Impacts of Demographic Growth, Land Use/Land Cover Change, and Climate Change on Groundwater Resources in Setubal Peninsula.

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Abstract

The urban sprawl and consequent land-use changes are a result of the continued and dynamic influx of the population. The quantification and qualification of the impacts of these dynamics on groundwater resources are therefore required. All over the district of Setubal, significant changes have been observed in both land use and population in the past decades. This phenomenon is reflected in the water demands, which induced an increased search for groundwater, mainly for public supply, industrial use, or agriculture. As the water supply in the region depends exclusively on groundwater resources, it is imperative to assess the temporal trend of water availability for a more adequate integrated management. This study is based on both physical and hydro-climatological parameters of the region, land-use change, population growth, and climate change as metrics to assess the state of groundwater resources in the district of Setubal, Portugal. The characterization of the land use was based on the information provided by the CORINE Landcover map between the years 1990 and 2018. The abstracted groundwater volumes for this period, the demographic evolution, and the respective temporal and spatial distribution of water balance were also evaluated. Future climate scenarios were applied based on RCP4.5 and RCP8.5 climate scenarios. The results show that there was a very significant land-use change. An extension of the built-up area from 12.5% in 1990 to 19.2% in 2018 is observed. At the same time, there was a reduction in the area occupied by agriculture and pine forests. The population of this region has increased considerably in all municipalities. The increase is about 27% between 1990 and 2018. Based on this, a corresponding increase in groundwater abstraction was observed with the construction of about 14,620 wells between 1970 and 2018. The application of the WetSpass (Abdollahi et al., 2012) model to calculate the recharge in the study area showed a very significant variation in recharge values between the analyzed years. This spatial and temporal variation is mainly related to the inter-annual variation in precipitation, exacerbated by the land-use change. The analysis of future scenarios (2041-2070) showed that in both climate change scenarios, there observed a slightly lower recharge as compared to 2018 if the precipitation intensity in both periods is the same. The risk assessment to contamination by the application of the susceptibility index (Stigter et al., 2005) shows that the main recharge zones are classified as susceptible to pollution from agricultural sources. The analysis of the different components of the temporal variation of the piezometric series was based on the application of singular spectrum analysis (SSA). The result of this analysis allowed the identification of upward, downward, and non-trend trends in the long-term components. The application of several methodologies in this work was to obtain a holistic view of the current and future status of groundwater resources in the study area. The tools applied demonstrated their potential for decision support, both in the management of water resources and the territory.

Keywords: Land use change, Climate Change, Demographic Growth, Groundwater Management, Singular Spectrum Analysis, Vulnerability, Setubal Peninsula, Piezometric Level, RCP.

Introduction

As urban space continues to grow to accommodate the influx of people from rural areas, there remains a real need to quantify and qualify its impacts on groundwater systems. The extension of global urban areas has led to significant variations in water demands that are reflected in groundwater abstractions, for public supply, industries, or agriculture. The impacts of this exponential groundwater use can therefore be directly related to overexploitation, pollution, or indirectly in groundwater-dependent ecosystems deterioration.

The increase in urban population can also be correlated to a substantial change in land use and land cover. The urban landscape influences infiltration and evapotranspiration, affecting the water available for groundwater as recharge. The imperviousness of the surface and the slope of the terrain play a key role in influencing the hydrological cycle. If the percentage of impervious surfaces and the slope of surface terrain is greatly influenced, the water balance will be altered leading to increased runoff and reduction in infiltration (potential recharge).

Climate change will also have a strong impact on the recharge variation in the future, especially in stressed areas. It is therefore important to assess the wider impacts of substantial development on both quantity and quality dynamics of groundwater. With the increased consumption of water in groundwater-dependent counties, the sustainability of this water and the future state should be evaluated for proper planning and management.

This work focuses on the assessment of the impacts of climate change, land use/land cover change, and demographic growth on the groundwater system in five counties in Setubal Peninsula, Portugal.

Description of the study area

The study area is the district of Setubal consisting of nine municipalities which include Alcochete, Almada, Barreiro, Moita, Montijo, Palmela, Seixal, Sesimbra and Setúbal. It is delimited by Lisbon District and Santarém District on the north, Évora District on the east, Beja District on the south, and the Atlantic Ocean on the west. The specific counties evaluated in this study are Almada, Palmela, Sesimbra, Seixal and Setubal. The total area of the five municipalities is about 995km^2.

Climate

The climate of the study area is marked by oceanic regime with warm winters and hot summers, by proximity to the Atlantic Ocean. The annual average temperature is between 15 and 17^{0}C, and the average annual precipitation falls between 233 and 1142mm ([1]SNIRH). The mean annual values for potential and actual evapotranspiration, estimated with the Thornthwaite and monthly water soil balance methods, are 840mm and 485mm, respectively(Simões, 2009). According to the calculated annual average of PET using data from SNIRH, the minimum and maximum values are 630mm and 772mm, respectively.

[1] National Water Resource Information System

Figure 1: Location of the study area

Hydrogeology

The aquifer system in the study area is the Tagus-Sado aquifer system which is the biggest aquifer system in Portugal. The area under study is located on the left bank of the aquifer (T3 – Margem Esquerda). The southeast part of the area, Arrábida, are not included in this aquifer. It can be classified as an unproductive fissured aquifer. The information below was retrieved from Almeida et al. (2000) available in SNIRH database.

The dominant aquifer formations are Pliocénico, Arenitos de Ota, and Série calco-gresosa marinha which were deposited in the Tertiary period. Pliocénico formation which was deposited in Pliocene epoch has the lithologies consisting of sands, with lenticular intercalations of clays, with very variable thickness. Arenitos de Ota which was deposited in late Miocene to early Pliocene has its lithologies comprising of sandstones with some intercalations of clays. Série calco-gresosa marinha was deposited in the Miocene epoch and it comprises of limestone, sandstones, marls, with a thickness greater than 450m.

It is a multi-aquifer system, unconfined, confined, and semi-confined, in which lateral and vertical facies variations are responsible for insignificant changes in hydrogeological conditions. The aquifers are separated by layers of low or very low permeability (aquitards and aquiclude). On the Setúbal Peninsula, the system consists of an unconfined upper aquifer, overlying a confined, multilayer aquifer. Underlying this set, separated by thick marly formations, is a confined multilayer aquifer whose lithological support is the thick limestone formations at the base of the Série calco-gresosa marinha.

The Pliocénico have transmissivity between 100 and 3000m²/day. Arenitos de Ota have most frequent values of transmissivity between 45 and 179m²/day. Série calco-gresosa marinha have more frequent transmissivity values between 127 and 693m²/day and storage coefficient is 10^{-3}.

Recharge is done by rainfall, vertical leakage between aquifers, and infiltration through water streams. In general terms, the groundwater flow occurs towards the Tagus River and along the aquifer system to the Atlantic Ocean. The hydro-chemical facies consist of Pliocénico: sodium and calcic chlorinated, calco-magnesian bicarbonate; Arenitos de

Ota: sodium and calcium bicarbonate and Série calco-gresosa marinha: calco-magnesian bicarbonate.
The lithologies that were specifically identified in the five municipalities within the study area are shown in the Figure 2. The western part which is in Palmela is dominated by limestone, sandstone, and a combination of both with claystone. The North-eastern part, which is Almada region has various lithologies like clay, basalt, and alluvium. Generally, the main geology of the study area comprises of Sandstone, Limestone and Conglomerate.

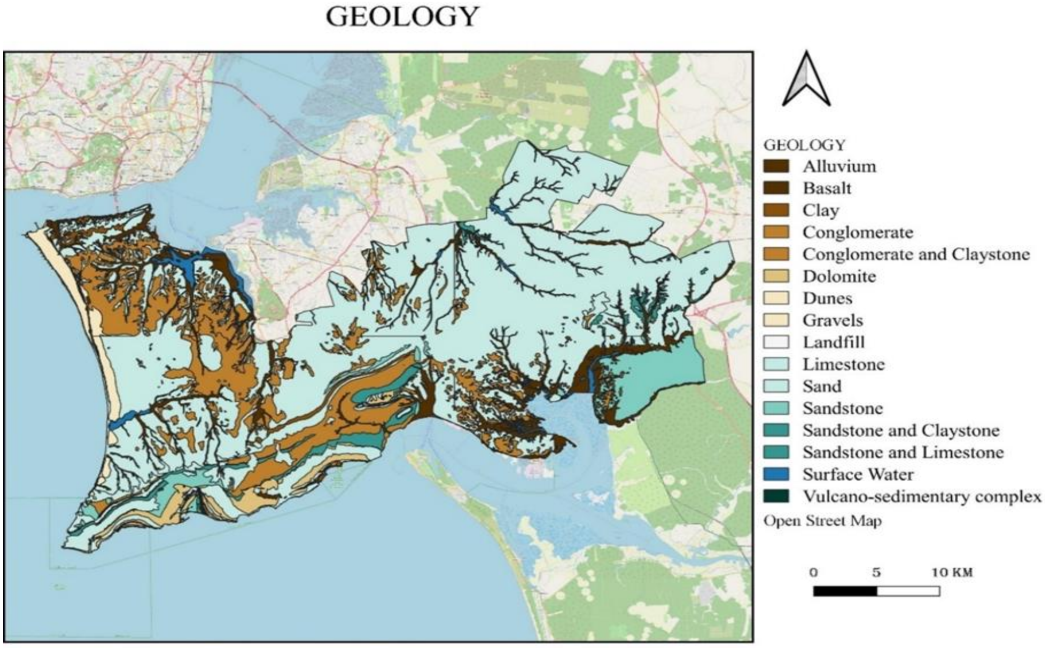

Figure 2: Geology of the study area

Data Sources, Processing and Methodologies

For this work, different methods and processes were used for the analysis of data. The data was gotten from different sources.

Demographic growth

Population growth is one of the indicators of development in an area. But the increase in population may lead to the over-exploitation of some natural resources. As regards the scope of this work, the natural resource to consider is water. More people will need more volume of water not just for their daily consumptions but also other things. To evaluate the population changes, data on population was retrieved from the Database of Contemporary Portugal (PORDATA). The reference years for this analysis are 1990, 2000, 2006, 2012 and 2018. These correlate with the years of Corine land use/cover.

Groundwater Abstractions and use

To analyse how water consumption has occurred over the past decades, the well information data was retrieved from the Planning and Information Division, Administration of Tagus, and West Hydrographic Region. Shapefiles for the wells' information were acquired and processed in QGIS and Excel.

Land use analysis

CORINE was produced by the Directorate-General for Territory (DGT) of Portugal in conjunction with the European Environment Agency (EEA) for the years 1990, 2000, 2006,2012 and 2018. The CORINE land cover cartographic products are created based on satellite images (e.g., Landsat, SPOT, LISS-III and RapidEye) and auxiliary information related to land use/occupation, coming from different institutions (Mar, 2017). The [2]CORINE map was integrated unto the GIS environment for reclassification and analysis.

Recharge Estimation and Water balance

1. Impacts of land use and climate: For the estimation of recharge and water balance, An hydrological software called WetSpass-M (Abdollahi et al., 2012)was used. The assessment was done with the CORINE maps, the climate data and groundwater level data from SNIRH. All input maps were prepared in QGIS.
2. Impacts of land use change: Following the same methodology as 1. The only difference is that the average climate values from 1990 to 2020 was used for the analysis for all the years under consideration.

Water balance was created with respect to the CORINE land use years which are 1990, 2000, 2006, 2012 and 2018.

Contamination Risk Assessment

Using the susceptibility index(Stigter et al., 2005) was used to assess the vulnerability of the groundwater to pollution for year 1990 and 2018.

Piezometric Analysis

Singular spectrum analysis was done in R on the groundwater level data retrieved from SNIRH for the years within the frame of 1990 and 2020.

Sustainability Assessment

This assessment was done to evaluate the effects of climate change on water balance under RCP4.5 and RCP8.5. Thirty (30) years (2041-2070) average climate data was used for this assessment under both scenarios.

Result

Demographic growth

The result shows a progressive increase in population in all municipalities in the study area as shown in Figure 3**.**

[2] Coordination of Information on the Environment

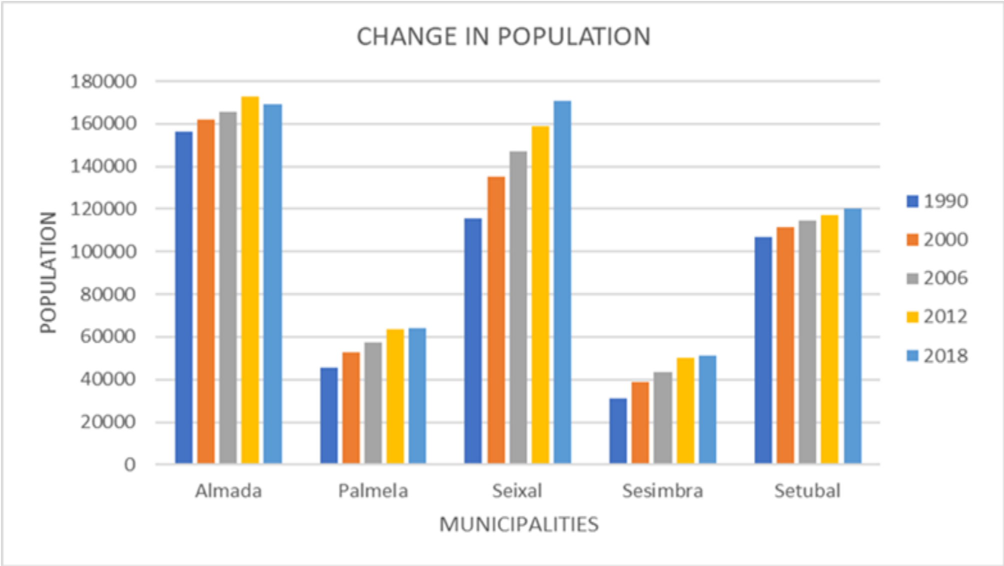

Figure 3: Evolution of population in each municipality for the reference years.

Groundwater Use

Many wells have been constructed in the area from 1970 to 2018. About 14,620 wells have been constructed and this means there has been significant abstraction of water.

Land use change

There has been a change in land use. Built up areas have extended while agriculture and pine have reduced in area from 1990 to 2018. Figure 4 and Figure 5 show the evolution of land use in the entire study area.

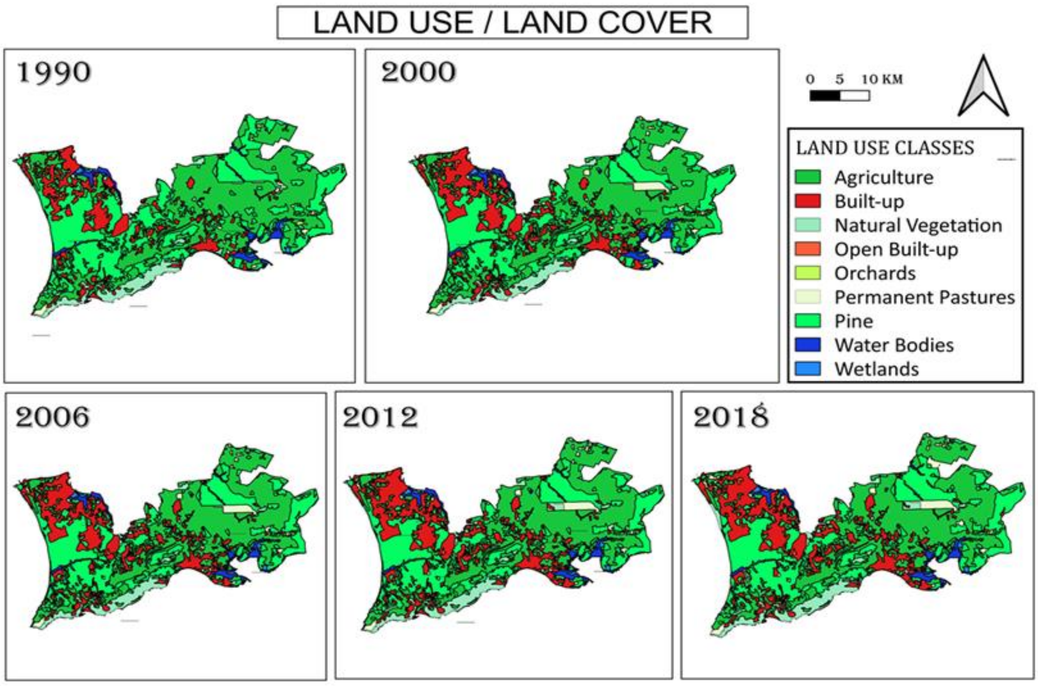

Figure 4: Change in land use

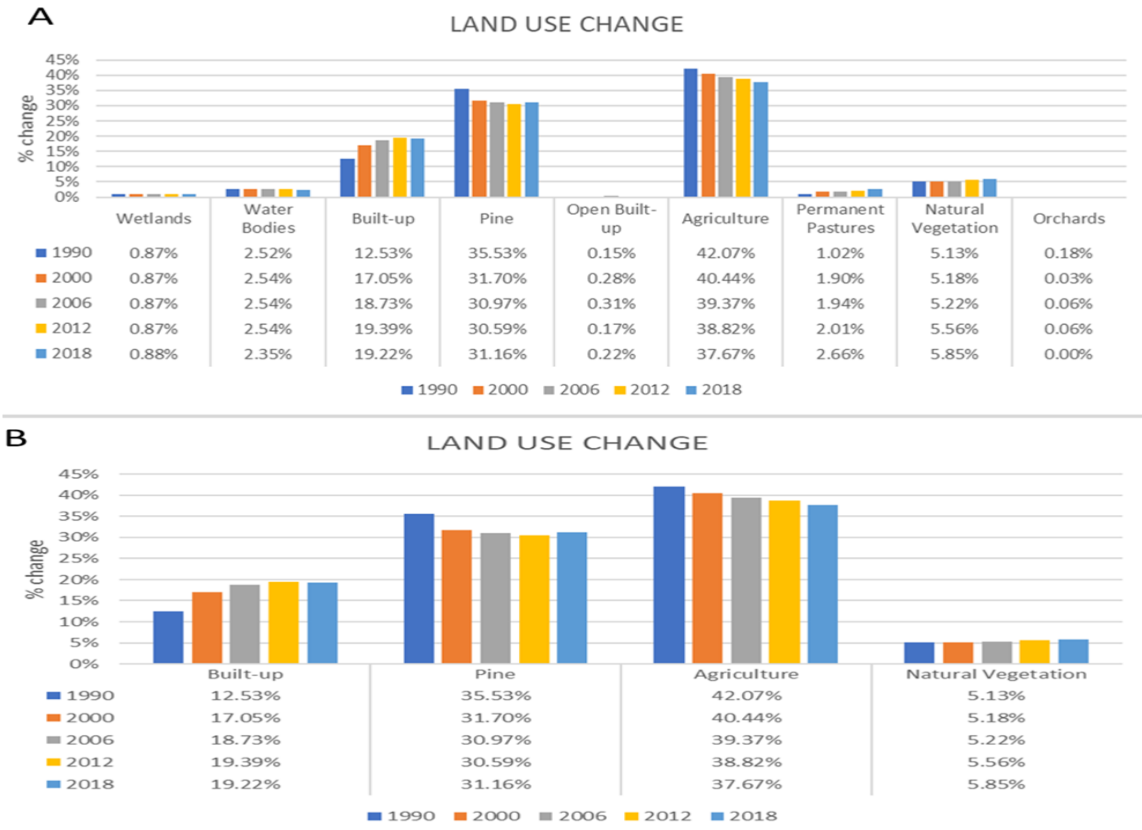

Figure 5: Plot of the change in land use. A is for all the land use types while B is for dominant land use types.

Recharge Estimation and water balance

Under the impacts of both climate and land use, there observed a change in recharge from 1990 to 2018. The lower recharge in 2012 and 2018 was because of the lower precipitation observed in those years. Table 1 shows the water balance

Table 1: Water balance under the variation of climate and land use

Year	AET	Runoff	Recharge	Total	%Recharge	Average Precipitation
1990	402	141	140	683	20	684
2000	487	213	68	768	9	730
2006	465	156	76	697	11	673
2012	110	131	62	303	20	294
2018	108	133	60	301	20	287

Under the impacts of land use only, the water balance did not change drastically. All the water balance components are still within a similar range. But generally, the recharge and runoff reduced and increased with increase built-up area respectively. Table 2 shows the result from this analysis.

Table 2: Water balance under the impacts of land use only with climate variables fixed

Year	Recharge	AET	Runoff	%Recharge
1990	106.1	354.0	125.6	18.11%
2000	105.3	349.2	135.7	17.84%
2006	104.1	347.5	138.7	17.63%
2012	104.1	347.0	139.7	17.62%
2018	105.1	345.0	132.9	18.03%

Contamination Risk Assessment

The assessment of the risk of contamination using the susceptibility index shows that the area with high recharge and land use of agriculture is more susceptible to groundwater contamination.

Piezometric Analysis

The result shows an intra-annual and inter-annual variation in piezometric level. The variation is also influenced by depth to water level as deeper wells have had a stable trend.

Sustainability Analysis

The water balance and recharge were assessed in the mid-century. The result showed a slight lower recharge compared to 2018 scenario. Table 3 shows the result of the future analysis under both RCP scenarios.

Table 3: Water balance in the future

	RCP4.5				RCP8.5			
Year	AET	Runoff	Recharge	%Recharge	AET	Runoff	Recharge	%Recharge
2041-2070	323.98	127.5	102.17	18	318.68	125.74	101.10	19

Discussion and Conclusions

This work was done to holistically assess the impacts of climate, land use and demographic growth on the groundwater resource. The study area has experienced a significant change in population from 1990 to 2018 with an increase of about 27%. The groundwater abstraction was also studied by the number of wells constructed in the area. There has been an increase in the number of wells especially in Palmela where the main land use is agriculture. This shows there has also been a significant groundwater abstraction in the area.

The dominant land use is built-up, agriculture, pine, natural vegetation, and permanent pastures. Others are water bodies, wetlands, open built-up and orchards whose changes were not too significant. The built-up area has expanded from 12.5% in 1990 to 19.22% in 2018. There has been a corresponding reduction in pine and agriculture from 1990 to 2018. The natural vegetation and permanent pastures have undergone a progressive increase in area from 1990 to 2018. The increase of the built-up area shows that urbanisation has occurred, and many green areas have been replaced by artificialized areas. This has an implication on the groundwater system especially recharge. The change in all these land use types has a corresponding alteration of the components of the hydrological systems. For example, increase in built-up areas lead to increased impervious surfaces thereby reducing the groundwater recharge, and increasing surface runoff. The change in land use types can also be said to be driven by the change in population and change in economic activities to accommodate the changing population. The change in each type is particular to some municipalities. For example, Almada has most of its land artificialized while Palmela has agriculture more agricultural lands. These land use types (anthropogenic activities) have a very strong influence on both overexploitation of groundwater and the vulnerability of shallow aquifers to pollution especially from industrial and agricultural sources.

The assessment of water balance and recharge using WetSpass-M was made under two scenarios. The first was the impacts of land use and climate which showed that the spatial variation of the hydrological components was driven my climate and land use. For example, there was a direct relationship between actual evapotranspiration and windspeed. There was an increase in runoff in the built-up areas. There was a lower recharge in 2018 than the previous years. Apart from the change in land use, this was also driven by the change in climate as precipitation in 2018 was less than 50% of that of 1990. This change in recharge with an increase in population can lead to overexploitation of groundwater since the region depends on groundwater for all consumptions.

The second is the impacts of land use change only. This showed that land use has an impact on water balance and recharge. Increased built-up areas led to an increase in impervious surface and ultimately, an increase in runoff. The reduction of the area of pine and agriculture also led to a reduction in actual evapotranspiration. The recharge also reduced because of the land use. The recharge zones were delineated to see the region with the maximum recharge. The zones with the maximum groundwater recharge in 2018 are in the western part for the study area. This area is particularly used for agricultural purpose. The other recharge zone is the southern part along the coast which has the land use of Natural Vegetation

From the contamination risk assessment using the susceptibility index, some parts of the areas are susceptible to groundwater contamination. These are areas with a high recharge and anthropogenic activities like agriculture and industries. Since the western part is the major recharge zone and with agriculture practices, the region is highly at risk of groundwater contamination.

The piezometric (groundwater level) analysis using the SSA showed that there has been an alternating upward and downward trend in the series. This trend is controlled by the seasonal variation of rainfall, abstraction, and the irrigation from agricultural lands. The series from some piezometers have a very small variation due to deep groundwater depth. There was a sharp drop in groundwater level (about 4m) in some monitoring stations in 2004, and this remained stable till 2013 after which there was a little upward trend. This was particularly noticed in piezometers in built-up areas. This could be attributed to groundwater abstraction and a corresponding reduction of recharge in those areas due to increase of imperviousness. Generally, the analysis showed that only one source (surface recharge by rainfall or irrigation) contributed to the fluctuations of the series and there was no downward trend for more than five years without an upward trend. The evaluation showed that even though there has been an increasing population and well construction over the years, there has not been a depletion of the groundwater resource in most of the monitoring stations. From the piezometric trends, it was not possible to establish a direct relationship between recharge and piezometric level. The major threat to groundwater is contamination from agriculture sources.

The sustainability assessment under climate scenario of RCP4.5 and RCP8.5 also showed that climate change will play a major role in the variation of the hydrological components in the future. In both scenarios, there was observed a decrease in rainfall by 6% and 7% under RCP4.5 and RCP8.5, respectively when compared to the present average values (1990 – 2020). And there will be an increase of the PET by 5% and 6% under RCP4.5 and RCP8.5 respectively. Generally, the windspeed remains the same and the temperature increases by 1.33^0C and 1.85^0C under both scenarios respectively. From the water balance analysis done for the mid- century, the recharge reduced compared to the present value, but the reduction was not dramatic (1- 5mm). Also, RCP4.5 has a more positive result than RCP8.5 in terms of groundwater recharge. The only uncertainty is the rain intensity and duration. If the rain intensity is high in the future, recharge will be lower than the one presented in this work and runoff will be very high.

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