assessing the availability of water resources was determined by previous research concerning recharge estimates in the MF (Chomba, 2004) as well as cross-analyses of climatology, hydrogeology, availability of water resources, and characterization of the study area.

Topography with Arc GIS

To represent topography and contour maps in this project, we were first required to define the site's location within the Projected Coordinate System (PCS); the selected PSC was "Lisboa_Hayford_Gauss_IGeoE, Datum_Lisboa." The use of these standard coordinate systems helps to ensure the applicability of our study; the maps created are transferable to other programs (Booth & Mitchell, 2001) and future research in this area. To represent and visualize topography of the study area, we used digital topographic data from the Military Map of Portugal, on the scale 1/25,000. Based on linear and point data, and using 3D Analyst tools in Arc Map, we created a Triangulated Irregular Network (TIN).

By combining archival data (for locality boundaries), topographical maps, and digital contour data, it was possible to create a 3-D model that allows viewers to change the position within the landscape and to get a sense of its shape and contour. When a flat topographical map of an area is transformed into a 3D model, topographic features became real, understandable concepts. The elevation data, built from the contour file, was extruded to create the "tin". The vertical distance was exaggerated by a scale of 10 to highlight the changes in the terrain (represented in Fig. 1). The TIN model was created by utilizing polyline and poly-point features from the surface elevation

data. Elevation is variable between 120 m and 523 m. According to this model, the elevation from the south to the north is decreasing. This model also demonstrates that the middle of this area has more variability in elevation. Also, elevation is gradually decreasing towards the town of Moura, which is located in the lowest northern part of the area.

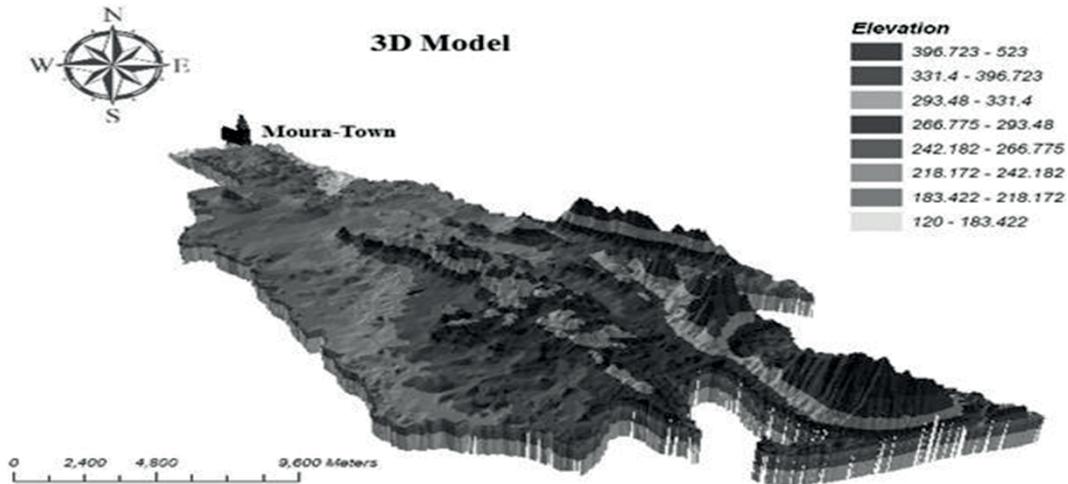


Fig. 1 3D topographic model.

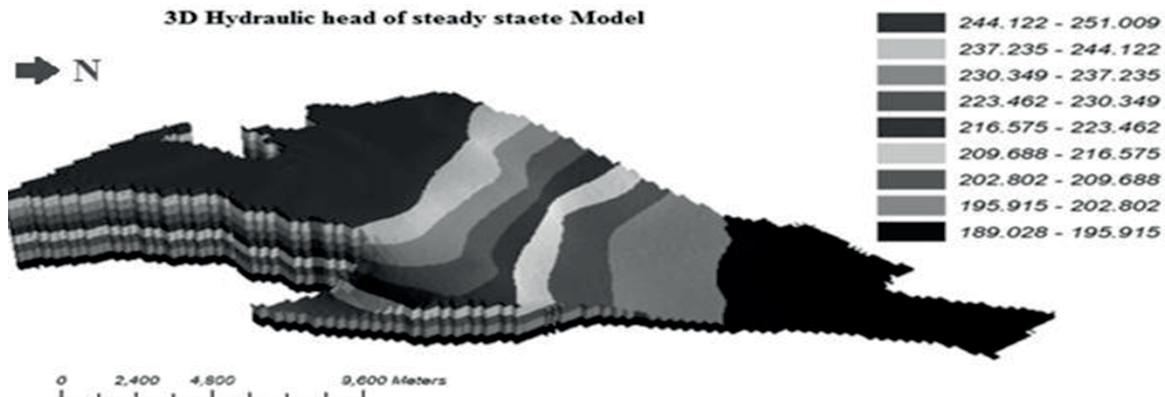


Fig. 2 3D Hydraulic head of the steady state model of the MF aquifer with 15× vertical exaggeration.

Model of hydraulic head

In order to simulate hydraulic head of the MF aquifer, data was collected from seven piezometric stations for 5 years (2000 to 2005). The data was measured with level sensors that were attached to loggers and downloaded periodically to laptops. Laboratrio Nacional de Energia e Geologia, (LNEG) used the Groundwater Modeling System (GMS, 2004) to model the hydraulic head. The software implemented various models useful not only to characterize local hydraulic groundwater flow, but to also validate interpretative techniques based on analytical and semi-analytical types of assays aquifers. Additional simulations of hydraulic head were performed through exports from GMS to the Arc GIS. With the help of the Surfer and Arc GIS software, it was possible to represent the hydraulic head of the steady state simulations (Fig. 2) as well as water level changes during the 5 years. According to Fig. 2, the hydraulic head varies from 189 m to 251 m in height. This elevation represents groundwater flow from the SE to the NW (towards Moura). However, there is some exceptional flow divergence towards the SE due to the existence of the Gargalão spring source in the “wing” of the aquifer “Abadzadesahraei (2010)”. The model shows that the hydraulic head is more variable in central regions of the aquifer than in the northern or southern regions. There are two possible explanations for this variability:

- There are changes in the aquifer's characteristics (hydraulic conductivity, thickness or both).
- The higher transmissivities in the northern and southern parts of the aquifer (Costa, 2001).

IDENTIFICATION OF SUITABLE SITES FOR GROUNDWATER RECHARGE IN THE MOURA REGION WITH ARC GIS

Groundwater storage space

Regarding the availability of underground storage space for recharge, this study (after merging the 3D tin elevation model and the hydraulic head simulation model) indicated that the northern, western, and eastern areas (light-coloured areas in Fig. 3), were not suitable for the MF's recharge. The reasons are:

- N, W, and E parts are located in confined layers and most of the discharge occurs in these areas through several springs. If we were to perform recharge in these regions, the water would go out through these springs; we did not increase the hydraulic potential of the entire aquifer except in a very small area and for a very short period.
- The best place for performing the recharge is where groundwater resources can effectively take place, which is not the case for the N or the W since the recharge would only increase groundwater reserves locally.
- Concerning the underground storage space, these areas did not provide suitable opportunities for recharge because the groundwater was near the ground surface. Some water may go into shallow storage, but when this storage space is filled, any additional infiltration will return to the stream channel or other discharge area (US Department of Agriculture, 1976).
- Therefore, the dark area in Fig. 3 represents the whole possible area for recharge according to adequate underground storage space.

The evaluation of the storage potential of sub-surface reservoirs is invariably based on the knowledge of dimensional data of reservoir rock, which includes thickness and lateral extent. The availability of sub-surface storage space and its replenishment capacity further govern the extent of recharge. The hydrogeological situation in each area of recharge needs to be appraised in order to assess the recharge capabilities of the underlying hydrogeological formations. The unsaturated thickness of rock formations occurring more than three metres below ground level should be considered in order to assess the requirement of water to build up the sub-surface storage by saturating the entire thickness of the vadose up to 3 m below ground level. The upper 3 m of the unsaturated zone is not considered appropriate for recharge since it may cause adverse

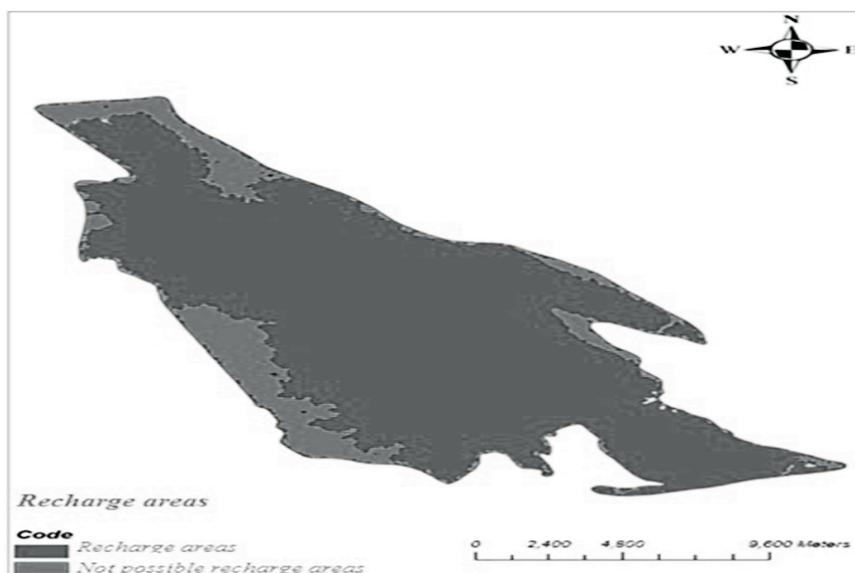


Fig. 3 Suitable sites for recharge according to underground Storage Space factor (in dark).

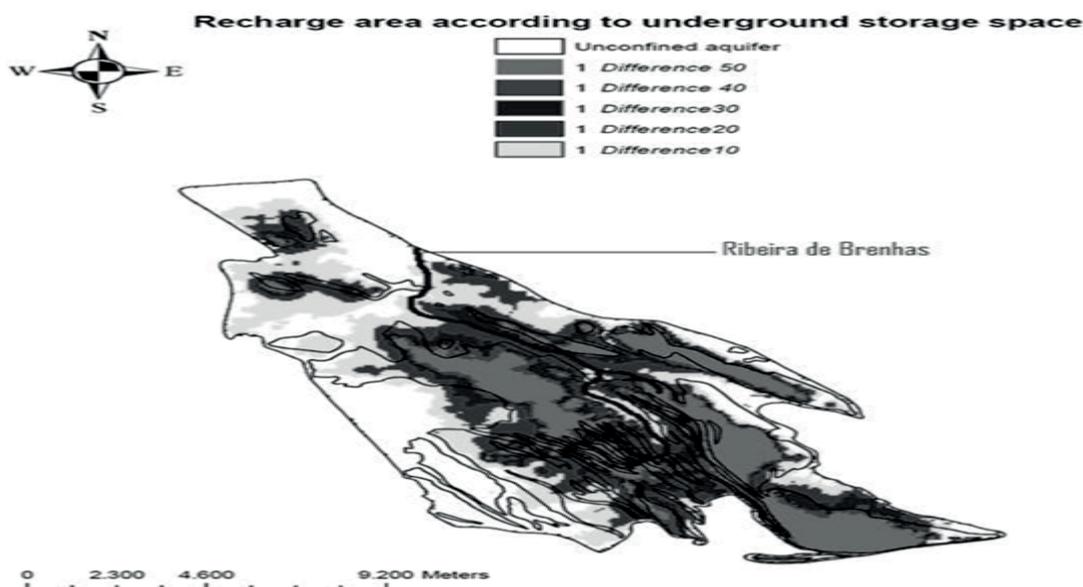


Fig. 4 Height differences between ground surface and groundwater level and Ribeira de Brenhas River.

environmental impacts such as water logging, soil salinity, etc. (Sharma *et al.*, 2000). Furthermore, to assess suitable sites for the recharge method we needed to choose specific areas with more than a 15 m difference between surface and groundwater levels. Assuming an availability of an underground reservoir, areas that have more than 15 m of depth are proper for groundwater recharge (Fetter, 2001).

Therefore, we classified the height differences between ground surface and groundwater level (Fig. 4). Figure 4 illustrates the variation of the groundwater depth expressed in five classes, varying from 10 m to 50 m. With all factors considered, confined areas of the aquifer must be excluded. Also, the areas close to the border of the aquifer, near a spring or any other natural discharge area, due to previously explained reasons, should be excluded. The southern part of the aquifer, which is located in the unconfined layers (Fig. 4), can therefore be considered as having adequate space for the injection of water to the aquifer. This area is also large enough to perform flooding techniques and to design an infiltration basin or other direct surface recharge techniques, which require more open land surface. In general, these methods function better in recharge basins that are located on relatively flat sites, eliminating the need for major excavation. The southern part of the MF aquifer fits these requirements as well.

Availability of water resources

The second consideration concerning groundwater recharge was to examine the availability of water resources in the Moura region. Understanding the availability of water needed for recharge requires the identification of major water sources in the Moura region. According to research done by Chomba and Alain Francés, precipitation (via rainfall) over natural streams is a sufficient water resource used for recharge. However, of all the factors in the evaluation of groundwater resources, the rate of recharge is one of the most difficult to derive with confidence (Bhattacharya, 2010). Costa (2008) assumed a recharge rate of 38% from precipitation; therefore increasing the rate of rainfall infiltration through MAR techniques, will compensate for the unbalanced condition of the MF aquifer.

Annual precipitation in the Moura region is approximately 500 mm/year with its peak from October to April (Costa, 2008). This volume may or may not be adequate for recharge purposes. If this volume proves to be inadequate, water from other sources should be pumped to the recharge site. In Moura, there are several streams that are formed after rainfall. These streams largely flow towards outside the MF hydrogeological basin. One of two major streams in this area, the "Ribeira

de Brenhas,” comes from the south (Serra da Adiça) and continues in a northeasterly direction. While the other one, called “Beco da Amoreira”, receives surface water flow from the Malpique area and flows out toward the west side.

RESULTS AND DISCUSSION

Considering hydrogeology, characterization of the MF area, the confined and unconfined aquifers, topography, underground water storage space, and other factors related to water resource availability, we were able to determine the suitable recharge site within the MF aquifer. The southern region of the middle part of the aquifer is perhaps the most suitable area for groundwater recharge. There is enough underground reservoir and suitable terrain relief, as well as several streams and rivers that can provide a sufficient source of water; this area can be considered a suitable place for performing the recharge method.

Considering all the aspects of this study, I would suggest the application of MAR on the southern part of the MF aquifer, including the Serra de Ficalho NE hill slope and the upper part of Ribeira de Brenhas basin and other confluent streamflows. There are two areas in the Serra de Ficalho NE hill slope which can be considered as proper sites for recharge through recharge wells and infiltration basins (Fig. 5). Nevertheless, in these areas, the expectable recharge effects would be expressed by increased flow rates within two natural springs (Nascente de Ficalho with coordinate of X:273089.75_Y:109969.14 and Nascente do Rosal with coordinates of X:278240.43_Y:111250.60). If this is considered an important issue, then these areas should be considered in a future MAR project. Otherwise, the other two areas located to the north should be used for recharge (also represented in Fig. 5).

The recharge well technique, (illustrated with grey dotted areas in Fig. 5), will be considered for those areas located in the impermeable layers or areas for which vadose zones are not suitable, or where aquifers are deep and/or confined (Bouwer, 2002). The infiltration basin technique (illustrated with grey areas in Fig. 5), will be used for areas with permeable surface soils, vadose zones without clay or other flow-restricting layers, and for unconfined aquifers. More detailed research on the improvement of MAR in the MF aquifer is certainly required. Accurate topographic surveys should be performed, since it is a karstic area and currently available topographic data sometimes lacks detail in order to identify and access natural depressions with endorheic drainage.

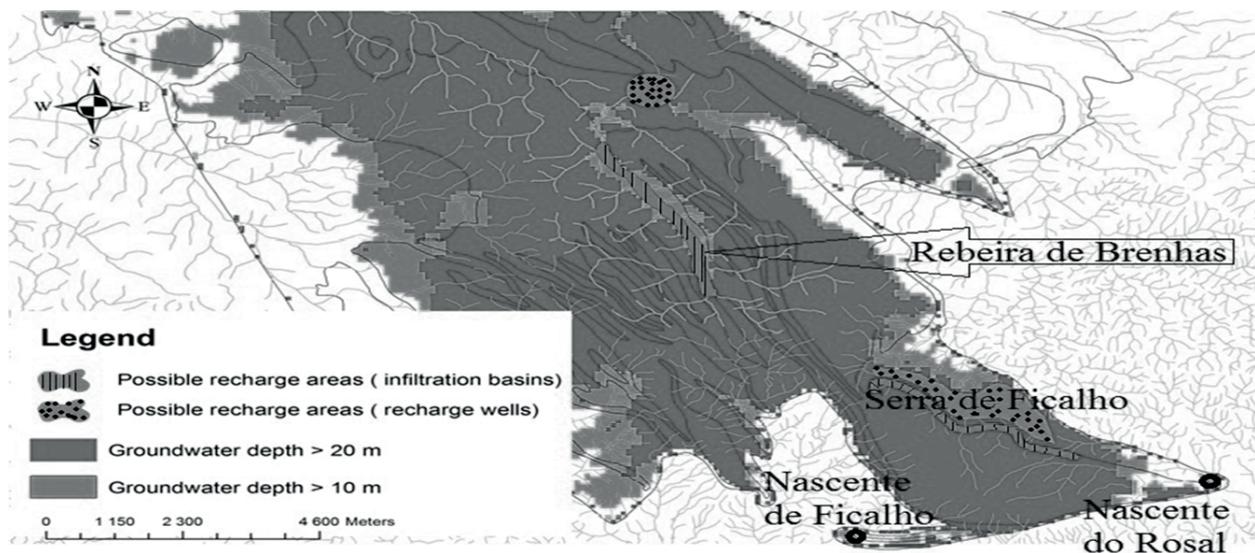


Fig.

CONCLUSION

The Moura-Ficalho aquifer system, located in the southern part of Portugal, has been suffering from increasing water depletion for the past few years. High temperatures during the summer are common in this area and there is an apparent, continual decrease in annual precipitation. The annual rainfall distribution is also non-uniform. The over-exploitation of groundwater has resulted in groundwater lowering within different parts of the study area. Further, the region has many resident farmers who require the use of water in order to grow olive and grape plants in order to produce olive oil and wine. Public use means expanded issues for the Moura region, which has already been widely recognized as having the greatest water scarcity. All these factors make this region an important area of study and of water supply management.

Water supply development in the Moura region is a challenging pursuit. Increasing demands for water, along with concerns for environmental protection, require a variety of new water management tools in order to keep the water supply flowing and stable for all involved. To understand the concept of groundwater depletion, this study has tried to focus on describing this problem and examining whether increasing natural recharge would be beneficial. To solve groundwater depletion, MAR has been considered as a main solution to increase groundwater levels in Moura. In addition, using this method has several advantages when compared with other alternatives. Furthermore, there is an urgent need to augment the groundwater resource in this area via suitable MAR techniques. The need to augment groundwater is driven by the need to keep the water supply flowing and safe guarded for future generations. MAR and aquifer storage are valuable water management tools that effectively help to offset increased demands for water, particularly for the Moura in a semi-arid area.

This study was carried out to propose a methodology for delineating MAR zones and to identify possible recharge sites in the Moura using Arc GIS software. In order to do so, topographic maps and hydraulic heads were constructed with the help of Arc GIS techniques. Together, these tools helped to find a proper site, which depended on the presence of sufficient ground storage space for artificial recharges. According to these analyses, as well as subsurface and surface models that were created with Arc GIS, the northern and western and eastern margins of the Moura region are not considered sufficient for recharge due to the presence of impermeable layers, insufficient groundwater storage space, and insufficient water resources. The central part of the MF is also improper for recharge, because in this region, it is not possible to increase groundwater and hydraulic potential within the whole aquifer. The most suitable place for recharge of groundwater has been identified in the southern part of the MF aquifer, which is recognized as having adequate groundwater storage space and availability of water sources.

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