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Integrated water and wastewater management strategy in North Cyprus - basis for an action plan

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ABSTRACT

This paper explored and assessed the essential elements of an integrated water and wastewater management strategy that could be easily translated into an action plan for North Cyprus. The evaluation was carried out in light of all numerical indicators related to water demand and wastewater generation. First, it showed the alarming state of the country, due to the inadequacy of surface water resources and deterioration of aquifers caused by pollution and seawater intrusion. The transport of 75 million m^3/year of high-quality water from Turkey (TC water) has been a milestone for solving the chronic water problem. Currently, the water demands of municipal, tourism and education sectors were assessed to 40.3, 5.5, and 4.8 million m^3/year, respectively. Together with agriculture and livestock farming, the overall water demand amounted to 84 million m^3/year. The new water potential created with the TC water amounted to 109 million m^3/year, way over the actual demand, which would enable us to boost the irrigated agricultural activities shortly. Furthermore, the quality of the TC water is quite suitable for reuse of the treated wastewater, which would create a new water resource. The new possibilities can only be put into action, within the context of a compatible integrated water and wastewater management strategy. This paper also defined the highlights of this strategy.

Keywords: Water reuse; Water transport; Sectoral water demands; Membrane bioreactor; Energy recovery from waste

1. Introduction

One of the crucial issues of small islands is the inadequacy of natural freshwater sources. They mostly face water scarcity due to the combined effect of population growth with expanding activities and climate change. This problem occurs when water consumption exceeds the existing potential to replenish water resources and especially groundwater sources under gradually declining rainfall. This situation not only limits water utilization but also causes more important problems, such as depletion of groundwater and deterioration of its water quality beyond tolerable levels. The only remedy to this problem is to come up with a scientifically sound integrated management strategy that will cover not only water but also wastewater to safeguard and re-generate available freshwater.

This picture describes the water situation in North Cyprus, where the rainfall levels significantly dropped

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in the last decades, due to the negative impact of climate change [1,2]. This change inevitably reduced the magnitude of surface water utilization, which was already quite limited, since most of the rainfall was lost through surface runoff and evapotranspiration due to the geography and topography of the area [2,3]. The decline in exploitable surface water has shifted the water demand towards groundwater resources, which supplied until recently, nearly 80% of the water demand in the island; the remaining part was provided by surface water and desalination of seawater and brackish water Rapid and unplanned escalation of withdrawals created severe problems not only in the available volume but irrevocable quality problems of salinity and saltwater intrusion [3,4]. Consequently, the water situation reached an alarming level, where there was practically no groundwater satisfying the expected quality level for safe utilization.

The project of freshwater transport amounting to 75 million m^3 from Turkey was completed by the end of 2015. This new water resource essentially solved the never-ending water problems in North Cyprus [4]. The amount of water transported Turkey (TC water) was enough to satisfy the need of all sectors, that is, municipal, tourism, agriculture, education, industry, etc. However, at this stage, the infrastructure that would allow full usage of transported water could not be completed, so that the utilization of TC water for municipal use could only extend to 71% of the demand, which still uses groundwater (wells) and a limited quantity of desalination.

Moreover, its quality almost reflects pure water with a minimum level of total dissolved solids (TDS). This feature is of paramount importance for North Cyprus, mainly because it offers the unique chance to define and implement an integrated water management strategy also covering wastewater as an important renewable water source.

In this context, the objective of the study was to explore and define the essential elements of an integrated water management strategy, which would focus on water recovery and reuse from wastewater treatment. Accurate, in situ assessment of all significant indicators related to water demand and wastewater disposal estimations was carried out as an integral part of the management strategy.

2. Water resources

One of the primary water resources of North Cyprus is surface water, which is carried by 38 streams, which are not perennial and flow during the rainy season and snowmelts. They originate from Girne (Kyrenia) mountains or Troodos mountains and discharge to the sea. Since the 1970s, water shortage problems associated with surface waters have increased tremendously due to the decreasing rate of rainfall, increasing temperature, and evaporation, growing population, and inadequate water management. Additionally, the topographic structure of the island is not appropriate to hold runoff water, which pours to the sea rapidly because of the inclines and short lengths of streams [1]. The magnitude of the surface water is estimated at around 190 million m^3/year [2]. Thirty dams with a total capacity of 35 million m^3 have been constructed on the streams to salvage as much water as possible. However, available water did not exceed so far 20–25 million m^3, due to poor operation of the system.

Groundwater was an essential resource for municipal water demand and irrigation until 2015. In North Cyprus there are thirteen aquifers as Girne/Kyrenia; Karpass/Karpasia, Gazimağusa/Famagusta and Güzelyurt/Morphou aquifers represent the majority of the groundwater potential [2]. These four aquifers are near coastal zone with a total capacity of 93.85 million m^3/year [4]. Groundwater is a renewable resource if recharge and extraction can be balanced [5]. In North Cyprus, the quality of groundwater has been a serious problem. In coastal aquifers, seawater intrusion is the main pollutant. Because of this chronic problem, coastal aquifers were seriously damaged and nearly disappeared. Inland aquifers also suffer from over-pumping and seepage of different sources of pollutants and soluble ingredients of geological formations [2,3]. In short, the service life is practically completed for most of the aquifers.

Desalination of seawater and brackish water is practiced at a local level, with a total magnitude of around 15,000 m^3/d, that is, 5,000 m^3/d for Famagusta municipal water demand; 2,000 m^3/d for Bafra tourism center and a total of 7,400 m^3/d for the water supply of eight resort facilities.

As mentioned above, the transport of 75 million m^3/year from Turkey has been the new freshwater resource for North Cyprus, which also opened immense possibilities for water reuse and groundwater recharge. Details of this project were provided by Gökçekuş et al. [4].

3. Water demand

3.1. Land use and population

North Cyprus covers a total surface area of 3,354 km^2. The major portion of this area, which is currently estimated at 57%, is devoted to agriculture. The residential area covers 11% and the remaining land is subdivided between forest area (20%); grassland (5%) and unused land (8%) [6].

North Cyprus houses a total population of more than 377,000. It is unevenly distributed between six main districts, namely Nicosia; Girne; Famagusta, İskelé, Lefke, and Güzelyurt, which include 25 municipalities responsible for water distribution. The location of the districts is indicated in Fig. 1.

3.2. Municipal water consumption

TC water, although supplied to cover the entire demand, is not fully distributed, due to still progressing network and infrastructure projects. Currently, 12 municipalities consume only TC water; the remaining 13 municipalities partly benefit from TC water together with local resources (mainly wells/groundwater). Only local resources are available to Lefke municipality; Akıncılar municipality utilizes water extracted from wells located in the intermediate zone adjacent to South Cyprus; Famagusta municipality consumes water from desalination units together with TC water and groundwater (Fig. 2.).

Table 1 gives a summarized account of the magnitude of municipal water consumption. The data presented in this table were evaluated for each municipality and the cumulative values of the indicators were then calculated for each district. Accordingly, the total daily water consumption in

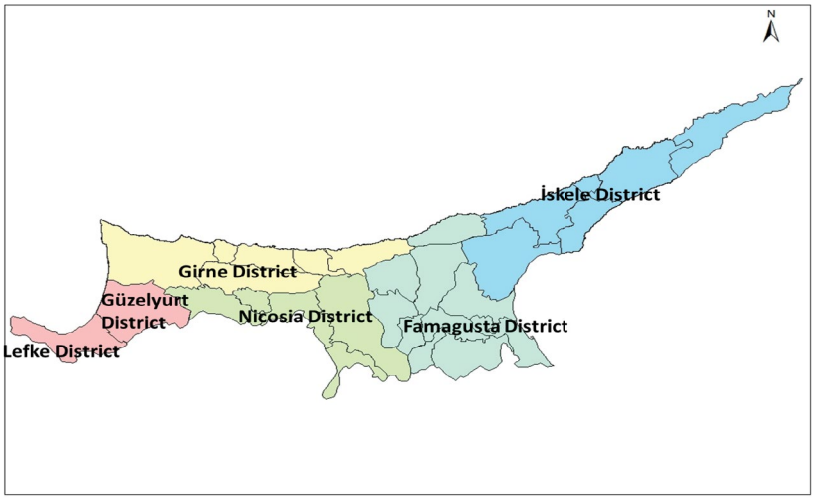

Fig. 1. Location of six districts in North Cyprus.

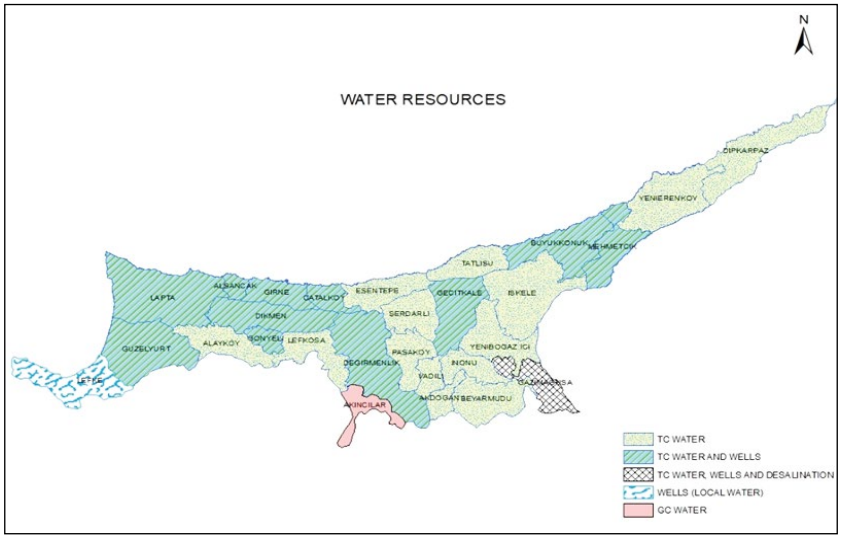

Fig. 2. Sources of water utilized for municipal demand.

Table 1
Numerical indicators of municipal water consumption in North Cyprus

Districts	Water consumption				Population	Water use (L/ca d)
	TC water	Wells	Total			
	(m^3/year)	(m^3/year)	(m^3/year)	(m^3/d)		
Nicosia	9,851,446	1,431,910	11,283,356	30,913	125,728	246
Girne	6,858,345	6,915,701	13,774,046	37,737	94,262	400
Famagusta	6,308,712	523,138	6,831,850	18,717	90,812	215
İskelé	3,802,871	105,718	3,908,589	10,709	28,745	373
Lefke	–	1,885,124	1,885,124	5,165	13,985	369
Güzelyurt	1,877,652	770,874	2,648,526	7,256	23,826	305
Total	28,699,026	11,632,465	40,331,491	110,497	377,358	295*

* average

residential areas amounted to around 111,000 m^3/d corresponding to 40.6 million m^3/year. The share of TC water utilization was calculated as 80,600 m^3/d, which is equivalent to 72% of the total municipal consumption. Conversion of this volume to yearly water consumption yielded 29.5 million m^3/year, which only represented 39% of the yearly water transport from Turkey.

The collected data were also used to calculate the average per capita water utilization as 295 L/ca d. This unit consumption rate was observed to vary in the range of 214–400 L/ca d among districts. A much wider variety of 150–600 L/ca d. was calculated to exist among different municipalities. This level of water consumption certainly looks very generous even compared with developed countries in Europe, but it is closely related to the general type of housing with big yards in North Cyprus where water is also used for irrigation of gardens and grassland. Generally, the unit consumption rate decreased in areas supplied with low-quality groundwater.

3.3. Water consumption in tourism and education

Tourism is an old but still developing sector in North Cyprus, which currently houses up to 150 facilities with more than 25,000-bed capacity. The highest tourism density is observed around Girne and İskelé districts. A comprehensive account of tourism potential was recently provided by Gökçekuş et al. [7], which revealed that the overall average water demand was around 500 L/bed d, increasing up to 1,000 L/bed d during high season. Similarly, the yearly average occupancy was approximately 50%, rising to 80%–90% during the summer period. This study carried out an up to date survey which provided the numerical potential of tourism in terms of all municipalities and districts. The interpretation of this potential for the corresponding water demand is summarized in Table 2. Based on the yearly occupancy rate of each district, the overall yearly water demand of this sector was calculated as 6,255 m^3/d. However, a more accurate image could be obtained when considering the summer conditions, which raised the water demand to 15,000 m^3/d, or 5.5 million m^3/year, based on 750 L/bed d and 89% occupancy.

Together with agriculture and tourism, which are the essential backbones of the economy, higher education constitutes another service sector with an input on the economy of North Cyprus. With 16 universities and more than 100,000 students from all over the world, North Cyprus well deserves the "education country" attribute. The distribution of tourism education potential throughout North Cyprus can be visualized in Fig. 3. This study assessed the distribution of this potential among districts, indicating the highest education activities in Girne, Nicosia (Lefkoşa) and Famagusta (Gazimağusa) districts. As given in Table 2, this sector was calculated to exert a water demand of 13,100 m^3/d or 4.8 million m^3/year, based on a unit consumption of 150 L/d per student, including the additional demand of campus premises. In Table 2, the student number was reduced to 87,000 excluding students, which are North Cyprus citizens because they were already accounted for in the municipal water demand.

3.4. Water demand for agriculture

Agriculture is the backbone of the economy in North Cyprus. In rural areas, citizens generally support and maintain their living through agriculture. Agricultural areas constitute approximately 57%, which is the highest percentage of land use in the country. Around 70% of the agricultural land is economically valued; currently, irrigation is provided to only 7% of the cultivated area [6].

Cereals, fodder crops, fodder legumes, vegetables, industrial crops, fruits vineyards, and citrus varieties are the main agricultural products. Farming and animal husbandry is another agricultural sector with significant water demand. The water demand related to agriculture, as calculated in the study based on the blue water footprints of different agricultural products [6,8–10], is summarized in Table 3, which yields the yearly optimum water demand of agriculture as 31.2 million m^3/year, under current conditions.

At present, North Cyprus houses approximately cattle and 357,000 sheep [6]. There is no reliable and precise data about the water requirements of livestock. Water needs are affected by many factors such as ambient temperature, class, and weight of livestock and even feed quality (grassland; saltbush). Temperature and weight increase daily water intake. Based on the available information in the literature [10] under hot climatic conditions in North Cyprus a daily water intake of 50–60 L/cattle d was adopted for related

Table 2
Numerical indicators of water demand for tourism and education in North Cyprus

Districts	Tourism			Education	
	Bed capacity (number of bed)	Average occupancy (%)	Water demand (m^3/d)	Number of students	Water demand (m^3/d)
Nicosia	826	39	161	40,585	6,088
Girne	15,723	59	4,638	17,751	2,663
Famagusta	1,710	75	641	16,065	2,410
İskelé	6,536	52	1,700	–	–
Lefke	94	100	47	9,902	1,485
Güzelyurt	38	100	19	3,297	495
Total	24,927	58	7,206	87,600	13,140

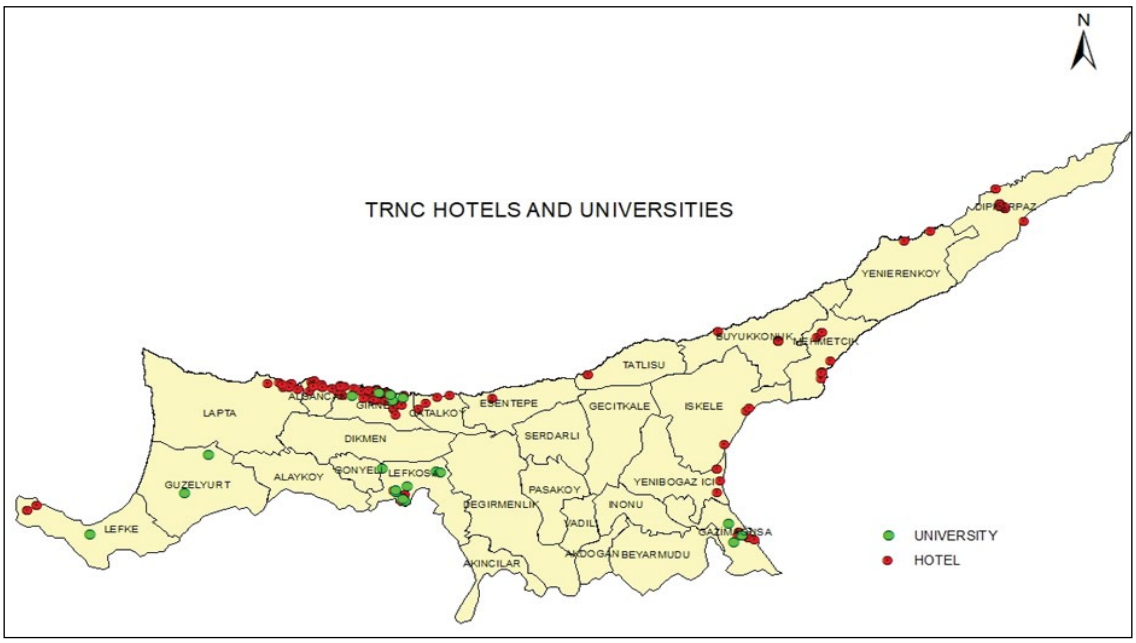

Fig. 3. Geographical distribution of tourism and education potential in North Cyprus.

evaluations, corresponding to approximately 1.5 million m^3/year. For the 357,000 sheep and goat, the daily requirement was accepted as 6 L/sheep d with a similar approach [11], which gives a yearly demand of around 0.8 million m^3/year. Consequently, the total water demand of livestock farming could be calculated as 2.3 million m^3/year.

Indeed, agricultural water demand was calculated based on existing production and activities. It should be noted there is huge potential to significantly increase the agricultural activities in vacant areas, especially in the eastern parts of North Cyprus, which will tremendously raise the water demand in the future. This is one of the reasons for implementing a wastewater recovery/reuse strategy in the suggested water management approach for diverting the recovered water to agricultural irrigation.

3.5. Overall water demand

The assessments of the study presented above indicated that the basic water demand for human activities amounted to 50.6 million m^3/year; the overall municipal water consumption was calculated as 40.3 million m^3/year, 80% of the total demand. As shown in Table 4, this demand was met by three different sources: TC water supplied 72% of this demand; the rest was supplied by groundwater (23%) and desalination systems (5%). At this point, desalination practice may be encouraged and expanded using different scale autonomous units that would function using the significant renewable energy potential (solar and wind energy) of North Cyprus [12].

The infrastructure of North Cyprus is presently adequate to serve the clean water transferred from Turkey to the majority of urban areas. The ongoing improvements of the infrastructure are planned to rapidly expand the availability of the water to remote areas.

Similarly, this study assessed the actual overall water demand of North Cyprus as 84 million m^3/year. Agriculture and livestock farming constituted 40% of this demand (Fig. 4a). This level should be compared with the current water resources available in the country, which corresponds to a magnitude of 109 million m^3/year, far more than the overall water demand. As illustrated in Fig. 4b, TC water covers the major portion (69%) of this water pool, together with 20 million m^3/year of surface water (18%). This overall picture underlines the immense benefit of the TC water (i) for expanding irrigated agriculture and increasing the share of agricultural good in the country's economy and (b) creating a significant additional water resource through reuse of treated wastewater in irrigation and groundwater recharge.

4. Water quality

Before the water transport from Turkey, the water demand of North Cyprus heavily depended on the extraction of groundwater at rates exceeding the capacity of existing aquifers, leading saltwater intrusion, and deterioration of water quality. A typical example of this trend was provided by Gökçekuş et al. [4], reporting the salinity profile of the Nicosia water supply, which started as 2,340 mg/L in 2010, increasing up to 4,100 mg/L in 2016, a level way beyond the acceptable threshold for consumption and exhibiting a sudden drop to 29 mg/L at the end of 2017 after TC water was started to be distributed in the network.

Table 5 illustrates the sparkling clear quality of the TC water with a salinity level of only 23–35 mg/L and a TDS content of 65–102 mg/L determined during this study, together with analyses conducted on different water sources: For instance, the water supply from wells to Değirmenlik included a salinity content of 1,112 mg/L in 2014 as the

Table 3
Numerical indicators of water demand for agriculture in North Cyprus

Products	Amounts (ton/year)	Water demand	
		m^3/ton [8]	Total (m^3/year)
Grain			
Wheat	8,548	342	2,923,416
Barley	110,168	79	8,703,272
Oat	352	181	63,712
Legumes			
Chick pea	2	224	448
Broad bean	50	205	10,250
Dry beans	65	125	8,125
Potato	8,026	33	264,858
Vegetables			
Coriander	200	1,865	373,000
Tomato	214	63	13,482
Cucumber	2,597	42	109,074
Pepper	951	42	39,942
Eggplant	1,233	33	40,689
Watermelon	11,335	25	283,375
Green beans	566	54	30,564
Green pea	230	63	14,490
Onion	3,180	44	139,920
Artichoke	7,112	242	1,721,104
Cauliflower	895	21	18,795
Others	4,076	33.5[a]	136,484
Citrus			
Orange	105,298	110	11,582,780
Lemon	8,094	152	1,230,288
Mandarin	15,208	118	1,794,544
Fruits			
Apricots	430	502	215,860
Peaches	458	188	86,104
Plums	302	188	56,776
Almond	447	1,908	852,876
Grape	1,723	97	167,131
Others	535	544[b]	291,222
Total	292,295	13,108	31,176,277

[a]Average of footprint of other vegetables.
[b]Average of footprint of other fruits.

salinity dropped to 23 mg/L in 2018, when TC water replaced groundwater.

5. Wastewater treatment potential

In North Cyprus six wastewater treatment plants are in operation, representing a total capacity of 17,400 m^3/d, only 13% of the municipal water consumption, including tourism and education. The volumetric characteristics of existing plants are summarized in Table 6.

The largest plant was built and operated at Nicosia, to treat the combined wastewater discharged from northern and southern parts of Nicosia. It was designed as a nutrient removal activated sludge system with a total capacity of 30,000 m^3/d. The wastewater flow collected from the northern part is only 9,000 m^3/d. A preliminary inspection of the plant indicated major flaws in system design, which would make it hard to comply with effluent limitations. This is impossible to check since the international group responsible for the operation of the plant also monitors the effluent quality in a closed-loop system. The capacity of the other five plants ranges between 500–4,100 m^3/d. No reliable information exists about the appropriate operation and the performance of these plants.

Table 4
Distribution of water demand and water supply for different sectors

Sector	Amount (million m^3/year)	(%)
Water demand		
Municipal	40.3	80%
Tourism	5.5	11%
Education	4.8	9%
Water supply		
TC water	36.3	72%
Wells	11.7	23%
Desalination	2.6	5%

6. Highlights of the management strategy

Currently, North Cyprus does not have the necessary structure and knowhow for implementing a management plan for its water resources. This situation is not sustainable, mainly because (i) there is no provision to safeguard water and a clean environment for the future and (ii) the technical and the institutional framework for such provision does not exist. Consequently, immediate action should be taken to define an integrated water and wastewater management plan, especially given the new water resource that is delivered from Turkey. This plan should be prepared in full agreement with the new approach of the European Union that regards waste as a resource, within the 3R concept (reduce/reuse/recycle). Essential elements of this management strategy may be highlighted as follows:

6.1. Water cycle and wastes

All components of the water cycle, that is, water, wastewater, and treatment sludge should be envisaged in a novel and comprehensive package in the same management approach. This approach should give priority to waste/energy interactions; waste recovery and reuse and especially, improvement of water resources.

6.2. Wastewater recycle and reuse

The water transported from Turkey reflects a high-quality drinking water characteristic. This is a golden opportunity for North Cyprus. This water should not be wasted after municipal use and discharged to the marine environment.

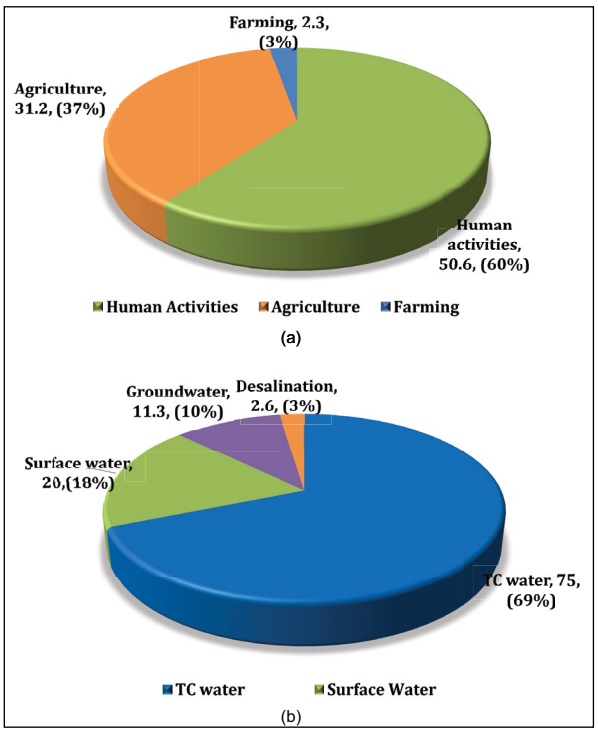

Fig. 4. Distribution of (a) water demand between different consumptive sources and (b) potential of different water sources (in million m^3/year).

Reuse of the treated wastewater should be adopted as the decisive principle of the management plan. This plan should adopt one of the most acceptable wastewater reuse options, where applicable (i) agricultural irrigation, (ii) aquifer recharge, urban, and recreational uses, and (iii) process water for industry.

Wastewater treatment is not fully applied in North Cyprus. While this is a major drawback for the tourism industry. It also presents a valuable opportunity to upgrade all existing plants and building new plants using novel membrane technology. It is essential that the same type of membrane bioreactors should be selected for all municipalities and touristic facilities, preferably a sequencing batch reactor type of activated sludge equipped with a membrane module, a treatment system that will easily withstand seasonal flow and fluctuations, which will generate reusable effluents for all municipalities [13–15]. In this context, the Haspolat treatment plant at Nicosia should be upgraded, separately for the wastewaters of the northern part of the town, which uses TC water with very low TDS content so that an important volume of treated wastewater can be recovered.

At this stage, it is important to remember that TDS content of the TC water is around 100 mg/L; the utilization of this water supply for municipal use induces a mineral pickup and a TDS increment of approximately 300 mg/L [16], so that the TDS content of the treated water will be in an all likelihood, below 500 mg/L. Then, the recovered treated effluent will even be a perfect source for the irrigation of garden/green areas at the local municipality level.

Table 5
Water quality of different sources assessed for several residential areas

Location		Conductivity (mS/cm)	Chloride (mg/L)	TDS (mg/L)	TSS (mg/L)	pH
Nicosia	TC water	480	21	64	5	8
Değirmenlik	Well water	3,140	670	966	10	7.2
	TC water	420	14		5	8
Tepebaşı	TC water	475	21	120	8	7.9
Geçitköy dam	TC water + local	480	21	126	6	8
Lapta	TC water + wells	720	64	128	8	7.6
Lefke	Well water	475	21	64	5	8

TDS: Total dissolved solids.
TSS: Total suspended solids.

Table 6
Volumetric characteristics of existing wastewater treatment plants in North Cyprus

Wastewater treatment plant (WWTP)	Capacity (m^3/d)	Existing effluent amount (m^3/d)	Discharge of effluent
Nicosia (NWWTP)	30,000	9,000 for SC	150,000 m^3/month reused in irrigation
Morphou WWTP	3,179	500	Discharged to the Pedieos river
Famagusta WWTP	8,883	4,100	Discharged to Yayla river
Kyrenia WWTP	1,800	1,800	Tatlısu fresh lake
Lapta WWTP	500	500	Grassland
Bafra WWTP	6,000	1,500	Sea
Total (m^3/year)	10,717,130	6,351	–

6.3. Water distribution and sewerage networks

The water distribution and sewerage networks must be expanded to cover the entire area in North Cyprus, for the full availability of TC water and also to collect, treat and recover all types of wastewaters generated.

6.4. Watershed management

Optimal utilization of surface water catchments and groundwater sources must be planned and implemented for all water structures, dams, ponds, etc. taking into account adverse impacts in the future, due to climate change. Water distribution from permitted wells must be under control for both capacity and quantity. All types of water demand and utilization must be controlled and recorded in open-access files.

6.5. Waste management

Waste management, that is, solid wastes, treatment sludges, agricultural wastes, etc., should be considered as an integral part of the management strategy, especially from the framework of energy from waste approach. The plan will foresee several novel treatment schemes for municipalities and tourist facilities, which will generate sludge with a high calorific value [17]. It should also recommend properly located central energy recovery systems using innovative technologies such as high-temperature pyrolysis [18].

6.6. Industrial pollution control and chemical safety

Although limited, industrial production is significant for pollution control in North Cyprus. Aside from slaughterhouses, dairy products with emphasis on halloumi cheese and citrus products processing may be cited as main industrial activities. The copper mining site at Lefke constitutes by itself a historical and still unresolved pollution source and environmental hazard of the international dimension, which requires immediate, effective solution [19]. The plan must also ensure that certain industrial wastes such as whey in cheese manufacturing will be recovered and processed into high added-value by-products. It should also enforce the treatment of industrial effluents separately from municipal wastewater in order not to impair the reuse quality of the treated effluent.

6.7. Environmental management

The foremost objective of the plan should be to monitor and control the quality of all significant elements of the environment such as seawater, surface waters, land, ecosystems, historical heritage, and related human activities for ensuring sustainable environmental protection in North Cyprus.

6.8. Institutional framework

It is important to note that North Cyprus does not have the necessary institutional infrastructure to cope, implement and enforce the essential components of this management strategy, especially when it is translated into an action plan. Existing institutional inadequacy includes almost all the constituents, that is, lack of responsible autonomous agency, different levels of critical mass/expert manpower for executing different functions and supporting facilities such as laboratories and monitoring stations. Related work should start with immediate initiative to design and establish an autonomous North Cyprus Environmental Agency (NCEPA) directly connected to the office of prime minister. Examples of such agencies such as the United States Environmental Protection Agency (US EPA), the European Environmental Protection Agency, German Environment

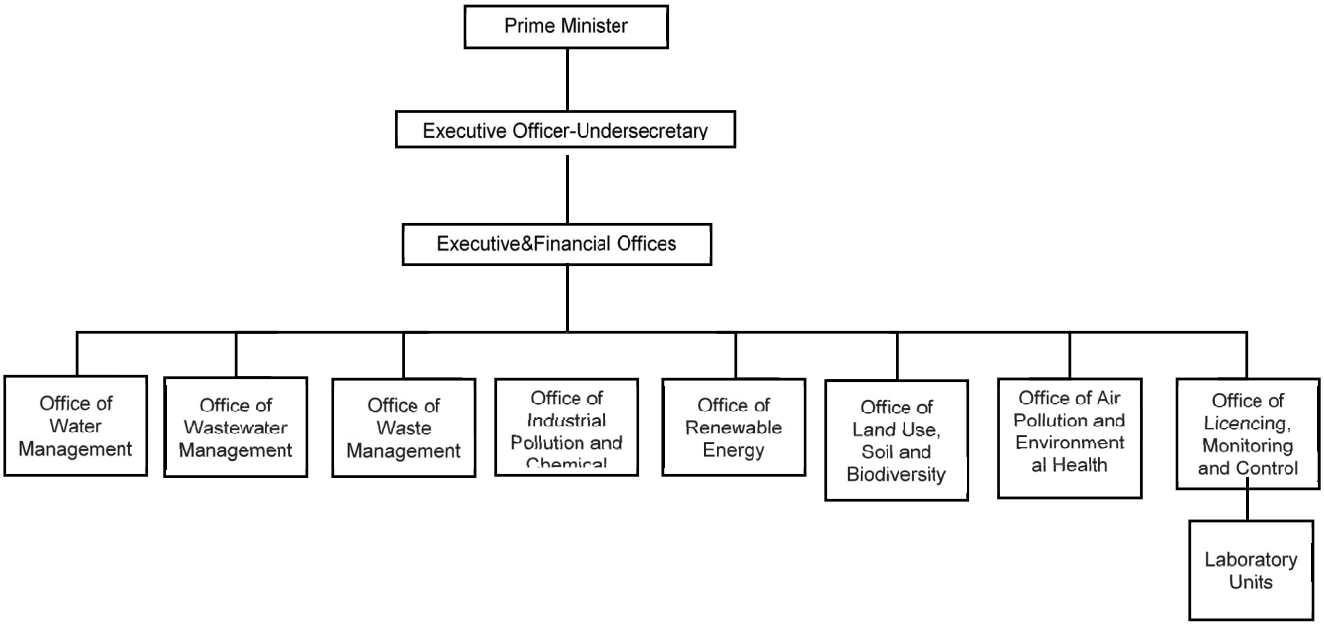

Fig. 5. Suggested organization chart for NCEPA.

Agency (UBA) exist with similar functions all around the world. Their organization mostly reflects the advanced state of environmental awareness and practice in developed countries. In the context, the organization chart illustrated in Fig. 5, is suggested given the nature and immediate needs of the environmental problems in North Cyprus.

7. Conclusion

Although the study was focused on the water problems in North Cyprus, it is believed that the main messages derived from the results of the study would be equally valid and applicable for all similar problems:

The quality and especially the TDS content of the water supply plays a decisive role in the success of the recovery and reuse of treated wastewater effluent. TDS is the most difficult pollutant for the reuse options. Since the incremental TDS intake after municipal use is around 300 mg/L, the level of residual TDS after treatment may become prohibitive for most reuse alternatives, if the quality of water supply is not suitable, which should be checked before attempting a recovery project.

All effluent recovery/reuse projects should be coupled with novel treatment technologies, that is, a suitable activated sludge configuration with a membrane module, which provides full treatment for suspended solids and coliforms and reduces organic carbon to a lowest possible level.

A water recovery and reuse scheme should be carried out as an integral component of sustainable integrated water and wastewater management plan.

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