Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2020.25021

177 (2020) 264–274
February

Water resources management and trend of water use in North Cyprus

Gozen Elkiran[a,*], Adamu Dahiru[b], Huseyin Gokcekus[a]

[a]*Faculty of Civil and Environmental Engineering, Civil Engineering Department, Near East University, Northern Cyprus via Mersin 10 Turkey, Tel. +90 392 224 64 64; emails: gozen.elkiran@neu.edu.tr (G. Elkıran), huseyin.gokcekus@neu.edu.tr (H. Gokcekus)*
[b]*Audu Bako College of Agriculture Dambada, Kano, Nigeria, email: adamu_kbt@hotmail.com*

Received 12 July 2019; Accepted 13 October 2019

ABSTRACT

North Cyprus has been experiencing water scarcity since 1960 due to the limited freshwater resources, climate impact, and high rate of evaporation. As there are no perennial rivers, the island is largely dependent on groundwater as the main source of supply. The gradual increase in water demand led to the excessive extraction of freshwater from aquifers; this caused seawater intrusion, thus making the scarcity more alarming. Hence, this research was conducted to provide an update on the trend of the water budget of the country. Data were collected between 2000 to 2012 from the relevant authorities and used to achieve the study objective. Statistical relationships and the Blaney-Criddle method were applied to process the data. It was found that domestic water demands increased from 35.9 to 50.4 MCM while conveyance losses declined from 55.8 to 24.2 MCM. Moreover, an assessment conducted for the agricultural economy of 21 groups of crops showed that about 146.7 and 115.1 million USD were generated in 2011 and 2012, respectively. The overall results implied that the trend of water demand for agricultural production fluctuates with time and the general trend of water use is negative owing to the modernization of irrigation systems that minimizes the losses.

Keywords: Water budget; Water scarcity; Agricultural economy; Water security; Aquifer status

1. Introduction

Cyprus is an island with a total land area of 9,251 km^2, a coastline of 1,364 km and is surrounded by the Mediterranean Sea. It is located towards the southern part of Turkey between the three continents of Europe, Asia, and Africa. North Cyprus (NC) has a land area of 3,229 km^2 and is divided into three central administrative regions: Lefkoşa, Girne, and Magosa. These three main regions are further subdivided into seventeen agricultural sub-regions [1,2]. NC has limited surface water resources, and therefore largely depends on groundwater as the primary source for domestic supply, industries, and agricultural production. A gradual increase in population, drought impact and high consumption in the agricultural sector have raised the water demand beyond available supply, thereby leading to extraordinary water scarcity [3,4].

Previous studies have verified that water scarcity in terms of quantity started in the 1960s, thus restricting the access of many regions to adequate freshwater supply. Efforts were made to increase the rate of groundwater pumping to satisfy the demand, and this was the first strategy adopted over a long period to meet all the water needs within the country. After an extended period, some studies reviewed the situation and demonstrated that the rate of pumping in Güzelyurt, Magosa and Girne coastal area (Fig. 1) has exceeded the aquifers' yield, thereby leading to a decline in the water table level, seawater intrusion, and groundwater contamination to very high amount of dissolved solids concentrations of about 5,000 mg/L, which make it neither

* Corresponding author.

Presented at the 2nd International Conference on Water Problems in the Mediterranean Countries (WPMC-2019), 6–10 May 2019, Nicosia, North Cyprus

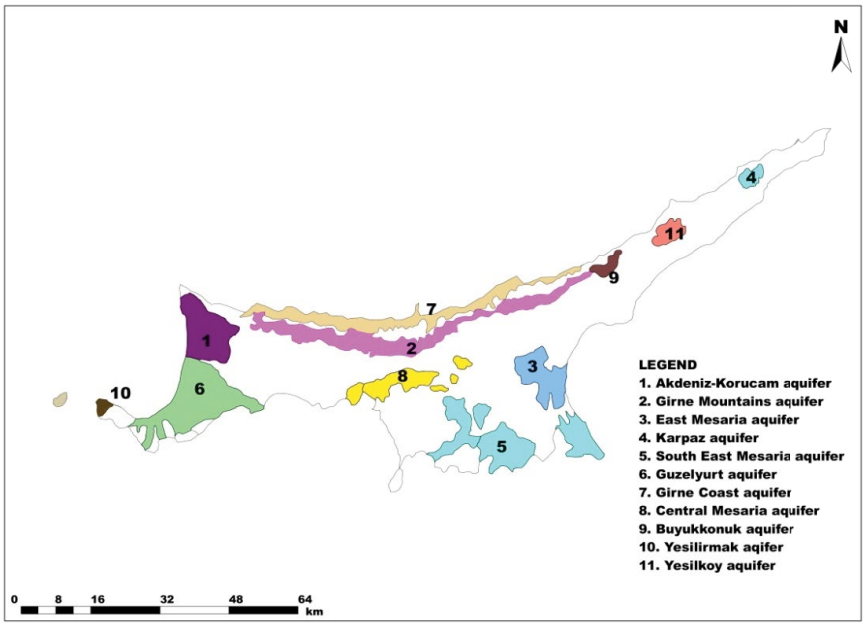

Fig. 1. Schematic map of aquifer and locations in NC [7].

suitable for domestic supply nor irrigation; this has significantly exacerbated the scarcity problem [5–7].

Generally, to deal with the water problem effectively, the current water demand and supply characteristics of an area should be determined. Secondly, it is important to understand who the water users are and how the management strategies are enforced. This problem is what prompts the need for the research to study water demand and supply characteristics to provide an update on the trend of water use of NC. This study was carried out based on the approach of integrated water resources analysis through the compilation and study of present and historical data. Water regulations in NC, relevant statistical relationships and the Blaney-Criddle method were applied where appropriate to process all the data collected. The water budget of NC was analyzed with a program that aids in data processing and the results obtained were compared with historical results. Finally, updates on the water demand, water availability, overdraft, trend variability, sector-wide water use and economic analysis on agricultural production were all provided.

2. Concept of water resources and water management in NC

Integrated water resources management is a systematic process for achieving sustainable development through appropriate allocation, and proper monitoring of available water resources, taking into account economic, social and environmental goals. It deals with sector-based challenges of management, where one agency is responsible for the drinking water supply, irrigation water is managed by another agency, and the environment is administered yet by another. The lack of coordination and linkage mostly leads to uncoordinated management and fragmentation of development efforts, thereby leading to contamination of resources, conflict and unsustainable development. Therefore, to achieve sustainable development and water security, it is imperative to have a linkage among water governing agencies that are in charge of sector-wide water use [8].

In recent years, the water resources of NC comprised of precipitation, dams, ponds, and groundwater, as well as other sources including desalinization and water recycled after treatment at the plants. These resources are limited because there are no perennial rivers except some ephemeral streams that flow for a short period during the rainy season contributing minor quantities of water for domestic and irrigation usage. With all the above resources at its disposal, the country has been experiencing water scarcity from 1960 onwards, and this is associated with scarce water resources, growth in population, urbanization, the impact of drought, high consumption by the old irrigation system and above all, conventional water management [5,9].

2.1. Geology and groundwater

Geological investigations show that several types of aquifers exist, including, confined, unconfined and perched. These aquifers are recharged in different manners: some by rivers that originate from the Troodos and Girne mountain ranges, and others by groundwater inflow (Fig. 1) [6].

The Girne mountain range contains permeable sedimentary rocks extending 160 km along the Girne coastline. It largely consists of limestone and sandstone of different types formed by seismic activity. During winter, a significant percentage of rainfall infiltrates into the rocks and flows downhill percolating in different layers as far as the layers remain porous. Considering the southern slopes, the porous layer extends up for many kilometers towards the south of the foothills up to Mesaria and conveys water to the Lefkoşa area. Similarly, there is no vadose water in the region, but several phreatic aquifers exist from which freshwater is extracted at different levels. The quality of the groundwater is generally fair because it contains hardness derived from limestone [10].

2.2. Characteristics of input and output components of water resources engineering in NC

Recently, the input components of the water resources of NC comprised of precipitation, groundwater, ephemeral springs, dams, ponds, desalinization, and recycled sanitary water. Previously, water was imported in Medusa bags from Turkey between 1998 and 2002, which was found to be unsuccessful. Similarly, to satisfy the water demands of the country, another capital project was designed and is now supplying 75 MCM of water on an annual basis. The output of the water budget constitutes the supply of water for domestic, agricultural, industrial needs, evaporation, and network losses [11,12].

The climate of Cyprus is characterized by hot, dry summers and cold, wet winters. Precipitation is largely recorded from October to April. Rainfall and other meteorological data are recorded at the following metrological regions: Besparmak, West Mesaria, Central Mesaria, East Mesaria, East Seaside/Coast and Karpaz station [1].

In NC, the need to construct dams arose shortly after the emergence of water scarcity in 1960. The hydraulics works of State of Turkey [13] considered dams and ponds as crucial renewable water resources and immediately designed 41 reservoirs of variable capacities, out of which 18 were constructed for irrigation, and 23 others were constructed to purposely prevent the direct flow of ephemeral streams to the Mediterranean Sea. Since then, this infrastructure has been contributing efficiently to its intended purposes [12].

About 27 MCM of water is obtained annually from 28 streams located in NC. There are also an additional ten ephemeral streams that originate from the Troodos mountain of South Cyprus, discharging about 43 MCM of water yearly. However, the rivers have now been dammed upstream in the southern part of the island [14].

As the result of the water supply project designed to deliver a 75 MCM annually, Geçitköy Dam has been upgraded and is expected to start distributing water to irrigation and domestic sectors in this year; the improved storage volume is now 26.5 MCM [11].

Because NC has limited water resources, it mostly depends on groundwater as the major source of supply for domestic and irrigation demands; the other sources include dams and ephemeral streams. There are 11 principal aquifers of various storage capacities. Güzelyurt, Magosa, and Girne coastal aquifers are the three principal aquifers with recharge capacities of 37, 5, and 10.2 MCM, respectively. The water extracted from these aquifers is directly used for domestic supply and irrigation purposes [7,15].

According to geological investigations, the Güzelyurt aquifer has the most significant storage area of 180 km^2, a storage capacity of 920 MCM, a safe yield of 37 MCM and approximately 80 km^2 lie in the southern part of Cyprus. The water obtained from this aquifer was previously being used for domestic and irrigation in the region and some parts of Lefkoşa. However, overdraft beyond safe yield has led to seawater intrusion with a decline in the water level to about 60 m below mean sea level [7].

As a result of the inefficient importation processes, an undersea pipeline water supply from Alaköprü Dam Turkey to Geçitköy reservoir of NC was designed with a capacity of 75 MCM/year. After conducting feasibility studies, the project was approved and eventually completed. The pipeline system is expected to supply NC with water for 50 years. Out of the 75 and 37.7 MCM (corresponding to 50.3%) is used for domestic supply, and the remaining 37.2 MCM (49.7%) is allocated for irrigation. It is hoped that this supply will help to offset the groundwater overdraft, thereby reviving the aquifer situation across NC. Similarly, the supply is also expected to positively contribute towards improving the standard of living in the Güzelyurt and Mesaria regions by supplying irrigation water to 6,413 and 7,435 ha of these areas, respectively, as well as other regions experiencing severe water stress [3,13].

Even though NC has been experiencing water stress for some time, the reuse of recycled water to minimize water stress has not been accepted due to traditional beliefs. Medium-scale central treatment plants have been established for sewerage treatment in Lefkoşa, Girne, Magosa, and Güzelyurt. In 2011 and 2012 the Lefkoşa modern central treatment plant has a capacity of 30,000 m^3/d, while Girne, Magosa, and Güzelyurt have a daily capacity of 3,000; 3,000; and 600 m^3/d, respectively [16]. Additionally, small private institutional sewerage treatment plants have been established at various hotels. The treated water from these hotels is being used to irrigate trees and flowers within their respective compounds [15,17].

NC considers desalination to be a cost-effective method of producing freshwater suitable for human consumption as well as for irrigation. This process is independent of rainfall. The cost of desalinating seawater (energy, infrastructure, and maintenance) is generally higher than other alternatives such as water recycling. The achievable cost of desalination treatment ranges between 0.5 to 1 USD per cubic meter of wastewater [9].

Generally, water demand is considered as one of the primary water outputs in world water budgets or any study area of interest. Three vital sectors require water supply in NC: agriculture, industry, and domestic use [11]. The domestic water supply comprises the supply of water to households, the tourism sector, and universities, as well as commercial and small-scale industries across the country. According to census data, the total population of residents has increased over time, which means that the demand will be increasing proportionally [18].

In 2011, the total population was 286,257 and based on the approved average consumption of 200 L/d/cap, the municipal water demand alone was estimated to be 57,251.4 m^3/d which roughly corresponds to 20.8 MCM/year excluding losses.

Agricultural production has been contributing a significant amount of income to the economy of NC, and the sector takes the most significant share of water supply, accounting for about 70%. The efficiency of production depends mainly on the quantity and quality of the water supplied as well as land fertility [5,9].

In NC, irrigation water is obtained mostly from dams and tube wells. The annual water need does not vary significantly but gradually increases over time. Previous literature has presented different accounts regarding the water demand for irrigation, for example, 144 MCM [14].

2.3. Agricultural structure and economy

NC agricultural sector is comprised of four subsectors: crop production, livestock farming, fishery, and forestry. Crop production has a significant share and therefore generates significant revenue for economic development. Out of the total land area of NC 329,890.8 ha, 56.7% has been suitably allocated as irrigation potential. This potential allows the cultivation of a wide variety of products such as cereals, citrus, legumes, and vegetables [1].

The agricultural products exported to adjacent countries include citrus, potatoes and processed products. In 1982, the share of agricultural exports was considerably high, where about 80.0% was citrus fruits. Potatoes, livestock and processed products accounted for 6.3%, 3.3%, and 5.3%, respectively. Later, due to water scarcity, the total exports trimmed down to 64.4%, out of which 28.6% were citrus fruits, potatoes accounted for 1.4% and 23.4% were for processed agricultural products. In 2009, the exports of the agricultural product accounted for $20.9 million, of which $14 million was from citrus and $2.4 million was generated by potato production [1].

2.4. Crop production and cropping pattern

Different types of crops are cultivated in NC; the profitability of this production depends mainly on the fertility of the available land, water quality, efficiency of the irrigation methods and soil management. Crops with relatively similar water requirements are grouped under the same cropping pattern.

3. Methodology

According to the Department of Agriculture, NC has three main administrative regions namely: Girne, Lefkoşa, and Magosa, as shown in Fig. 2. The main areas are further sub-divided into 17 agricultural sub-regions, which all require good quality water for domestic, agricultural and industrial use.

The hydrological and demographic data collected representing all the administrative regions formed the bases for the evaluation of water available and water demand, respectively. Until now, water demand and supply were evaluated with the aid of a program, after which, the outputs were compared with historical results.

3.1. Data collection

Hydrological and demographic data were formally requested by the responsible authorities. Rainfall data were collected from the meteorological department of NC for the determination of rainfall patterns and streamflow. A different set of data was obtained for monthly evaporation. Data on the groundwater were collected from the Geology Department for the assessment of aquifer storage capacities, safe yield, recharge capacity and status in terms of contamination. The storage capacities of dams and ponds as well as the variation in capacities every month were requested for the estimation of water availability. Daily production of various desalinization plants and historical data related to water importation were all collected from the Water Works Department of State. Data on the production of sanitary water for Lefkoşa, Girne, Magosa, and Güzelyurt central sewage treatment plants were collected from the municipality sewerage departments for the estimation and justification of sanitary water usage.

To determine the water demand for domestic and industrial consumption, demographic data on the population of residents and students at various universities were obtained from the NC Statistics and Planning Department (SPD) [18]. For determination of the water needs of hotels, data on bed capacities were collected from the statistical yearbook

Fig. 2. Schematic map of agricultural regions in NC [1].

published by the Tourism Department. Additionally, the population of livestock was obtained from agricultural statistics. The demand was evaluated based on water regulation in NC and by approved per capita demand.

For the evaluation of irrigation demand, data on the area of cultivated lands, various cropping patterns, and irrigation methods were obtained from publications on agricultural statistics. A description of how all the data were processed is provided in Fig. 3.

3.2. Evaluation of municipal water demand

Municipal demand includes the water need for domestic supply, universities, small-scale industries, livestock, and hotels. Domestic supply was evaluated regionally on a monthly scale and was based on the total population of residents of each region and in accordance with the approved per capita demand as provided in Table 1, likewise for universities, small-scale industries, livestock, and hotels.

For the tourism sector, bed capacities of all active hotels were obtained and entered into the program accordingly. Similarly, the population of livestock reared in all the subregions was taken into consideration.

As far as historical results are concerned, conveyance losses in respect of water supply pipelines were 30%, but in recent years it is considered to be 25% due to the replacement of the old water networks with new water supply pipes [11]. Water demand and losses were evaluated separately and then added together to obtain the required supply for each region on a monthly basis. The monthly demand was then summed up to obtain the annual demand of each subregion and then for the whole country.

3.3. Evaluation of irrigation water need

The prepared monthly crop water requirement was obtained from the Agricultural Department of NC, which was prepared based on the Blaney-Criddle method [19]. A total of 21 different groups of crops were studied, where each has different water consumption. The seasonal use of each crop was determined regionally by monthly consumption, cultivated area and the efficiency of the irrigation methods. In recent years, two different types of irrigation methods have been available in the country: Sprinkler and drip systems with efficiencies of 70% and 85%, respectively. The obtained results were added together to calculate the total irrigation demand.

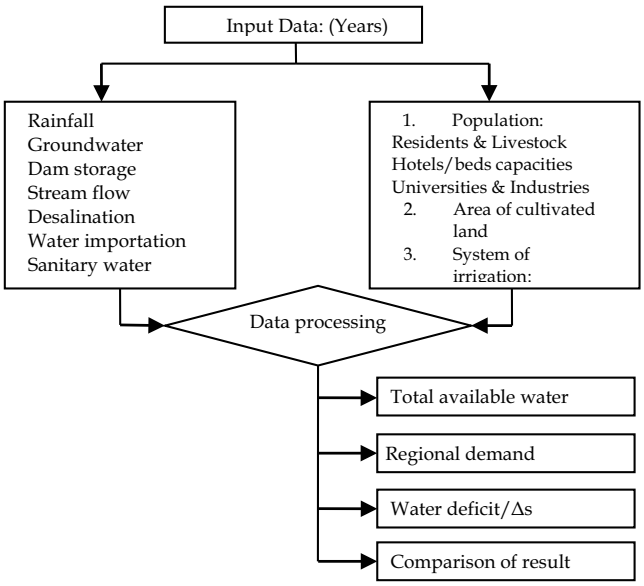

Fig. 3. Flowchart of data processing using the prepared program.

3.4. Evaluation of water availability for water supply

The municipal and irrigation water supplies are being obtained from various water resources of NC, which consist of rainfall, groundwater, dams, springs, and desalination plants. The quantity of fresh water available from the sources mentioned above was evaluated regionally on a monthly and yearly basis to determine whether there is a balance or deficit between demand and supply.

3.5. Evaluation of agricultural economy

One of the aims of this study was to conduct economic analysis on agricultural production related to water supply and incomes generated. Water is being supplied to farmers in the Güzelyurt area at the costs of 0.21, 0.24, 0.32, 0.5 to 0.59 USD/m^3, in which there is no fixed value and this figure fluctuates in every region. Different groups of crops were studied, and the income per cubic meter of water used for each crop was evaluated and compared to find out which of these crops generate an appreciable return. To achieve this aim, data on the annual production of each crop and its corresponding producer (gate) price were considered. The program prepared computed the water required to grow each crop and their corresponding incomes for the comparison and assessment of profit and losses.

4. Results, comparison and discussion

4.1. Results

The water budget of NC was created in the form of excel sheets/program. This program was adopted for all evaluations based on the regional measurement of the following components: water demand, groundwater extraction,

Table 1
Approved consumptive water supply of different sectors

Sectors	Consumption (L/d/cap)
Residents	200
Small industries	30
Commercial	20
Cattle	50
Sheep	15
Universities	150
Tourism	200

precipitation, streamflow, dam/pond storage, desalination, losses in conveyance system, hotel sanitary treatment, and central sewerage treatment.

The results are summarized and presented for easy assessment and comparison. These presentations provide detailed results on the water need for agricultural and domestic use along with losses in conveyance systems on a regional scale. Similarly, detailed results with regard to water availability from various sources could also be easily observed in a simplified manner.

By careful inspection, we can observe how the components of the water budget fluctuate based on population growth, size of the cultivated areas and the adopted irrigation methods. Likewise, the water available in dams, desalination, and groundwater extraction, etc is observed. All the results obtained are given in Tables 2–4 and compared and discussed as follows.

Table 2
Annual agricultural water extractions (m^3)

Year	Irrigation	Losses	Total
2000	58,987,522	47,547,350	106,534,734
2001	53,482,084	35,947,347	89,429,293
2002	54,722,610	30,238,274	84,960,746
2003	55,369,551	27,255,659	82,625,072
2010	53,569,649	22,802,245	76,371,894
2011	51,996,009	10,750,135	62,746,144
2012	62,179,693	12,615,727	74,795,420

4.2. Comparison and discussions

Tables 2 and 3 illustrate the trend of domestic and agricultural water demand as well as the total consumption. It was observed that the pattern of domestic consumption gradually increased every year, ranging from 35.9 MCM in the year 2000 to 50.4 MCM in 2012, losses inclusive.

This was associated with a gradual increase in the population of residents, international students at various universities and the tourism sector. However, the trend of agricultural demand gradually descended from 106.5 MCM in the year 2000 to 62.7 MCM in 2011 owing to the modernization of primitive irrigation methods with modern techniques such as sprinkler and drip systems. Then, the demand rose to 74.8 MCM as a result of more cultivated areas in 2012 compared to 2011. Similarly, the total demand fluctuated due to the effects of the fluctuation of agricultural demand. The tables also indicate a gradual decline in conveyance losses from 55.8 MCM in 2000 to 24.2 MCM in 2012, while the total demand fluctuates slightly based on the fluctuation of irrigation consumption.

Table 4 illustrates the trend of water extractions from the resources available in NC from 2000 to 2012. There is a dependency on groundwater extraction for supply to domestic and agricultural sectors, and this was relatively associated with limited supply from other resources, especially streamflow. It is observed that groundwater extraction gradually decreases, which is undoubtedly due to the implementation of some desalination plants along with the adoption of new irrigation methods. The quantity of groundwater extracted was 138.5 MCM in the year 2000 which fortunately decreased to 99.9 MCM in 2011; however, the amount fluctuated in

Table 3
Annual sector-wise water extractions (m^3)

Year	Livestock	Hotels	Universities	Residents	Losses	Total
2000	1,900,357	738,679	629,716	24,363,137	8,289,539	35,920,875
2001	2,033,816	760,141	673,984	24,651,814	8,435,899	36,555,101
2002	2,187,612	765,397	675,149	24,955,707	8,575,132	37,158,445
2003	2,249,597	834,528	721,684	25,265,122	8,721,252	37,791,630
2010	2,033,678	760,003	673,846	24,651,676	8,435,761	36,554,964
2011	2,290,189	1,391,088	1,281,595	32,765,942	11,318,644	49,047,457
2012	2,619,950	1,391,088	1,456,446	33,272,294	11,621,933	50,361,711

Table 4
Annual water extractions from the resources (m^3)

Year	Springs	Reclaimed	Dams	Medusa bags	Desalination	Groundwater
2000	350,649	3,443,438	3,071,506	359,508	109,500	138,473,532
2001	365,292	3,536,478	3,082,803	1,661,901	109,500	120,673,984
2002	384,529	3,629,798	7,372,465	1,694,720	109,500	112,489,542
2003	386,924	3,731,709	8,450,913	161,350	109,500	111,208,231
2010	365,292	3,536,478	3,118,803	0	109,500	108,903,380
2011	377,662	9,517,815	5,368,174	0	5,821,750	99,918,231
2012	400,550	9,569,924	7,126,204	0	5,821,750	111,503,069

2010 and 2012 due to an increase in the area of cultivated land. Desalination accounted for 109,500 m^3 in 2000, 2001, 2002 up to 2003, but to provide more clean water to the general public, more desalination plants were implemented thereby increasing the quantity to about 5.8 MCM in 2011 and 2012.

The combined capacity of the central sewerage treatment plants of Lefkoşa and Girne was 3.4 MCM in the year 2000, but in recent years, Güzelyurt and Magosa sewerage treatment plants were constructed, which led to an increase in production to 9.6 MCM in the year 2012 (Table 4). However, despite the water scarcity, a large quantity of water is diverted to the sea without any reuse. Similarly, the treated sanitary water in hotels was being used to irrigate flowers and plantations within their respective compounds. In the year 2012, their production accounted for about 0.23 MCM.

Streamflow is minimal as a result of the impact of the Mediterranean climate, aridity and the absence of perennial rivers. As such, the statistics of water stored in dams varies from year to year.

The annual water stored in all irrigation dams is being used for irrigation and in some places, for aquifer recharge. The trend analysis shows that only 3.1 MCM was available for supply in the year 2000, but the quantity fluctuated with incremental value up to 7.1 MCM in the year 2012. This information is an indication of drought relief which alternatively allows more cultivation in the rainy season.

Figs. 4 and 5 exemplify the three main administrative regions in NC along with their respective water demands for the years 2011 and 2012. It can be observed that for the year 2011, the main Lefkoşa regions have higher water consumption compared to the Girne and Magosa central regions. The Lefkoşa main region accounts for 27.2 and 51.0 MCM of water demand for domestic and agricultural demand, respectively, with a total of 78.2 MCM, followed by the Magosa main region with a total of 19.6 MCM. The Girne main region has total domestic and agricultural demand of 9.7 and 4.3 MCM, respectively with a total of 14 MCM.

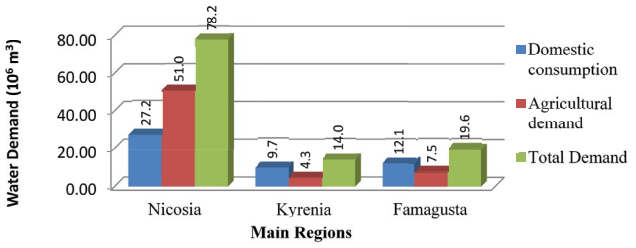

Fig. 4. Regional water demand year 2011.

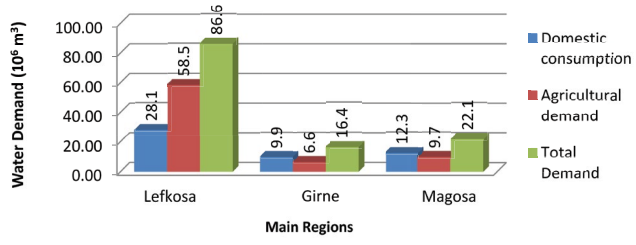

Fig. 5. Regional water demand year 2012.

Considering the year 2012, the total of domestic and agricultural water demand for Lefkoşa main region increased to 86.6 MCM, followed by the Magosa main region with 22.1 MCM while the total demand for the Girne main region increases slightly to 16.4 MCM.

NC is blessed with fertile land suitable for the production of a variety of crops. Up to the year 2012, several types of crops were grown in almost all regions despite the problems of water quantity and quality. Efforts were made to conduct an assessment of the agricultural economy the groups of crops listed in Tables 5 and 6.

The evaluation was intended to be a focus on the average charge of water consumption per hectare, cost of farm management and farmer profit per hectare. Unfortunately, data on the cost of farm management were difficult to obtain and varied according to crop type and regions. The only available guiding information is water charge per cubic meter for the Güzelyurt region, which also varies from 0.21 to 0.59 USD/m^3.

Tables 5 and 6 the crops along with their evaluated incomes. It can be seen that some crops are very profitable, some are intermediate, while others have minimal or no gain at all. Similarly, the incomes fluctuate from one year to another, which is associated with water quality, land fertility, and societal need. The conducted assessment of the agricultural economy shows that about 146.7 and 115.1 million USD were generated in 2011 and 2012, respectively, which is a valuable income for the NC.

Based on the approach of incomes generated per cubic meter, the cultivation of tomato, cucumber, pepper, squash, artichoke, strawberry, potato (spring), eggplant, cabbage, and grapes are most profitable to the farmers with incomes of over 5.0 USD/m^3. The profit of other crops such as potato (autumn), onion (dry), vegetable, etc. ranges from 2 to 4.99 USD/m^3 except for beans (dry), fruit and alfalfa, which have very minimal profit. Within these valuable incomes, the farmers pay water charges, cost of land management and other miscellaneous expenses and also to gain relatively considerable benefit to take care of themselves and their families.

In addition, it is observed that citrus production consumed the highest percentage of water with quantities of 42.0 and 41.1 MCM for 2011 and 2012, respectively. However, the farmers generated a very low income of 2.18 USD in 2011 and this dropped to 1.59 USD/m^3 in 2012. For that reason, farmers gained only minimal levels of profit as a result of the overall costs associated with cultivation.

Finally, it can be concluded that by a good inspection of Tables 5 and 6 the government agencies might have a viable reference list of products in revenue to inform the farmers to cultivate the high profitable crops and to give up the ones with minor income. In some cases, the agencies might also force the farmers to cultivate these profitable products or suggest alternative ones considering the regional water quality of the irrigation water as well.

It can be concluded that, generally, without groundwater, life would have been difficult and threatening in NC. This is because, in 2012, the total quantity of desalinated water and dam storage was 12.9 MCM, while that of fresh groundwater was minimal. Altogether, the total available amount was far less than the aggregate demand. This clearly shows that there was a very significant imbalance between demand

Table 5
Economic analysis of agricultural production vs. water use for 2011

No	Crops	Cultivated area (ha)	Average water consumption (m^3/ha)	Total water consumption (m^3)	Incomes (USD)/ha	Total incomes (USD)	Incomes (USD/m^3)
1	Beans (Dry)	209	3,111	650,285	678	141,720	0,22
2	Potato (Atm)	630	4,959	3,123,982	12,042	7,586,354	2,43
3	Onion (Dry)	162	4,027	652,373	10,613	1,719,317	2,64
4	Green vegetables	322	2,524	812,813	4,984	1,604,827	1,97
5	Tomato	201	5,919	1,189,749	30,955	6,221,900	5,23
6	Cucumber	50	4,194	209,683	44,862	2,243,083	10,70
7	Pepper	33	5,753	189,835	29,392	969,926	5,11
8	Squash	20	3,476	69,529	17,718	354,353	5,10
9	Peas	23	3,761	86,500	15,888	365,431	4,22
10	Artichoke	321	3,191	1,024,431	15,081	4,841,057	4,73
11	Strawberry	12	5,370	64,435	26,469	317,629	4,93
12	Potato (Spr)	279	3,023	843,484	31,608	8,818,669	10,46
13	Eggplant	52	5,737	298,317	25,539	1,328,036	4,45
14	Melon	277	3,717	1,029,632	13,908	3,852,453	3,74
15	Beans (Gr)	199	4,337	863,034	19,836	3,947,412	4,57
16	Carrot	31	4,445	137,809	12,216	378,690	2,75
17	Cabbage	74	3,317	245,436	19,434	1,438,131	5,86
18	Fruits	850	8,420	7,157,311	5,378	4,570,906	0,64
19	Grapes	92	3,956	363,951	34,640	3,186,869	8,76
20	Citrus	5,476	7,667	41,982,430	16,712	91,515,149	2,18
21	Alfalfa	279	6,276	1,751,121	4,560	1,272,209	0,73
	Total	9,592	97,181	62,746,140	392,512	146,674,119	

and supply, and this justifies and proves the dependency on groundwater owing to the limited supply from these sources. Excessive extraction of groundwater led to a decline in the water table level within the whole country along with the salinization of most coastal and inland aquifers (Table 7). The best alternative way of relieving the aquifers will be the active use of the 75 MCM of water annually delivered from Turkey to NC, which via proper distribution, will simultaneously give rise to the cultivation of more irrigable land and allow aquifers to replenish back to fresh status.

Table 7 provides information about the aquifer situation in NC for the period 2000–2012. According to reports produced by the Geology Department, the average annual recharge capacity of all the available aquifers is about 103.9 MCM. However, the findings of this research show that there has been over-pumping beyond safe yields; as such, almost all the aquifers have become contaminated with seawater except for a few. In addition, the water level in some of the aquifers has gone down, which has allowed limited extraction only through deep pumping wells. The groundwater extraction for the year 2000 was 138.5 MCM while in the year 2001 it was 120.7 MCM and for 2002, it was found to be 112.5 MCM. Similarly, for 2003 the quantity was 112.2 MCM while for 2010, 2011, and 2012, the extraction levels were 108.9, 99.9, and 111.5 MCM, respectively. These values also indicate that there was over-extraction, which needs to be well managed to avoid further contamination.

Although there was an overdraft, the Yeşilköy and Lefke aquifers were not contaminated. Likewise, Girne mountain aquifer is also fresh because it is above sea level and it is recharged by rainfall. However, owing to the overdraft, only a limited supply is available from the Koruçam, East Mesaria, Büyükkonuk, and Karpaz aquifers.

Mineral contamination has also contributed to making groundwater unfit for drinking and irrigation; for example, Lefkoşa Serdarlı was contaminated by gypsum, as indicated in Table 7. In the same way, Yeşilköy was contaminated by sulfur and therefore could not be used to serve the society. Apart from the above-discussed aquifers, all others, such as Güzelyurt aquifer, are in contact with seawater and have become severely contaminated due to overdraft beyond their respective safe yields.

The Güzelyurt aquifer is the main aquifer supplying water to the Güzelyurt area, Lefkoşa and some other parts of the country with an annual recharge capacity of 37 MCM. However, water scarcity has necessitated over-pumping beyond its safe yield. It can be observed that in the year 2000, there was an overdraft of 46.2 MCM; although the salt concentration was very high, the aquifer was continuously being over-extracted up to the year 2012 (Table 7). Similarly, the Girne coastal aquifer experienced the same problem of over-extraction. It appears that over-pumping is to continue in this manner until judicious water resources management is enforced.

Table 6
Economic analysis of agricultural production vs. water use for 2012

No.	Crops	Cultivated area (ha)	Average water consumption (m^3/ha)	Total water consumption (m^3)	Incomes (USD)/ha	Total income (USD)	Income (USD/m^3)
1	Beans (Dry)	224	3.099	692.766	2.146	479.841	0,69
2	Potato (Atm)	527	4.966	2.617.339	10.870	5.729.724	2,19
3	Onion (Dry)	164	4.041	662.251	8.515	1.395.410	2,11
4	Green vegetables	348	2.525	877.704	5.650	1.963.868	2,24
5	Tomato	197	5.870	1.158.323	20.711	4.086.843	3,53
6	Cucumber	48	4.149	197.599	8.361	398.216	2,02
7	Pepper	31	5.755	180.942	32.213	1.012.713	5,60
8	Squash	34	3.465	118.664	17.768	608.512	5,13
9	Peas	47	3.594	167.810	5.243	244.782	1,46
10	Artichoke	325	3.132	1.017.774	18.526	6.019.917	5,91
11	Strawberry	14	5.277	75.543	34.047	487.365	6,45
12	Potato (Spr)	444	3.009	1.337.454	14.921	6.631.173	4,96
13	Eggplant	59	5.703	335.694	32.659	1.922.413	5,73
14	Melon	281	3.705	1.039.996	9.956	2.794.374	2,69
15	Beans (Gr)	215	4.321	929.480	18.768	4.037.386	4,34
16	Carrot	73	4.524	332.288	13.245	972.766	2,93
17	Cabbage	81	2.945	239.123	18.810	1.527.447	6,39
18	Fruits	855	8.449	7.226.098	4.375	3.741.544	0,52
19	Grapes	3.230	3.964	12.804.648	1.366	4.412.980	0,34
20	Citrus	5.361	7.665	41.091.553	12.210	65.457.494	1,59
21	Alfalfa	270	6.275	1.692.379	4.329	1.167.651	0,69
	Total	12.828	96.435	74.795.427		115.092.419	

5. Conclusions and recommendations

5.1. Conclusions

At the beginning of this research, it was hypothesized that water demand for domestic and agricultural purposes might be increasing, decreasing or fluctuating over time based on several factors to be investigated.

Based on the assessment of the water budget of NC for 2010, 2011, 2012, and a comparison with the historical results, it was realized that the trend of domestic water need is positive, which has gradually increased in relation to population growth and is expected to keep rising in line with the growing population. On the other hand, the trend of water demand for agricultural production fluctuates with time due to changes in the area of cultivated land. However, on average, the trend is negative owing to the modernization of irrigation methods as well as the minimization of losses through the replacement of old water conveyance systems.

Though there are limited water resources in NC, these findings strongly show that the trend of water demand in NC will be positive meaning that the demand will keep increasing if more land will keep being cultivated through irrigation.

Lefkoşa main region which comprises of Central Lefkoşa, Değirmenlik, Ercan, and Güzelyurt have higher water consumption compared to Girne and Magosa main regions.

In the year 2012, the Lefkoşa main region accounted for 86.6 MCM of the total water need for domestic and agricultural demand, followed by Magosa main region with a total of 22.1 MCM, while the Girne main region comprising Girne East, Girne West, Boğaz and Çamlıbel had a total domestic and agricultural demand of 16.4 MCM. Therefore, the Lefkoşa main region has higher water demand due to the high population and irrigation practice and consequently requires more freshwater than both Magosa and Girne.

According to the geology department, the average annual aquifer recharge capacity is 103.9 MCM, but the findings of this research indicate that in 2012, groundwater extraction accounted for 111.5 MCM. The Güzelyurt aquifer supplies water to most parts of the country but as a result of water scarcity, an overdraft of 25.2 MCM was recorded in 2012.

The total demand for the year 2012 was 125.2 MCM; however, the total quantity of desalinated water and dam storage was 12.9 MCM, and that of fresh groundwater obtained from uncontaminated aquifers is minimal. The combined total of clean water available is far below demand, leading to a very significant imbalance between demand and freshwater supply.

Therefore, despite the 75 MCM water supply from Turkey to NC, of which 50.3% will be allocated for municipal supply, and the other 49.7% will be used for agriculture, the total available freshwater will be less than demand.

Table 7
Aquifer storage capacities and status due to over extraction and mineral contamination

Aquifer name	Sub-region	Rech. cap. (10^6) (m^3)	2000		2001		2002		2003		2010		2011		2012		Status
			Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	Wat ext. (10^6) (m^3)	Aqu. st. (10^6) (m^3)	
Güzelyurt	Güzelyurt	37	83.2	–46.2	73.6	–36.6	65.8	–28.8	67.2	–30.2	52.2	–15.2	60.1	–23.1	62.2	–25.2	Contaminated
Lefke	Lefke	15.5	5.2	17.3	5.2	17.3	3.6	18.9	3.3	19.2	14.6	8.4	11	11.5	14.1	8.4	Safe
Yeşilırmak	Lefke	7															
Serdarlı	Lefkoşa	6	0.6	5.4	0	6	0	6	0	6	0	6	0	6	0	6	Gypsum contamination
Girne mountain	Değirmenlik	10	4.7	5.3	4.7	5.3	4.8	5.2	5.1	4.9	4.5	5.5	4.9	4.85	6.2	3.55	Safe
	Total	75.5	93.7	–18.2	83.5	–8	74.2	1.3	75.6	–0.1	70.8	4.7	76	–0.75	82.5	–7.25	
Girne coast	Girne	9	14.4	–5.4	10.9	–1.9	11.1	–2.1	11.5	–2.5	10.9	–1.9	7.6	1.4	9.9	–0.9	Contaminated
Koruçam	Çamlıbel	1.1	2.1	–1	2.1	–1	1.5	–0.4	1	0.1	2.1	–1.1	0.5	0.6	0.5	0.6	Limited supply
Akdeniz	Çamlıbel	1.5	2.3	–0.8	2.2	–0.7	2	–0.5	2	–0.5	2.2	–0.7	1.2	0.3	1.4	0.1	Contaminated
	Total	11.6	18.8	–7.2	15.2	–3.6	14.6	–3	14.5	–2.9	15.2	–3.6	9.3	2.3	11.8	–0.2	
East Mesaria	Magosa A	5	10.6	–4.1	7.8	–1.3	7.7	–1.2	7.4	–0.9	6.4	–0.1	3.7	2.8	5	1.5	Contaminated
Maras	Magosa A	1.5															
Türkmenköy	Akdoğan	0.5	4.6	–2	3.5	–0.9	3.8	–1.2	3.3	–0.7	5.0	–2.4	3.9	–1.3	4.2	–1.6	Contaminated
Beyarmudu	Akdoğan	0.5															
Çayönü	Akdoğan	0.8															
İncirli	Akdoğan	0.8															
Güvercinlik	Magosa B	0.6	0.9	–0.3	1.1	–0.5	0.9	–0.3	0.9	–0.3	0.8	–0.2	0.9	–0.3	1.7	–1.1	Contaminated
Büyükkonuk	Mehmetçik	0.5	1.9	–1.4	2.1	–1.6	2.2	–1.7	2.6	–2.1	1.2	–0.7	0.2	0.3	0.2	0.3	Safe/Limited supply
Karpaz	Y. Erenkoy	1.5	3.9	–0.9	3.6	–0.6	6.1	–3.1	4.3	–1.3	4.4	–1.4	3.1	–0.15	2.8	0.15	Safe/Limited supply
Yeşilköy	Y. Erenkoy	1.5															Sulfur cont.
Gypsum aquifers	Scattered	3.6	4.1	–0.5	3.9	–0.3	3	0.6	2.7	0.9	3.6	0.0	3	0.6	3.4	0.2	Gypsum contamination
	Sub-total	16.8	26	–9.2	22	–5.2	23.7	–6.9	21.2	–4.4	21.5	–4.7	14.8	1.95	17.3	–0.55	
	Total	103.9	138.5	–34.6	120.7	–16.8	112.5	–8.6	112.2	–7.4	107.5	–3.6	99.9	3.5	115.1	–8	

Hence, it could be concluded that the water supply will significantly alleviate water scarcity, but there will be a tendency for some parts of the country to continue experiencing such problems.

Lastly, the assessment of the agricultural economy conducted shows that about 146.7 and 115.1 million USD were generated in 2011 and 2012, respectively, which were valuable incomes for the NC. However, there was high water consumption in the agricultural sector, particularly due to citrus cultivation.

5.2. Recommendations

Because the trend of the water budget of the NC is positive concerning the increase in population growth, urbanization and irrigation practice, the following recommendations could be made:

There is a need to periodically assess the water budget on a regional basis, for example, every 5 or 10 years, to provide a periodic update on demand and supply for proper water management in the domestic and agricultural sectors.

- There is a need to provide a periodic update on the groundwater extraction and yield capacity of all available aquifers including the extent of contamination or replenishment.
- There is a need to provide a periodic update on streamflow and dam storage including the extent to which these resources are affected by drought.
- As a result of water scarcity and limited water resources in the country, it is advisable to look at the possibility of implementing solar desalination plants to guarantee water security for sustainable development. This will also give rise to the cultivation of more land for generating more economic revenue.
- Although there are many dams all over the country which depend entirely on rainfall/runoff for recharging, the storage capacity of the dams should be investigated against siltation to ensure that all runoff water is collected, stored and distributed judiciously for optimum benefit.
- The quantity of water treated by the Lefkoşa, Girne, Güzelyurt and Magusa central sewerage treatment plants is relatively large, accounting for about 9.5 MCM in 2012, which water officials say was being diverted to the Mediterranean Sea without any reuse. By considering the level of water scarcity in the country and the need to allocate more land for cultivation, there is a need to look at the possibility of utilizing such treated water. Meanwhile, it is advisable to consider the level of the treatment and the quality based on an acceptable standard; if the quality is below standard, then more treatment should be done to ensure that it is useful for agricultural production as it contains many macronutrients needed by crops.
- Based on the assessment of the agricultural economy of some selected crops, where it was found that citrus consumed higher percentage of water but yielded less economic benefit, it is recommended to investigate its production yield to increase productivity or else minimize its production and introduce new crops that are demanded and profitable with less water consumption.

References

[1] Anonymous, Agricultural Structure and Production, Annual Statistics, Ministry of Agriculture and Forestry, Department of Agriculture, Nicosia, NC, 2000–2012.
[2] G. Elkıran, A. Türkman, Water Scarcity Impacts On Northern Cyprus And Alternative Mitigation Strategies, J.G. Qi, K.T. Evered, Environmental Problems of Central Asia and their Economic, Social and Security Impacts, Springer, Dordrecht, 2008, pp. 241–250.
[3] G. Elkiran, M. Ergil, A General Outlook of Aquifers in TRNC, Proceedings of Second FAE International Symposium, Gemikonagi, NC, 2002, pp. 101–104.
[4] G. Elkiran, M. Ergil, Integrated Water Resources Planning and Management of North Cyprus, Where Waters Meet Proceedings NZHS-IAH-NZSSS Conference, Auckland, New Zealand, 2005.
[5] G. Elkiran, Z. Ongul, Implications of excessive water withdrawals to the environment of Northern Cyprus, Water Environ. J., 23 (2009) 145–154.
[6] M. Necdet, Groundwater in NC, Geology Department, Ministry of Geology and Mines, Nicosia, North Cyprus, 2006.
[7] G. Elkiran, F. Aslanova, S. Hiziroglu, Effluent water reuse possibilities in Northern Cyprus, Water, 11 (2019) 191.
[8] C. Ontario, Integrated Watershed Management–Navigating Ontario's Future Water Budget–Overview for Ontario, Ca, 2010. Available at: www.conservationontario.
[9] G. Elkiran, M. Ergil, The assessment of a water budget of North Cyprus, Build. Environ., 41 (2006) 1671–1677.
[10] UN, Survey of Groundwater and Mineral Resources in Cyprus, New York, United States, 1970.
[11] T. Riza, Desalination Plants and Daily Production in Northern Cyprus, Water Works Department, Ministry of Interior, Nicosia, North Cyprus, 2014.
[12] Y. Mavioğlu, Discussions on Water Budget of North Cyprus and Consumptive Water Supplies, Water Works Department, North Cyprus, 2004.
[13] DSI, Water Supply Project from Turkey to Northern Cyprus, 2018, Available at: http://www.ansamed.info/ansamed/en/news/sections/economics/2012/10/15/Turkey-starts-water-supply-project-North-Cyprus_7632671.html.
[14] S. Ozturk, Up to date Water Situation of North Cyprus, Water Congress, KTMMOB, 1995, pp. 23–35.
[15] G. Elkiran, M. Ergil, The Water Budget Analysis of Girne Region, North Cyprus, Proceedings of the 6th International Congress on Advances in Civil Engineering, Bogazici University, Istanbul, Turkey, 2004, pp. 6–8.
[16] N. Oznel, Sewerage Treatment and Production of Sanitary Water in NC, Sewage Division of Lefkoşa Municipality, Nicosia, North Cyprus, 2014.
[17] T. Muslu, Institutions Serving Tourism Sector and Wastewater Use, 31.T.C.B. 75/01–335, Department of Tourism and Planning, Ministry of Tourism and Environment, North Cyprus, 2012.
[18] SPD, North Cyprus Census, Newsletter, State Planning Department, Nicosia, North Cyprus, 2013.
[19] H. Kilickaya, How Often to Irrigate and How Much Water Should be Released, Ministry of Agriculture and Forestry, North Cyprus, 1977.