Desalination and Water Treatment
www.deswater.com
doi:10.5004/dwt.2018.23135

132 (2018) 215–225
November

Massive freshwater transport: A new dimension for integrated water-wastewater management in North Cyprus

Hüseyin Gökcekuş[a], Anoosheh Iravanian[a], Umut Türker[b], Gözde Oğuz[a], Seval Sözen[c,d], Derin Orhon[a,d,*]

[a]*Faculty of Civil and Environmental Engineering, Near East University 99138 Nicosia, North Cyprus, Mersin 10, Turkey, Tel. +905488534960, email: huseyin.gokcekus@neu.edu.tr (H. Gokcekus), anoosheh.iravanian@neu.edu.tr (A. Iravanian), gozde.oguz@neu.edu.tr (G. Oğuz)*
[b]*Department of Civil Engineering, Eastern Mediterranean University, Famagusta, 99628 North Cyprus, Mersin 10, Turkey, email: umut.turker@emu.edu.tr (U. Türker)*
[c]*Environmental Engineering Department, Faculty of Civil Engineering, Istanbul Technical University, 34469 Maslak, Istanbul, Turkey, Tel. +902122856544, email: sozens@itu.edu.tr (S. Sözen)*
[d]*ENVIS Energy and Environmental Systems Research and Development Ltd., ITU ARI Technocity, 34469 Maslak, Istanbul, Turkey, Tel. +902122860303, email: orhon@itu.edu.tr (D. Orhon)*

Received 18 July 2018; Accepted 12 September 2018

ABSTRACT

Freshwater transport of 75 × 10^6 m^3/y from Turkey was a milestone to solve the never-ending water problems in North Cyprus. This water transport not only covered the demand of different sectors, but it also enabled to define and implement sustainable *integrated water management* (IWM) strategy considering wastewater as an integral part of the management approach. The paper identified all essential components of the IWM plan, defined sustainable action strategies based on beneficial use concept. Municipal water demand, agricultural use, groundwater recharge and water-contact recreation were defined as primary beneficial uses for priority consideration. Innovative membrane bioreactor technologies were suggested for recovery and reuse of the effluents. It was recommended that (i) all urban wastewater treatment plants be upgraded/built as nutrient removal MBRs, for using the effluent directly for agriculture and/or groundwater recharge; (ii) all rural wastewaters be treated in lower-technology delivering effluents suitable for agricultural use. Energy potential of sewage was also underlined, proposing utilization of sewage sludge for energy recovery. Novel alternatives with high energy capture rates, such as *high ratepyrolysis, gasification*, were suggested instead of the traditional anaerobic sludge digestion. Current status of major factors and modules likely to take part in the management strategy were also covered.

Keywords: Transboundary water transport; Water management; Beneficial uses; Wastewater reuse; Groundwater recharge; Energy recovery from sludge

1.Introduction

Water management in islands involves serious problems associated with its geographic, demographic and economic features, aside from smaller watershed areas compared to the mainland. Islands have limited surface area and natural resources, i.e., freshwater, cultivable land, mineral sources, conventional energy sources; their isolation from the mainland and limited resources make them more vulnerable for appropriate water management [1,2]. Most small islands have to deal with limited water resources, which are depended on the quantity and distribution of rainfall [3]. Therefore, they mostly depend on groundwater aquifers, often limited in capacity; excessive/unplanned withdraw-

*Corresponding author.

als at rates exceeding the affordable yield lower the water level and result in seawater intrusion severely damaging groundwater quality to the extent that it can no longer be used for the same purpose.

The Cyprus island is located in the semi-arid zone: Due to the negative impact of climate change, it suffered a substantial reduction in rainfall during the last few decades [4,5], which reflected as a significant decrease of the available water resources in the island. In North Cyprus, the decrease in the magnitude of surface water, reaching the existing dams reached a peak value of 58% [5]. The shortage of available surface water has diverted the water demand to limited groundwater resources, which until recently, supplied more than 90% of the water utilized in North Cyprus for domestic, industrial and agricultural purposes. The rest of the demand was met by surface water and desalination [6]. Despite many studies and warnings on the subject [7,8], unplanned and large withdrawals have seriously decreased the groundwater levels, leading to sizeable seawater intrusion. Therefore, the water problem in North Cyprus has reached an alarming stage in the last few decades, related not only to quantity but to severe deterioration of groundwater quality below the level that secures safe usage.

The freshwater transport of approximately 75 × 10^6 m^3/y from Turkey should be considered as a milestone and a unique opportunity to solve the never-ending water problems in North Cyprus. This constitutes perhaps the most prestigious trans-boundary water transport envisaged in the world, involving a pipeline system of more than 80 km across the Mediterranean. The implementation stage of the project was completed by the end of 2015. This project will not only meet all water demand of different sectors at present stage and, with all possible development strategies in the future but also, it offers the chance to define and implement a sustainable *integrated water management* strategy that would consider wastewater as an integral part of the management approach. This strategy, when structured with all necessary institutional, technical and administrative components, will enable to trigger all innovative steps such as treatment, recovery, and reuse of treated effluents, energy recovery from sludge. It will replenish and restore all water resources and sustainable environmental protection.

In this context, the objective of the study was to identify all essential components of the integrated water management plan and to define sustainable action strategies for these components, based on related beneficial use concept. It also covered a brief overview of the current status of major factors and modules likely to take part in the management strategy.

2. Major components – current status

2.1. Land use and water demand

North Cyprus has a surface area of 3,300 km^2, housing a population of approximately 340,000. As shown in Fig. 1, the agricultural area represents the largest fraction, covering 57% of the total area; forests cover another 20%. Populated land with towns and villages totals 350 km^2, corresponding only to 11% of the surface area.

Aside from the population, tourism activity with nearly 22,000 bed capacity and university education with 80,000

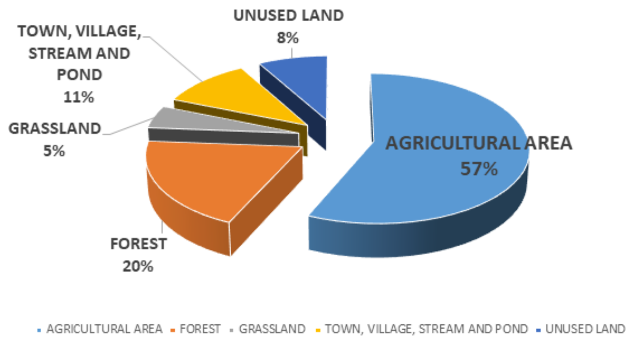

Fig. 1. Distribution of land uses of North Cyprus.

enrolled students mostly from different countries create significant domestic water demand. Although no reliable data is reported in the literature, the total domestic water demand may be approximated around 90,000 m^3/d, or 32.8 × 10^6 m^3/year, distributed as 68,000 m^3/d among urban and rural residential areas (200 L/ca·d); 11,000 m^3/d (500 L/bed·d) for the tourism industry and 10,000 m^3/d (125 L/stu·d) for university students. Water demand for industrial activities can be estimated as less than 5,000 m^3/d [5].

2.2. Rainfall and surface water resources

Substantial evidence is commonly expressed on the relationship of climate change to related anthropogenic processes [9]. Thermal readings on land surfaces over the last century demonstrate a global warming effect of approximately 0.6°C [10]. The impact of global warming was much more pronounced in Northern Cyprus. In fact, the yearly average temperatures increased from 19.0°C in 1996 to 20.1°C in 2016 corresponding to a significant rise in 1.1°C in 20 years [11]. It should be noted however that it is still not precisely clear what portion of the global warming is related to natural climate inconsistency, and what portion is attributable to concentration increase of greenhouse gases in the atmosphere.

At the same time, observations in the eastern part of the Mediterranean area indicated a decline in yearly precipitation over the 1950–2000 period. An increase in the mean rainfall intensity per wet day was recorded in most areas of the mainland, even in some parts, which were getting drier [12]. Within Europe, *the Mediterranean* and some parts of *Central* and *Eastern Europe* are the most drought susceptible regions associated with the highest increase in irrigation water demand. A similar rainfall pattern holds true for Northern Cyprus: By the beginning of the 20^{th} century, Northern Cyprus has experienced a reduction in precipitation values [13], resulting in unexpected environmental concerns such as increase in environmental pollutions from abandoned mines [14]. As shown in Fig. 2, the annual rainfall fluctuated in the range of 200–700 mm/year between 1930 and 2016 [15]. A recent study conducted in the *Lefka area*, suggested a mean design value of 300 mm/year, based on fluctuations between 185–517 mm/year in the 2010–2014 period [4,5].

Northern Cyprus is subdivided into four main hydrological zones: (1) West Mesaoria; (2) East Mesaoria; (3) North

Coastal Zone and Pentadaktylos and (4) Karpasia. While the surface area of Northern Cyprus is 3,298 km^2, its total hydrological area extends to 4,990 km^2, due to the streams flowing from the *Troodos* mountains. Based on the average rainfall of 300 mm/year, the annual volume of rainwater may be calculated as 150 million m^2/year. However, due to geography, topographic features, climatic conditions, and vegetation, 80% of this water is lost immediately through evapotranspiration and surface runoff. Observations indicated that approximately 24 million m^3 of the rainfall volume might be diverted from flowing streams and used for irrigation [16].

Dam construction for water reservoir developments is the most critical aspect of surface water management. 19 reservoirs were constructed between 1900 and 1974 with a total storage capacity of 20 million m^3. After 1974, reservoir construction was accelerated, and 18 new reservoirs were added till 2001, increasing the capacity to 35 million m^3 [16]. Xeros reservoir with a capacity of 4 million m^3 is the biggest in Northern Cyprus. However, a capacity of only about 25.6 million m^3 is currently operational, due to siltation problems. The actual annual volume of surface water stored behind the dams and actual annual volume provided for irrigation and groundwater recharge are not known, but it is estimated that the volume of surface water stored for irrigation purposes is in the magnitude of 8.4 million m^3 annually [17].

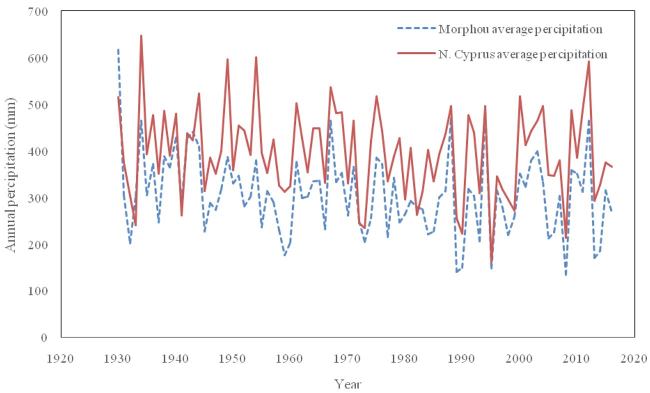

Fig. 2. Rainfall data between 1930-2016, for North Cyprus and Morphou (Güzelyurt).

2.3. Groundwater resources

As shown in Fig. 3, Northern Cyprus has four principal aquifers, namely *Morphou, Famagusta, Kyrenia and Karpasia* with a total capacity of 93.85 million m^3/year (Table 1) [18]. *Morphou* and *Famagusta* aquifers are unconfined whereas, *Kyrenia* aquifer is karstic [19] and *Karpasia* aquifer includes different sub-aquifers in which the sub-aquifer *Agios Andronikos* is a confined aquifer [20]. Due to uncontrolled and excessive water extractions from these aquifers, most of them are polluted or almost completed their service lives. Apart from the seawater intrusion, there are many other factors behind the degradation of groundwater resources

Table 1
Main aquifers of Northern Cyprus and their capacities [18]

Name of Aquifer	Capacity (m^3/y)
Kyrenia Aquifer	9.0×10^6
Morphou Aquifer	60.27×10^6
Karpasia Aquifer	9.45×10^6
Famagusta Aquifer	15.13×10^6

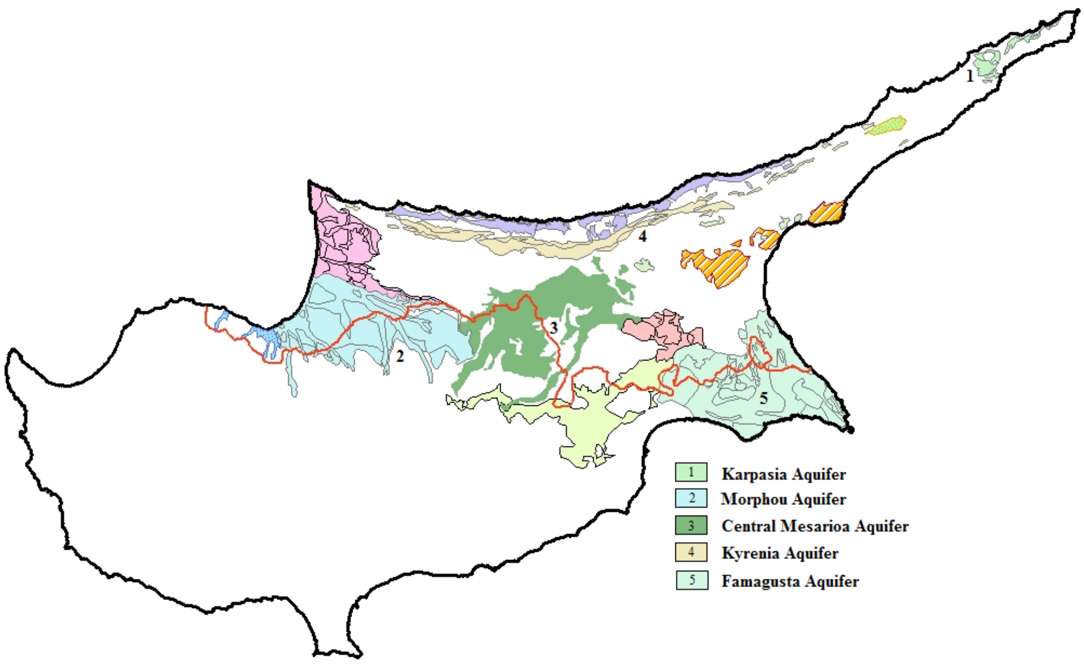

Fig. 3. The aquifers of the northern part of Cyprus [17].

quality in northern Cyprus, such as: (a) contamination caused by mining remnants [14]; (b) contamination caused by untreated wastes of small industries; (c) fertilizers used in agriculture aimed at increasing productivity and the used pesticides; (d) contamination caused by domestic wastes (solid and liquid) [21]; (e) contamination caused by geological formations and their soluble ingredients. The contamination caused by saltwater intrusion appears to be the most significant contamination among others. Famagusta, which is the second biggest aquifer, was the first one to be used extensively to irrigate 6,000 hectares of citrus trees and vegetables; it faced severe seawater intrusion by the seventies and was soon abandoned.

The major and best-quality fraction of arable land is situated in the *Morphou* region. Therefore, the agricultural activities in the island, mainly carried in this region, are increasing the water demand. Since the 1960's this demand is supplied from *Morphou* Aquifer causing depletion of water table [22]. Due to unplanned exploit of water, the salt contamination in the *Morphou* aquifer was increased from 1,000 to 5,000 mg/L, which makes it fall into brackish water classification. This situation has extensively reduced the production of some salt-intolerant crop patterns [23].

The scarcity of qualitative water resources was experienced with the total drawdown in Morphou Aquifer, which fell under seawater elevation. Abrupt saltwater intrusion into aquifer was due to over pumping for furrow irrigation-based agriculture. Morphou aquifer covers a total area of 240 km^2 where 150 km^2 lies at the boundaries of northern part of Cyprus. Early in the 1960s the inflow and the outflow to the aquifer were in balance. Unfortunately, the effects of the enlargement of the agricultural areas and the increase in the number of wells changed the balance within the following 8–10 years. In 1969, the groundwater levels within a 20 km^2 of the area declined below sea level, and this was recorded as a maximum of –3.0 m. By 1980, the area below the sea level was 75 km^2, and the maximum descent was –32 m (Fig. 4). The situation recorded in 1988 was even more severe as the decline at the water levels was –55 m affecting an area of 100 km^2 [24]. In 1990, groundwater budget studies at the region indicated a severe deficit of 28 million m^3, signaling the need for urgent precautions for the aquifer [25].

Although no detailed studies were carried out for other regions, adverse situations are believed to exist in all areas similar to that of Morphou region. The decline in water levels due to excessive groundwater pumping rates is evident with the fact that the springs discharging from *Kyrenia* aquifer that use to flow out during the winter months are no longer discharging. Groundwater is recharged directly from precipitation, whereas the urbanization problems are negatively affecting the recharge possibilities. The rivers flowing at *Kyrenia* Mountains mostly discharge to the sea due to short distances. This water loss was estimated at 7.3 million m^3/y [26].

Only a few second-class aquifers of strictly local importance exist in the *Karpasia* Peninsula. The replenishment of the region involves 9.5 million m^3. In contrast to the quality of drinking water in the *Kyrenia* Mountains, the quality of the water in *Morphou* and *Famagusta* are now well below the limits when compared with suggested standards of the World Health Organization [27] and Turkish Standards Institute [28].

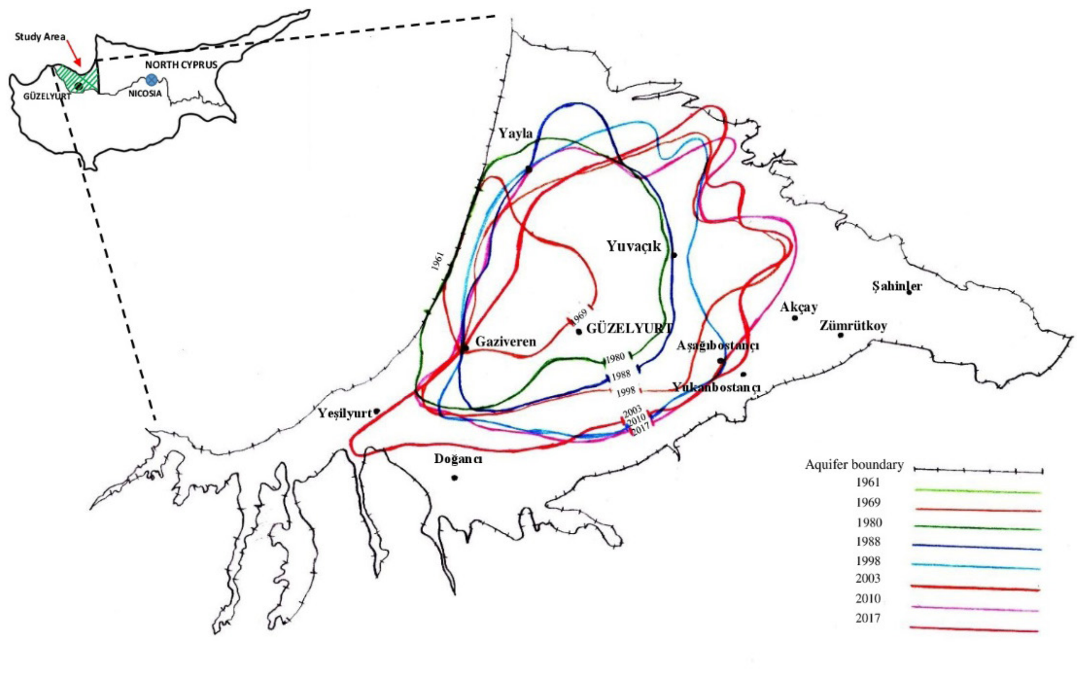

Figure : Effected area ('0' Contour map) of Güzelyurt Aquifer

Fig. 4. Groundwater level changes in the Morphou aquifer between 1961–2017 [24].

2.4. Sewerage and wastewater treatment

Only six wastewater treatment plants are now in function in Northern Cyprus with capacities varying between 500–9,000 m^3/d (Table 2). The largest plant is a nutrient removal biological plant treating jointly collected wastewater from the south and north Nicosia. Taking into account that the plant only treats a volume of 9,000 m^3/d generated by north Nicosia, the total volume of treated municipal wastewater in Northern Cyprus amounts to 17,400 m^3. Assuming a unit domestic sewage rate of 100 L/ca.d, this volume corresponds at best to 174,000 people, roughly equal half the population. The remaining part is either without sewerage or not connected to existing plants. There is no information available regarding the type and status of these plants and the effluent quality they generate. It will be safe to assume that they would require at least significant upgrading to meet the needs of the new integrated water management strategy.

2.5. Tourism activities

Tourism activities are mainly associated with the coastal zones of Northern Cyprus. In these areas, the quality of coastal water is, on the one hand, the prime concern for the value of the resort, and on the other hand, it is quite susceptible to pollution by the activities in the resort. Water scarcity is the most vital environmental problem for tourism activities. Given the water scarcity in Northern Cyprus, resort areas have to take measures to increase the efficiency of water utilization and to stimulate greater conservation. A study conducted in 1999, identified a total of 104 tourism installations of different classes with a total bed capacity of 8,940 [7]. The same study projected that the bed capacity would be doubled in 2015. Currently, tourism activities surpassed these estimations so that the total bed capacity reached nearly 22,000 in 2017.

Water usage, wastewater generation and related pollutant loads were estimated as shown in Table 3 in different studies [7,29]. Obviously, availability of water and occupancy rates at different seasons have a decisive effect on wastewater generation. Many studies have discussed and evaluated the optimum treatment strategies in view of wastewater fluctuations at different seasons and diverse reuse and discharge options [30–32]. At this time no reliable data is available both on wastewater and waste generation and monitoring of their treatment and disposal. It was indicated that seven resorts derived a total of 7,500 m^3/d of fresh water using seawater desalination [5]. Undoubtedly, tourism activities will be a prime subject of comprehensive investigation in integrated water management studies.

3. Water Transport from Turkey

This engineering work was perhaps the most impressive trans-boundary water conveyance project so far realized in the world. It was designed and built to transmit 75×10^6 m^3/y of fresh water from the *Anamur* district in *Mersin*, Turkey to Northern Cyprus. The implementation was started on March 7, 2011, with the construction of the *Alaköprü* dam and completed in October 2015; it was officially inaugurated on October 17, 2015. The project included three main parts (i) the structures in Turkey; (ii) sea crossing and (iii) the structures in Northern Cyprus.

The components of the structures in Turkey are briefly outlined below:

1. Rock-filled, with a concrete covered facade, *Alaköprü* dam with 130.5 m^3 capacity; its construction started on March 7, 2011, and finished by March 7, 2014.
2. A ductile transmission line of 1.5 m diameter and 22 km long between *Alaköprü* dam and *Anamuryum* balancing tank, which further extended another kilometer to the shore.
3. *Anamuryum* balancing tank with a capacity of 10,000 m^3.

High-density polyethylene (HDPE) pipes with 64.8 mm thickness, 1.6 m diameter and 500 m length,made the sea crossing, which consisted of an 80,167 km passage between Turkey and North Cyprus shores. The sea crossing was completed on August 6, 2015. The bathymetric cross-section of the passage is schematically illustrated in Fig. 5: The main components of the passage are described below:

1. The part from Turkey's shore till code –20 m depth inside the sea, involved embedding 2,918 m of a pipe by excavating the seabed.

Table 2
Wastewater treatment plants and their capacities in service in Northern Cyprus [5]

Wastewater treatment plant	Capacity (m^3/d)	Existing effluent amount (m^3/d)
Mia Milia/Nicosia	9,000	9,000
Morphou	3,179	500
Famagusta	8,883	4,100
Kyrenia	1,800	1,800
Lapta	500	500
Bafra	6,000	1,500
Total (m^3/d)	29,362	17,400

Table 3
The basis of water utilization, wastewater generation and pollutant loads in tourism installations [7, 29]

Activity	Water consumption (m^3/d)	Wastewater generation (m^3/d)	COD load (g/ca·d)
Hotels/Holiday resorts	1,000	650	150
Hostels	400	300	100
Daily use	100	75	70
Restaurants	50	40	90
Entertainment complexes	100	80	90
Settlements	200	160	75

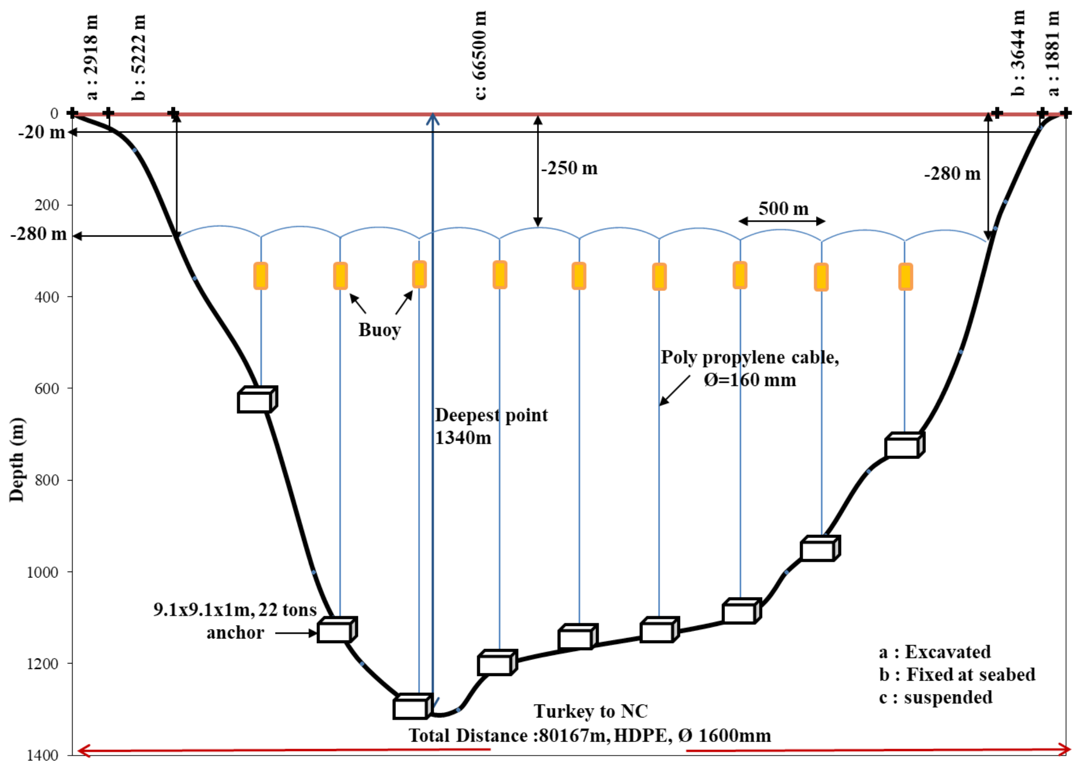

Fig. 5. The bathymetric cross-section of the passage between Turkey and northern part of Cyprus. The suspended pipes were in total 66500 m in length.

2. 5,222 m of pipes were laid at seabed from –20 m depth to –280 m depth; this part was fixed to the seabed by concrete weight blocks.
3. From –280 m depth onward, the 500 m long single pipes were connected to each other by "Y" shaped connections hanged to buoyancy modules at the top and anchors at the seabed by 16 cm diameter cables. What makes this project to be unique is the technology that passes more than 66 km of suspending pipes through the sea. The 9.1 × 9.1 × 1 m size-anchors, weighing 22 tons each, were fastened at the sea floor by 16 cm diameter polypropylene cables with a total length of 85,417 m. The maximum sea depth between Turkey and North Cyprus was 1,340 m, and the maximum length of cable used as a one-piece unit was 1,115 m at the two sides of the maximum depth.
4. After the hanging part, the passage additionally included 3,644 m of pipe fixed at the seabed from –280 m to –20 m depth toward the North Cyprus shore.
5. At the Northern Cyprus shore, 881 m of pipe was buried from –20 m depth till the shore.

The main components of the structure in Northern Cyprus are listed below:

1. A 5.5 MW pumping station at *Güzelyalı*, at the shoreline.
2. A 3,694 m pipeline with a diameter of 1.4 m between Güzelyalı pumping station and pumping station.
3. An 8.8 MW pumping station at *Geçitköy*.
4. The clay core, rock-filled *Gecitköy* dam, with a capacity of 26.5 million m^3.
5. A water treatment plant (WTP) with a daily capacity of 200,000 m^3.
6. A total of 477 km of potable water pipeline in Northern Cyprus; (i) Nicosia: 67,100 m, (ii) Kyrenia coastline: 160,431 m; (iii) Nicosia-Iskele-Famagusta; 153,710 m and (iv) Iskele-Dipkarpaz: 95,713 m [6].

In July 2016, the construction of distribution pipelines in Northern Cyprus was completed, and Government Water Board delivered the water to 28 municipalities starting from *Morphou*, at an increased rate of 26–27 million m^3 starting from August 2017. In the first phase, it is projected that 38 million m^3 of the transferred water will be used for municipal demand and the remaining 37 million m^3 for modern watering and irrigated farming of 70 km^2 land [33]. After the completion of municipal water delivery, Northern Cyprus started the agricultural water use of the project in 2017. In this project, water will be pumped to a 115 m higher level (180 m from mean sea level) through a 5.7 km long tunnel from *Geçitköy Dam* to a reservoir to be built in the Kalkanlı Region, to irrigate *Morphou Plains* and if possible the middle *Mesaoria* region. Although, similar projects in the past had adversely affected by increasing demand for water, as in Tagus-Segura pipeline, Spain 1978 [34], this project is estimated to be of vital importance for ending the water problem and especially for allowing to design and implement a sustainable integrated water management action plan.

4. Highlights of management strategy

The water management approach should start by visualizing the technical merit of water transport from Turkey: Inspection of the data in Fig. 6 clearly defines the considerable benefit that was provided by introducing this new water source into Northern Cyprus. The figure essentially outlines the quality changes in the Nicosia water supply before and after the start of usage of transported fresh water. The numerical dimension of water quality was quantified by four main parameters, namely pH, conductivity (mS/cm), salinity (mg/L) and chloride (mg/L): First, it depicts the high and escalating levels of dissolved matter, evidenced by the increase in conductivity from 4,420 to 8,950 mS/cm, and also in salinity from 2,340 to 4,095 mg/L, during the period 2010 and 2016. It should be noted that these values are above the levels indicated for safe utilization for domestic purposes. Second, the figure reflects the immense water quality change after the supply of fresh water, which is characterized by a salinity of only 30 mg/L. Therefore, the water transport for Turkey should not be regarded, only as a significant improvement in the life quality of the population in Northern Cyprus but more, as a turning point for improving and upgrading the existing polluted water resources, through a carefully tailored integrated water management strategy. This strategy should be so arranged that the transported water will not be wasted and reused for different purposes. A brief sketch on the highlights of the required strategy is given below.

4.1. Beneficial uses

A sustainable management strategy should recognize and give priority to the concept of beneficial uses: Beneficial use of water defines a water utilization system resulting in appreciable gain or benefit to the user. In other words, it is a water use that, in general, contributes to public benefit, and promotes the health, safety, and welfare of the people in Northern Cyprus [35]. This concept embraces considerations of social and economic values as well as utilization efficiency. Therefore, the management strategy should be directed toward sustaining the highest water quality consistent with maximum benefit to people. It should be noted that beneficial use designations for any given water body in Northern Cyprus should not rule out the possibility that other beneficial uses exist or may potentially be considered in the future. Given the present conditions, the following beneficial uses among others have cardinal importance:

Agricultural supply – water utilization for farming, horticulture or ranching, including but not limited to, irrigation; stock watering or support of vegetation for range gazing. Quality thresholds and limiting concentrations should be established for livestock and irrigation water, in a way to prevent possible hazards of continued irrigation: (i) soluble salt accumulation; (ii) chemical changes in the soil; (iii) toxicity to crops; (iv) potential disease transmission to humans through reclaimed water use.

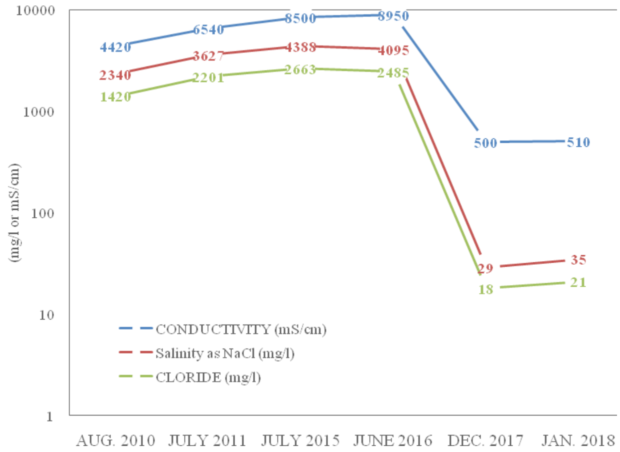

Fig. 6. Quality changes in Nicosia water system after the supply of fresh water from 2010 to 2018.

Groundwater recharge - use of water for natural and artificial recharge of groundwater for purposes of future extraction, improvement of water quality to a level that would permit future usage and preventing saltwater intrusion. The latter is of prime importance for Northern Cyprus, and it may be started immediately without too much concern on the quality of recharged waters. Natural groundwater recharges that would occur naturally in many areas from stream and reservoirs should be controlled and improved through the maximum capture of rainfall and effective use of reservoirs. The management plan should recognize and implement that the most important source of recharge is wastewater after appropriate innovative treatment.

Water contact recreation – Uses of water for recreational activities involving body contact with water where its ingestion is reasonably possible. These uses include, but are not limited to, swimming, wading, water-skiing, skin and scuba diving, surfing, and fishing. This beneficial use is directly associated with coastal-zone tourism activities, which are of vital importance for the social and economic life of the island and sustainable environmental protection in the area. Water contact implies a risk of waterborne disease and involves human health. Aesthetic considerations associated with pollution and algal growth also affect and reduce all recreational water uses, including fishing.

Other beneficial uses, such as industrial uses, *public parks, wildlife and game preserves* may also be significant in different local areas of Northern Cyprus.

4.2. Innovative wastewater treatment

Domestic sewage, i.e., wastewater from urban and rural communities is one of the most vital pools of water for recovery and reuse if properly treated. Therefore, it should be considered as an integral part of the water management strategy. In fact, in the last few decades, there has been a drastic change in the conceptual understanding of waste management: Waste is no longer considered as a matter to be disposed of at the expense of additional cost, but as a *resource.* Given the water scarcity in the islands, wastewater should be regarded as a suitable resource for many beneficial uses, conditional to being subject to appropriate innovative treatment.

The activated sludge (AS) process, i.e., the widest implemented biological treatment system in practice, has long passed the phase of strict dependency on gravity settling: In fact, the *membrane bioreactor* provided a major breakthrough for the AS technology, simply be replacing gravity settling by *membrane filtration* and enabling total retention of biomass in the reactor with no escape to the effluent [36]. Essentially, the membrane bioreactor (MBR) configuration of activated sludge combines the aeration tank of the activated sludge process with a membrane filtration module. Related research coupled with successful practice quickly improved and established the MBR process as one of the most popular AS configurations due to rapidly escalating public satisfaction and acceptance [37,38,39]. The MBR flow scheme now involves two different flow schemes: (i) external or *re-circulated MBR*, where the module is located outside the aeration tank; (ii) the submerged or *integrated MBR* where the membrane is submerged into the reactor (Fig. 7).

The possibility of total biomass retention within the reactor was construed as a relief of limitations imposed by gravity settling on biomass concentrations in the reactor. This ability was initially used for sustaining much higher biomass levels in the MBR, operated at excessively high SRTs without facing settling problems. MBR operation at high SRTs was primarily utilized for nitrogen removal, because the nitrifying community did not run the risk of being washed out from the reactor, under different environmental conditions [40]. Conventional MBRs were also coupled with an anoxic reactor for pre-denitrification. However, Sarioglu et al. [41] reported almost complete denitrification in a submerged MBR fed with municipal wastewater without a separate anoxic reactor; the complete denitrification was explained by limited diffusion of dissolved oxygen (DO) through the flocs, creating micro-anoxic zones.Insel et al. [42] studied the effect of biomass concentration on mass transfer limitations for oxygen diffusion; the results showed that full nitrogen removal could be achieved by selecting optimal DO set-points associated with different biomass levels. Hocaoglu et al. [43,44] successfully operated pilot-scale tests coupled with model evaluations, proving successful application of MBRs for carbon and nutrient removal from domestic sewage, black and grey waters.

Later the MBR system was adapted to operate at extremely low sludge age range of 0.5–2.0 d [37,38,45]. Studies were conducted with different substrates, namely readily biodegradable mixture; acetate; starch; peptone mixture and settled sewage using both side-stream and submerged reactors under different conditions. The results provided strong experimental evidence that high-rate MBR proved to be equally successful in COD removals as effluent/permeate COD always remained in the range of 12–19 mg/L [45]. MBRs usually operate with ultrafiltration membranes with pore sizes of 0.02–0.04 µm. Effective filtration size is further reduced by the formation of a cake layer on the membrane [46]. Therefore, aside from the complete removal of particulate matter, MBRs have the potential of providing a polishing effect on the quality of the effluent, removal a considerable fraction of soluble residual COD, more substantial than the effective filtration size.

It is worth mentioning that after 2004, the European Union set forth an environmental management program in Northern Cyprus. The plan included the construction of two wastewater treatment plants, one in *Morphou* and the other at *Famagusta*, together with the rehabilitation of existing *Mia Milia*wastewater treatment plant in *Nicosia*. *Mia Milia*wastewater treatment plant was designed for a daily sewage flow of 30,000 m^3, to jointly treat sewage coming from South and North Nicosia. All these treatment plants included conventional technology with gravity settlers [47]. Thus, their effluents could not meet the quality requirement for reuse because (i) sewage originated from water supply with very high dissolved solids content, which cannot be removed by biological treatment; (ii) conventional treatment cannot provide the degree of treatment suitable for reuse.

The quality of the transported new water supply, with practically no dissolved solids, offered an entirely new and promising perspective for the water management strategy: It should be remembered that domestic use imparts to the wastewater incremental total solids of 300–400 mg/L [48]. This range should be compared with 4,000–5,000 mg/L of total solids levels previously associated with groundwater supplies. In this context, the new integrated water management strategy should impose (i) all urban wastewater treatment plants be upgraded of built as nutrient removal MBRs, where the effluent could be directly used for agriculture and/or groundwater recharge (ii) all rural wastewaters be treated in lower-technology, *extended aeration* plants with sand filtration, capable of delivering effluents suitable for agricultural use. Similarly, the *Mia Milia* treatment should be expanded into two parallel systems; one unit should be converted into an MBR system and dedicated only to the treatment of 9,000 m^3/d of sewage generated by North Nicosia, also yielding a reusable effluent.

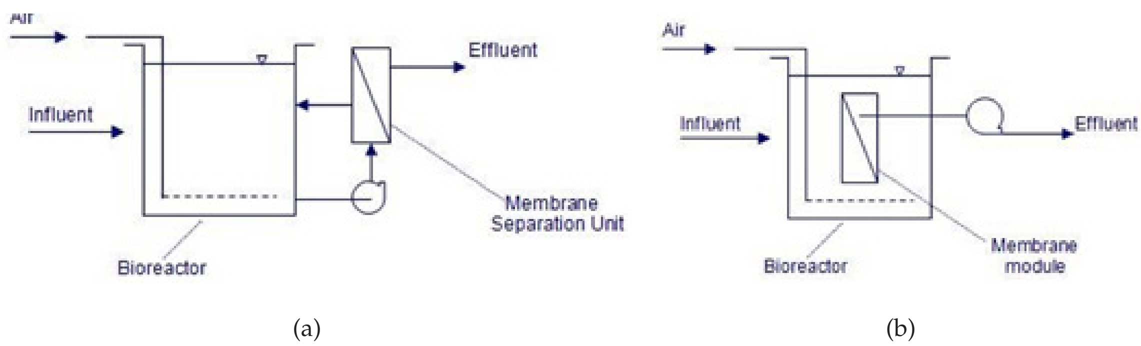

Fig. 7. Schematic configurations of (a) external MBR (b) submerged MBR.

4.3. Energy recovery for waste

Perhaps, the most significant resource component is *energy*, given present and future energy shortages expected in Northern Cyprus. Therefore, energy recovery from waste has become a hot topic now, both regarding scientific efforts and practical applications. The energy contained in wastewaters and especially sewage has become quite trendy in accordance with the major conceptual transition, which regards all waste materials as a resource. It is well known that the calorific value of the organic content of sewage is around 3,300 kcal/kg COD [49]. The conventional AS process overlooks this energy conservation potential that may be achieved in the treatment plant through the generated sludge; on the contrary, it is attempting to utilize the highest possible fraction of the organics in sewage to oxidize to the generated biomass at the expense of additional energy input. Energy conservation in sludge is a prerequisite for recovering the conserved energy. Optimizing energy recovery necessitates maximizing the sludge generated from the process, obviously discarding the traditional habit and practice of targeting low sludge generation. Therefore, the energy conservation component of the unified recovery approach entails a major change in the conventional treatment strategy towards higher levels of sludge generation.

A recent study calculated the energy conservation rate in sludge as 34% for nutrient removal AS systems and 28% for extended aeration AS systems [50]. This rate could go up to the 60–70% range for different configurations of high rate AS systems. Assuming an average COD equivalent of 75 g COD/ca·d, the domestic sewage generated in North Cyprus embodies a total COD load of 25,000 kg COD/d, with a corresponding energy potential of 82.5×10^6 kcal/d.

Currently, anaerobic digestion is widely used as an integral part of large treatment plants. Under normal conditions, it breaks down 40–50% of the COD in sludge and converts it into methane; it leaves behind a highly diluted, half stabilized sludge, which needs to be processed before final disposal. It is surprising to note that in all the evaluations towards energy efficient treatment systems, anaerobic digestion and biogas maintained its place as the sole energy source. Thus, anaerobic digestion should be considered as the weakest link of the conventional treatment scheme towards energy recovery. A novel energy efficient alternative for this purpose should be considered, for Northern Cyprus, such as high rate *pyrolysis, gasification* [51–54]. Karaca et al. [55] provided experimental proof that *high rate pyrolysis* systems could be operated with a 70% energy recovery rate for sewage sludge. This corresponds to 20×10^6 kcal/d of recovered energy as syngas or approximately 4,800m^3 of syngas with 4,200 kcal/m^3 for nutrient removal AS systems, excluding tourism activities.

4.4. Towards zero waste society

The integrated water management plan may also be extended to include solid waste/garbage management for an action plan, leading communities in Northern Cyprus towards exemplary *zero waste societies*. This action plan would then cover all major environmental components, namely *water, wastewater, solid waste* and *sludge* and define for each of the most sustainable approaches for resource recovery and reuse. It would also include education programs for the young generation at schools and homes, highlighting interesting aspects of a *zero-waste* lifestyle. The action plan will have the following components:

Save water – This phase will focus on the sustainable use of water resources: The primary effort will be devoted to the collection, storage, and utilization of rainwater, with due consideration of existing reservoir.

Save wastewater - This phase will evaluate wastewater as a resource: Sustainable and novel treatment technologies will be defined, generating a clean, reusable effluent in agriculture and non-contact water uses.

Save energy - This part of the action plan will concentrate on energy recovery from all types of wastes, namely solid wastes (garbage), agricultural wastes and treatment sludge, which traditionally cause serious environmental problems during their disposal. Not only that these problems will be eliminated, but also significant amounts of energy will be generated through appropriate handling of these waste materials.

Education -Education programs mainly targeting young generation will be defined and offered at schools and homes to illustrate typical examples of a *zero-waste* lifestyle.

4.5. Management of tourism activities

It is true that Northern Cyprus, like all small islands with limited resources, heavily depends on promoting tourism activities, which is strongly depended on the quality and aesthetic value of the environment. These factors are related to the quality of freshwater resources, as well as the ecosystems they support. Despite the economic potential, uncontrolled tourism may run the risk of destroying its ecological value through increased generation of wastewater and pollution caused by its discharge to the coastal zone. In this context, the integrated water management strategy should envisage a detailed inventory of tourism activities regarding water consumption and waste generation and define, if necessary, regional collective facilities for wastewater treatment, effluent reuse and sludge/solid waste processing.

4.6. Institutional framework

As in many similar communities, a number of different agencies are involved with different aspects of water management in Northern Cyprus. Data collection, compliance monitoring, enforcement, health issues, service delivery, environmental protection, and similar, are delegated to different government agencies, with little communication on important issues. Moreover, their programs are not integrated with those of other agencies on activities with impacts on water resources, such as tourism, land-use planning, and residential areas. These concerns indicate a significant absence of an integrated approach to water management. It is therefore recommended that the water management plan entails the establishment of an *Environment Protection Agency* as a new independent institution under the umbrella of Prime Ministry, which would also define, enforce and coordinate all actions related to integrated water management.

5. Conclusions

Aside from the unique and outstanding engineering features of the HDPE pipeline system, which crossed a span of more than 80 km and going as deep as 1,340 m in the Mediterranean, the freshwater transport from Turkey fundamentally changed the hydrologic cycle of North Cyprus. The magnitude of the yearly supply was more than threefold of the recoverable rainfall in the area. While the yearly 75 million m^3 input mostly covered domestic, agricultural and industrial water demand of the area, it also provided an exceptional opportunity of replenishing and upgrading the existing and water resources which are mostly polluted.

Northern Cyprus cannot afford to waste this opportunity: The water transport needs to be used as a stepping stone to set forth an integrated water management plan that would also consider wastewater as an integral component of the water cycle, treated to the degree that it may be recovered and reused for groundwater recharge. This management plan should offer a novel environmental perspective, leading towards a near-zero waste community.

The management plan should entail innovative wastewater systems based on membrane bioreactor technology, i.e., membrane bioreactor systems, generating clear effluents for direct recovery and reuse in agriculture and groundwater recharge. It should also recognize the energy potential of sewage proposing utilization of sewage sludge for energy recovery, suggesting novel process alternatives with high energy capture rates, such as *high ratepyrolysis, gasification*, instead of the traditional anaerobic sludge digestion.

References

[1] E. Khaka, Small islands, big problems, Our planet, 9 (1998) 25–26.

[2] T. Falkland, Water resources issues of small island developing states, Natural Resour., 23 (1999) 245–260.

[3] B.C. Bates, Z.W. Kundzewicz, S. Wu, J.P. Palutik, Climate Change and Water, Technical Paper of the Intergovernmental Panel on Climate Change, 2008, pp. 33–48.

[4] S. Sözen, D. Orhon, H. Dincer, G. Ateşok, H. Baştürkçü, T. Yalçon, H. Öznesil, C. Karaca, B. Allı, H. Dulkadiroğlu, Resource recovery as a sustainable perspective of the CMC mining waste site in Northern Cyprus, Bull. Eng. Geol. Environ., 76 (2017) 1535–1547.

[5] Ministry of Agriculture and Natural Resources. Agricultural Master Plan. Turkish Republic of Northern Cyprus (2017) pp. 514 (in Turkish).

[6] H. Gökçekuş, TRNC's Water Problems and Solutions: Importance of "The Water Supply Project from Turkey to Cyprus". TRNC's Water Law and Policies, 3th International Water Forum, Istanbul, Turkey. 2014.

[7] Ministry of Health and Environment. Environmental Master Plan, Turkish Republic of Northern Cyprus, 2nd Interim Report; I.T.U. Environmental Engineering Department, 1999 pp.297 (in Turkish).

[8] GHK, ECOLAS, IEEP, and CE., Strategic Evaluation on Environment and Risk Prevention Under Structural and Cohesion Funds for the period 2007–2013, Synthesis Report, 2006.

[9] J.T. Houghton, L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg, K. Maskell, Eds., Climate Change 1995, The Science of Climate Change, Cambridge University Press, 1996, 572 p.

[10] P.D. Jones, T.M.L. Wigley, G. Farmer, Marine and land temperature data sets: a comparison and a look at recent trends In Greenhouse-Gas-Induced Climatic Change, a Critical Appraisal of Simulations and Observations. M.E. Schlesinger (Ed), Elsevier, Amsterdam, 1991, pp. 153–172.

[11] A.H. Payab, U. Türker, Analyzing temporal–spatial characteristics of drought events in the northern part of Cyprus, Environ. Dev. Sustain., 20 (2018) 1553–1574.

[12] C. Norrant, A. Douguédroit, Monthly and daily precipitation trends in the Mediterranean (1950–2000), Theor. App. Clim., 83 (2006) 89–106.

[13] H. Gökçekuş, S. Gücel, U. Türker, Effects of climate change on North Cyprus forests, Transactions of the International Academy of Science, International Conference, Oslo 2009, Innsbruck, 2010.

[14] H. Gökçekuş, S. Kabdaşlı, I. Kabdaşlı, U. Türker, T. Olmez, K. Olcay, Pollution of coastal region impacted by acid mine drainage in Morphou Bay, Northern Cyprus, J. Environ. Sci. Heal. A, A38(8) (2003) 1445–1457.

[15] Ministry of Environment and Natural Resources Department of Meteorology, The Annual report, Climate of Cyprus, Department of Meteorology, Nicosia Turkish Republic of Northern Cyprus, 2016.

[16] H. Gökçekuş, C. Atalar, M. Sıdal, Water reservoir development in North Cyprus. Proceedings of the International Conference on Water Problems in the Mediterranean countries. Lefkoşa, TRNC: Near East University, 5(1) (1998) 293–310.

[17] U. Türker, B.R. Hansen, River Basin Management and Characterization of Water Bodies in North Cyprus, 10th International Congress on Advances in Civil Engineering,Ankara, Turkey, 17–19 October, (2012) 1–10.

[18] O. Gökmenoğlu, B. Erduran, C. Özgür, Ö.F. Tamgaç, KKTC Hidrojeolojisi, Maden TetkikveAramaGenelMüdürlüğü, Ankara, 2004. (In Turkish).

[19] A.A. AJamal, U. Türker, Assessment of the regional water balance of the limestone subaquifers of Cyprus, J. Earth. Syst. Sci., 124 (2018) 541–551.

[20] U. Türker, B.S. Alsalabi, T. Rızza, Water table fluctuation analyses and associated empirical approach to predict spatial distribution of water table at Yeşilköy/AgiosAndronikos aquifer, Environ. Earth Sci., 69 (2013) 63–75.

[21] U. Türker, Alternative sewerage solution: Condominial method and its application, Phys. Chem. Earth, Parts A/B/C, 36(5–6) (2011) 179–86.

[22] H. Gökçekuş, Su kaynakları yönetiminin KKTC açısından önemi. KTMMOB İnşaat Mühendisleri Odası Bülteni, 4 (2002) 53–60 (in Turkish).

[23] G. Elkiran, Z. Ongul, Implications of excessive water withdrawals to the environment of Northern Cyprus, Water Environ. J., 23 (2009) 145–154.

[24] H. Gökçekuş, V. Doyuran, Optimum management of the groundwater resources of Morphou basin TRNC, Bull. Geol., 9 (1993) 421–428.

[25] H. Gökçekuş, Hydrogeological and hydrochemical evaluation of the Morphou groundwater basin (Turkish Republic of Northern Cyprus). Phd Thesis, Middle East Technical University, Department of Geological Engineering, Ankara (1990) pp. 179.

[26] UNDP, Survey of groundwater and mineral resources of Cyprus. A technical method prepared for the Government of Cyprus by United Nations (1970) pp. 233.

[27] World Health Organization, Guidelines for Drinking-Water Quality (1959) pp. 130.

[28] TSE, "Içme suları (Drinking Water)" Turkısh Standard Institution, Ankara, Turkey 266 (1986) pp. 97.

[29] D. Orhon, H. Gökçekuş, S. Sözen, Environmental basis of sustainable tourism along sensitive coastal areas, Proceedings, Survival and Sustainability Environmental Concerns in the 21st Century, H. Gökçekuş, U. Türker, J.W. LeMoreauxeds Spinger-Verlag, Berlin, 2011 pp. 235–241.

[30] N. Artan, D. Orhon, S. Sözen, Conceptual basis of wastewater nitrogen removal in sensitive coastal areas, Water Sci. Technol., 32 (1995) 77–84.

[31] S. Sözen, E. Görgün, N. Artan, D. Orhon, A merit of SBR technology for wastewater management in sensitive coastal areas, Fresenius Environ. Bull., 6 (1997) 190–195.

[32] D. Orhon, S. Sözen, E. Görgün, E. Ubay Çokgör, N. Artan, Technological aspects of wastewater management in coastal tourist areas, Water Sci. Technol., 39 (1999) 177–184.

[33] H. Gökçekuş,"TRNC Drinking Water Supply Project Will Be the Project of the Century", OSRAM Water Research Program, 2012, (in Turkish).
[34] E. Gies, Northern Cyprus sees hope in water pipeline, The New York Times, April 3, (2013).
[35] P.H. McGauhey, Engineering Management of Water Quality, McGraw-Hill Book Co., New York (1968) pp. 295.
[36] D. Orhon, Evolution of the activated sludge process: The first 50 years, J. Chem. Technol. Biotechnol., 90 (2015) 608–640.
[37] D. Orhon, S. Sözen, S. Teksoy Basaran, B. Alli, Super fast membrane bioreactor—transition to extremely low sludge ages for waste recycle and reuse with energy conservation, Desal. Water Treat., 57(45) (2016) 21160–21172.
[38] S. Sözen, I. Pala-Ozkok, M. Aysel, S. Teksoy Basaran, A. Akarsubasi, I. Ergal, H. Kurt, E. Ubay Cokgor, D. Orhon, Performance and microbial behavior of submerged membrane bioreactor at extremely low sludge ages, Desal. Water Treat., 56 (2015) 862–874.
[39] N. Yagci, M. Konuk, S. Sozen, S. Meriç, D. Orhon, Chemically enhanced membrane process–towards a novel sewage treatment concept to potentially replace biological processes, Desal. Water Treat., 57(35) (2016) 16238–16249.
[40] E.B. Muller, A.H. Stouthamer, H.W.V. van Verseveld, D.H. Eikelboom, Aerobic domestic wastewater treatment in a pilot plant with complete sludge retention by cross-flow filtration, Water Res., 29 (1995) 1179–1189.
[41] M. Sarioglu, G. Insel, N. Artan, D. Orhon Model evaluation of simultaneous nitrification and denitrification in a membrane bioreactor operated without an anoxic reactor, J. Membr. Sci., 337 (2009) 17–27.
[42] G. Insel, S.M. Hocaoğlu, E.U. Cokgor, D. Orhon Modelling the effect of biomass induced oxygen transfer limitations on the nitrogen removal performance of membrane bioreactor, J. Membr. Sci., 368 (2011) 54–63.
[43] S.M. Hocaoglu, G. Insel, E.U. Cokgor, D. Orhon, Effect of sludge age on simultaneous nitrification and denitrification in membrane reactor, Biores. Technol., 102 (2011) 6665–6672.
[44] S.M. Hocaoglu, E. Atasoy, A. Baban, D. Orhon, Modeling biodegradation characteristics of grey water in membrane reactor, J. Membr. Sci., 429 (2013) 139–146.
[45] S. Sözen, S.T. Başaran, I. Ergal, C. Karaca, B. Allı, C. Razbonyalı, E.U. Cokgor, D. Orhon, A novel process maximizing energy conservation potentials of biological treatment: Super fast membrane reactor, J. Membr. Sci., 545 (2018) 337–347.
[46] S.J. Judd, A review of fouling of membrane bioreactors in sewage treatment, Water Sci. Technol., 49 (2004) 229–235.
[47] U. Türker, M. Okaygün, S.J. Almaqadma, Impact of anaerobic lagoons on the performance of BOD and TSS removals at the Haspolat (Mia Milia) Wastewater Treatment Plant, Desalination, 249 (2009) 403–410.
[48] G. Tchobanoglous, D. Schroeder, Water Quality, Addison Wesley Publ. Co., California (1985) pp. 768.
[49] P.L. McCarty, J. Bae, J. Kim, Domestic wastewater treatment as a net energy producer-Can this be achieved? Environ. Sci. Technol., 45 (2011) 7100–7106.
[50] D. Orhon, S. Sözen, B. Allı, Comment on "Bioflocculation management through high-rate contact stabilization: A promising technology to recover organic carbon from low strength wastewater by R. Rahman, F.A. Meerburg, S. Ravadagundhi, B. Wett, J. Jimenez, G. Bott, A. Al-Omari, R. Riffat, R. Murthy, H. DeClippeler [Water Research, 104 (2016) 485–496]", Water Res. 126 (2017) 524–526.
[51] M. Inguanzo, A. Dominguez, J.A. Menéndez, C.G. Blanco, J.J. Pis, On the pyrolysis of sewage sludge: the influence of pyrolysis conditions on solid, liquid and gas fractions. J. Anal. Appl. Pyrol., 63 (2002) 209–222.
[52] A. Dominguez, Production of biofuels by high-temperature pyrolysis of sewage sludge using conventional and microwave heating, Biores. Technol., 97 (2006) 1185–1193.
[53] M.K. Hossain, V. Strezov, P.F. Nelson, Thermal characteristics of the products of wastewater sludge pyrolysis, J. Anal. Appl. Pyrol., 85 (2009) 442–446.
[54] C. Karaca, H.C. Okutan, S. Sozen, D. Orhon, Energy recovery with syngas production from sewage sludge using high rate pyrolysis at high temperature, Proc. SEEP, (2015) 11–14.
[55] C. Karaca, S. Sözen, D. Orhon, H.C. Okutan, High temperature of sewage sludge as a sustainable process for energy recovery, Waste Manage., 78 (2018) 217–226.