Uluslararası Fen Araştırmalarında Yenilikçi Yaklaşımlar Dergisi
International Journal of Innovative Approaches in Science Research 2022, Vol. 6 (4), 222-234
https://doi.org/10.29329/ijiasr.2022.512.4

Original article

Natural Swimming Pools: Design and Implementation Principles

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Abstract

While natural (biological) swimming pools have started to become widespread around the world, particularly in European countries, it is a new development that has recently come to attention and practiced in Turkey. For this reason, scientific studies are mostly carried out in USA and Europe, which take into account the climate conditions and vegetation of those regions. The technology used in natural swimming pools is also quite diverse and has been privatized through private firms in practice.

The objective of this research is to identify the principles to be considered with the design and implementation of natural swimming pools, based on both scientific research and experience gained from implementation in Turkey. In this research, in addition to the literature review, face-to-face interviews were conducted with companies that implement natural swimming pools in Istanbul. The initial results of the research presented here can both guide local practices and contribute to the limited scientific literature in Turkey.

Keywords: Aquatic Plants, Biological Filtration, Natural Filtration, Nutrient Removal.

Received: 27 August 2022 * **Accepted:** 08 December 2022 * **DOI:** https://doi.org/10.29329/ijiasr.2022.512.4

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INTRODUCTION

Natural swimming pools are presented as an environmentally friendly solution to the traditional, chemically treated swimming pool (Farb, 2020). Natural swimming pools are complex ecosystems that effectively remove nutrients from the water and filter harmful bacteria (Hoffman, 2013) enabling its use for swimming purposes. While natural swimming pools function like an ecological pond, its appearance can be in the form of a traditional swimming pool or a pond.

High level chlorine use with traditional pools is known to be harmful to aquatic organisms. In addition, respiratory problems are encountered among adolescents and children due to exposure to high levels of chlorine in swimming pools. This is discussed as a public health issue, in which precautions should be taken. In response to health problems from exposure to chlorine by-products and pool water, some European countries have popularized natural swimming pools (Farb, 2020).

The general purpose of this research is to ensure the correct, widespread and active use of natural swimming pools, which are widely used in European countries and are just beginning to be implemented in Turkey. The more specific purpose of the study is to contribute to the limited literature on the subject, especially in Turkey, by examining scientific research in different disciplines. At the end, it is aimed to compile information obtained from implementation experience with information obtained from scientific studies.

As a result of the research, a design and implementation guide that describes different types of natural swimming pools, determines the factors to be considered in filtration and maintenance, and takes into account the ecological conditions and native vegetation of Turkey has been developed in order to assist in the implementation of more affective systems in the future.

Natural Swimming Pools

Natural swimming pools are a technology developed in response to concerns about increased wetland habitat loss and the health effects of chemical filtration. The natural swimming pool concept was developed in Austria in the 1970s under the leadership of D. I. Werner Gamerith, Professor Roldinger, and Richard Weixler and was commercialized by the Austrian ecologist Peter Petrick in 1985 through a company called Biotop. Later, a German company BioNova and a Swedish company Biotech were established leading the way to many other small companies in Europe. While natural swimming pools have started to gain popularity rapidly in Europe, they have recently started to attract attention in North America (Dold, 2008).

Natural swimming pools are a chemical-free alternative to traditional swimming pools cleaned with chlorine. Natural swimming pools can also be defined as balanced, self-sufficient and self-cleaning ecosystems. The water quality in such pools is achieved as a result of cleaning the water with mechanical and biological processes. The water cleaning function performed naturally by plants and bacteria is combined with mechanical skimmers and filtration devices. Thus, pools become living aquatic ecosystems. In addition, factors such as microbial activity, water chemistry, sunlight and temperature, and nutrients entering and withdrawing from the water form a complex web of interactions (Dold, 2008).

Operation of Natural Swimming Pools

Natural swimming pools use the same technology as artificial wetlands and bioretention systems that mimic the physiochemical processes of natural wetlands and biocenoses. Biological filtration is used in these pools to clean and purify the water. Biological filtration provides the clarity and cleanliness of the water by combining plants, beneficial bacteria and microorganisms to remove nutrients and harmful bacteria from the water (Hoffman, 2013). These pools are not treated with any chemicals or UV radiation (Thon and Kircher, 2017).

It is known that natural swimming pools differ from treatment wetlands in some ways. These differences are treatment goals, operating parameters, aesthetics and maintenance. Wetlands and bioretention systems for treatment are open systems. One of the goals of bioretention systems is to reduce stormwater runoff volume as well as certain pollutants. In both systems, there are external inputs (precipitation, wastewater, fertilizer, sediment, etc.) and in both systems, water is released back after the treatment process (Hoffman, 2013).

Natural swimming pools, however, are closed systems. Nutrients are mixed into the pool through pool fill water and this water is circulated through the biofilter without being discharged. Natural swimming pools are artificial bodies of water with an impermeable lining between soil and water. A complex ecological structure, hydraulic system and skimmer are used for filtration in natural swimming pools (Hoffman, 2013).

Natural swimming pools consist of two parts, the swimming and the regeneration (treatment) area (Thon and Kircher, 2017) where nutrient removal by plants take place. Nitrogen and Phosphorus are the two main nutrients that are targeted to be removed from natural swimming pool systems. Excess Nitrogen and Phosphorus causes eutrophication in aquatic systems if they are above the recommended levels. Eutrophication occurs when Nitrogen and Phosphorus are introduced into the environment in large quantities as a result of human activity in aquatic environments and causes excessive plant growth (Hoffman, 2013).

METHODOLOGY

The methodology of this research consists of two phases. The first phase is the review of the limited literature on the subject. For this purpose, academic databases were scanned and, in addition, all available information on natural swimming pools was compiled by following the websites of companies that make natural swimming pools.

The second phase of the research is carrying out face-to-face interviews using purposive sampling. Permission has been obtained from the Ethics Committee of Çanakkale Onsekiz Mart University for the interviews to be carried out with all companies located in Istanbul that design and implement natural swimming pools. In this initial phase of the study, however, the results of two interviews are presented. At the end, the data obtained from these interviews combined with the literature review are used to develop the principles to be considered in the design and implementation of natural swimming pools.

Findings

Types of Natural Swimming Pools

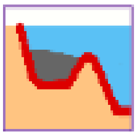
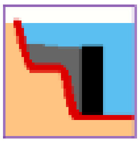
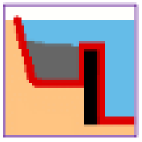
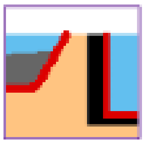
According to the interviews and company websites, there is a wide variety of natural (biologically filtered) water bodies including ornamental ponds and fishponds. There, however, is also a variation among those that are constructed for swimming purposes, namely swimming pools. For example, two types of swimming pools can be designed based on whether their form is formal or informal, called biobride and bionatur (Interview 1). In addition, these swimming pools vary depending on whether biological filtration is carried out with or without plants (Figure 1a) and whether the regeneration area is separate from the swimming area (Figure 1b) or adjoining (Figure 1b) (BioNova, n.d.; Biotop, 2021).

(a) (b) (c)

Figure 1. Different types of natural (biologically filtered) swimming pools, a) plant-free filtration b) regeneration area separate from swimming area c) regeneration area adjoining the swimming area (Biotop, 2021)

Another difference in natural swimming pools arises from the construction of the wall separating the swimming and the regeneration area. Thon and Kircher (2017) explain this difference as in the table below.

Table 1. Different construction types of natural swimming pools (Thon and Kircher, 2017)

No wall	Wall on sealing	Wall under sealing	Separate pool
			
The swimming area is modelled into the underground with a slight slope under the sealing	The wall framing the swimming area is constructed on top of the sealing, and stone or timber is used as wall material	A concrete, masonry or plastic wall defining the swimming area is built under the sealing	The swimming area is constructed separate from regeneration area. This is the easiest construction type when converting a traditional swimming pool to a naturally filtered one

Filtration in Natural Swimming Pools

Filtration in natural swimming pools can be done mechanically or biologically. Mechanical filtration can be through skimmers or UV filters. In biological filtration, filtration is done by aquatic plants located on a substrate layer. Water is circulated using a water pump through circulation and drainage pipes, and aeration is done using a small fountain or waterfall (Dold, 2008). The section describing the operation of natural swimming pools is given in Figure 2. It should, however, be noted that this process can be adapted based on demand.

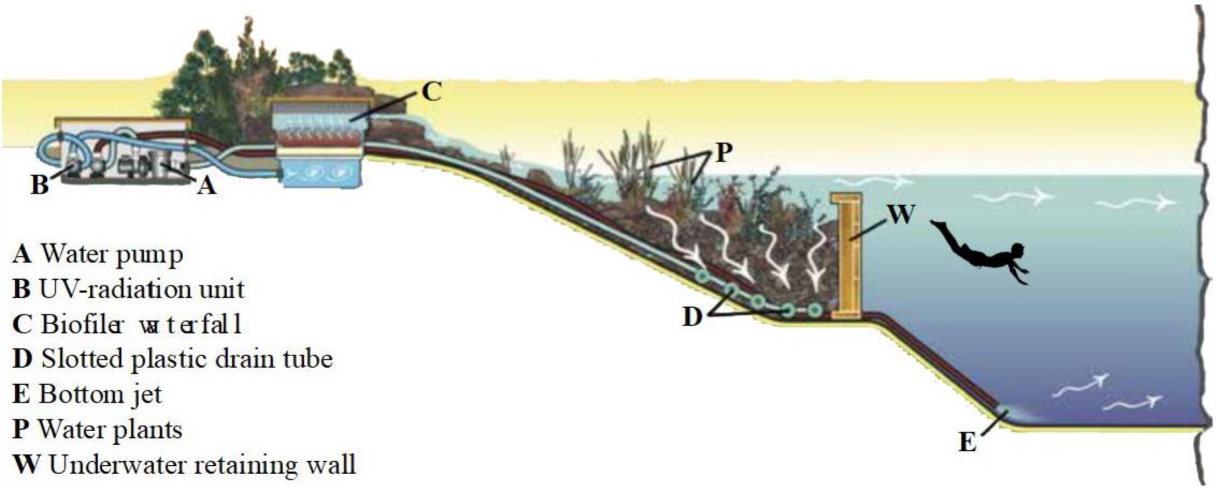


Figure 2. An example of a natural swimming pool operation (Farb, 2020)

Companies can use different technologies when they want to perform a plant-free biological filtration in natural swimming pools. Specifically, the biofiltration technology devised by the companies themselves allow the pools to be cleaned without the use of chemicals or plants. An example of the technology used by some companies can be seen in Figure 3.

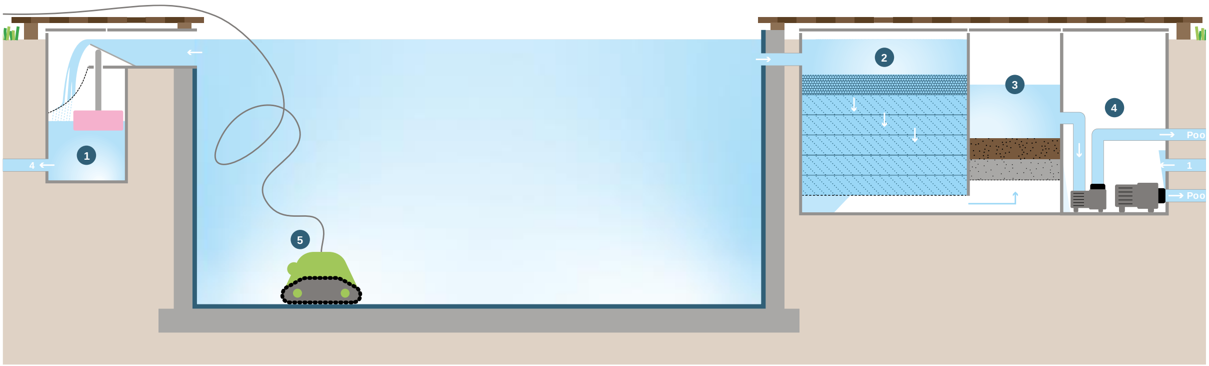


Figure 3. Cross-section of the technology used by Biotop for plant-free filtration 1) Curved sieve skimmer 2) BioCompact filter 3) PhosTech upstream phosphate filter 4) Submerged pump chamber 5) Pool robot (Biotop, 2021)

According to Dold (2008), a designer can organize the plants and substrate material within natural swimming pool systems, regulating the microclimate, microbial growth, water chemistry, and controlling algae. By choosing the right plant and substrate fill, large surface areas where microbes can develop can be created. Submerged aquatic plants whose roots release a high amount of oxygen or emerged plants that can create a shadow on the surface of the water and mechanical aeration methods that increase the amount of dissolved oxygen in the water can be used in order to achieve increased microbial growth. In addition, the substrate material used and residues from plant parts or roots can be a source of nutrients for microbial development.

Intervening with the water chemistry too much can be dangerous to the health of the system. For this reason, it is considered that the best approach for the designer is to ensure that the ecosystem finds its own balance by using healthy macrophyte species and substrate filling that support microbial development (Dold, 2008).

Planting Design in Natural Swimming Pools

When considering plants for natural swimming pools, designers also need to consider several important points. These include the nutrient removal ability of plants, tolerance to low nutrient environments, plant establishment rate, plant climate adaptability, water depth, plant form, aesthetics and other plant characteristics (Dold, 2008; Hoffman, 2013; Farb, 2020). A chart of these factors influencing design principles in natural swimming pools can be found in Figure 4.

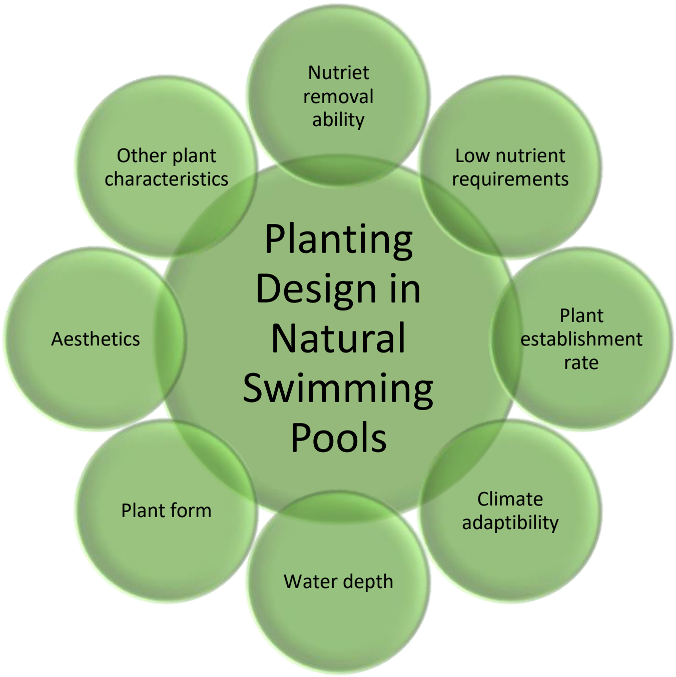


Figure 4. Factors influencing planting design in natural swimming pools (Dold, 2008; Hoffman, 2013; Farb, 2020)

Nutrient removal ability:

Plants to be used in natural swimming pools should be selected based on their ability to remove nutrients from the water. In order to combat algae, plants need to uptake either the carbon (C) or phosphorus (P) in the water (Thon and Kircher, 2017). In natural swimming pools where there is a low load of nutrients, plants can further contribute to nutrient removal by enhancing microbial growth. Plants can also mediate fluctuations in nutrient filtration during seasonal changes (Farb, 2020).

Low nutrient requirement:

Since the nutrient load is low in natural swimming pools, the plants used should have low nutrient requirements. If planting includes helophytes from eutrophic areas, they may come across to nutrient deficiency and may show weak growth. Oligotrophic and mesotrophic species from bogs and fens may offer a solution, particularly on top of submersed gravel filters (Farb, 2020).

Plant establishment rate:

Plants to be used in the regeneration areas of natural swimming pools need to be chosen from those that are quick to establish, because pool owners want to minimize establishment time. A combination of species with different prime uptake periods is suggested, however, where some species rise early and others uptake nutrients at a later season (Hoffman, 2013). In addition, high reproductive ability, widespread availability, high adaptability and resistance to climatic conditions are of great importance in selected plants. Hay grass, reed and reedmace are among plants that can be widely used in this means (Cop, 2017).

Climate adaptability:

The plant species to be used in natural swimming pools should be suitable for being in the water continuously. The use of local and native plant species from wetlands can produces healthier results. Native plant species adapt faster to the climate and soil of the region (Gülgün et al. 2010). According to the interviews with companies, it can also be seen that imported plants are not preferred because they can be expensive and incompatible, however, there are not many native plant options.

According to Gülgün et al. (2010), there are some plant species that are actively used natural and constructed wetlands. These are; *Typha* sp., *Phragmites australis*, *Cyperus alternifolius, Fontinalis antipyretica, Pistia stratiotes, Lemna minor, Eichhornia ccrassipes, Nymphaea alba*. Some of these wetland species may also be suitable for use in natural swimming pools. *Typha* and *Phragmites*, however, should be avoided because of their sharp and pointed rhizome tips (Hoffman, 2013), as well as *Lemna minor* as it has a risk of becoming highly invasive in pool environments. There also need to be further research on the suitability of the above mentioned and other native wetland species for natural swimming pool environments.

Water depth:

Another thing to consider in plant selection is water depth. As can be seen in Figure 5, aquatic plants can be of different types according to the water depth they require. The regeneration area of the swimming pool to be built, in particular, should be designed taking into account these water depths required by the plants. Design of stepped shelves that incorporate different substrate needs and water depth requirements for emergent, submergent and floating leaved plants is essential (Dold, 2008).

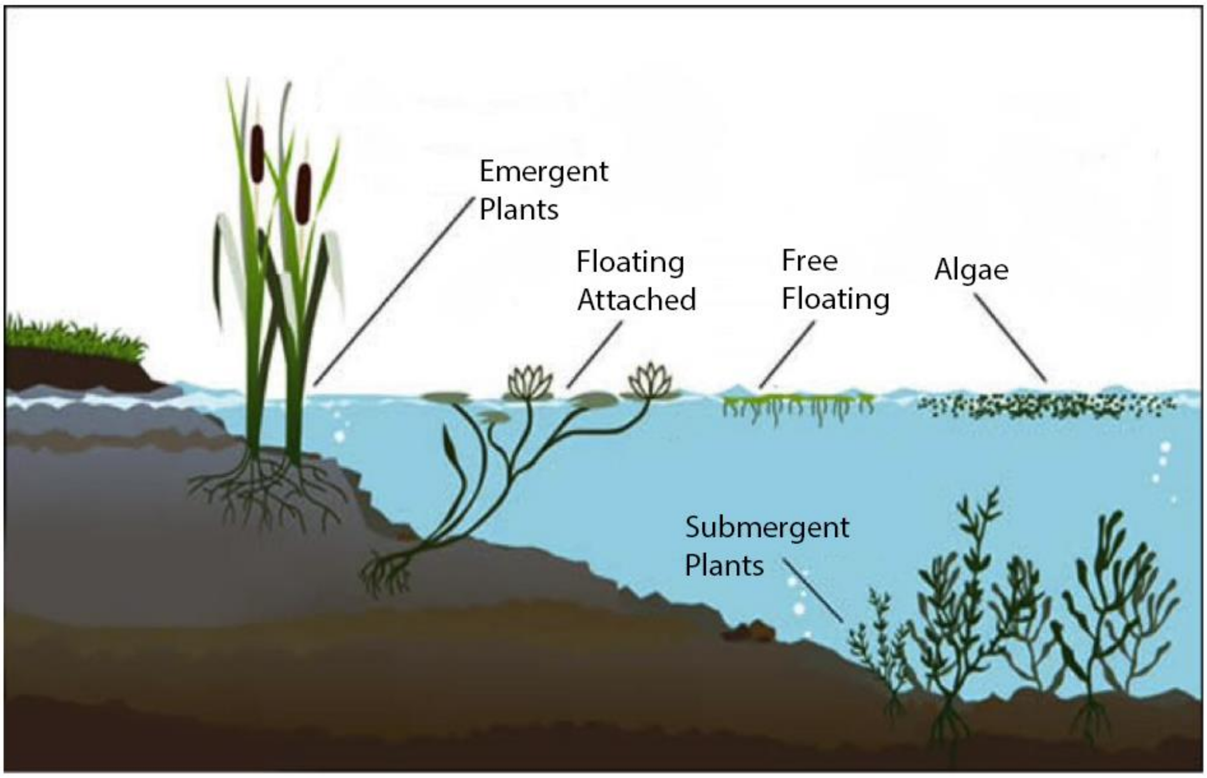


Figure 5. Aquatic Plant Types (Bütünoğlu, 2018)

Plant Form:

Plant form is another factor to be considered in the planting design of natural swimming pools, not only for aesthetic reasons but also for the health of the ecosystem. Natural swimming pools should have a dense mix of 5-10% dominant plants (tall plants planted spaciously), 20-40% companion plants (planted in small groupings) and 50% groundcover plants (planted closely) to prevent weed competition. This type of planting is also beneficial for the system by increasing biodiversity and preventing monoculture (Farb, 2020). Another important factor to be considered with plant form is that the use of species with sharp rhizomes or aggressive roots should be avoided because these type of plants can cause damage to the pool liner (Hoffman, 2013; Farb, 2020).

Aesthetics:

Aesthetics is another important factor to be considered in the planting design of natural swimming pools. Using plants with different textures, heights, foliage and flower color are important in creating a pleasing environment (Dold, 2008). In addition, design principles such as order, unity and repetition should be taken into account when planting in natural swimming pools. For this reason, it should contain at least two species and a good combination of aquatic plants (Hoffman, 2013).

Mixed plant use has three advantages. From the customer's point of view, aesthetically mixed plantings attract more attention and have a longer flowering time. More importantly, mixed plantings are biologically more diverse, and with increased diversity, different niches are created, both in terms of habitat and nutrient removal (Hoffman, 2013). However, when placing plants, a separator should be used in between because some plants can dominate others as the plants do not grow equally (Interview 1).

Other Plant Characteristics:

In terms of beneficial plant characteristics, according to Dold (2008), a combination of oxygenator plants, allelopathic plants, plants that assimilate nutrients from water column, plants that grow in nutrient limiting environments, plants that exhibit root release of oxygen, plants that filter and clarify the water, plants with slender or filiform leaves, plants that grow late into the growing season, plants with mychorrizal associations and carnivorous plants could be used in natural swimming pool environments. A more detailed plant list and a planting design guide can be found in Dold (2008).

Maintenance and Monitoring of Natural Swimming Pools

Harvesting the emergent aboveground and free floating biomass is a very important maintenance element for natural swimming pools. Generally, harvesting is done in autumn before the leaves fall. In this case, harvesting should be planned before nutrients begin to move into root systems. However, for some aquatic plants, harvesting can be done intermittently throughout the growing season. Free-floating plant species should only be used in areas where these species do not pose an ecological risk (Hoffman, 2013).

Plants used in natural swimming pools should be periodically inspected for diseases and pests. It is not recommended to use fertilizers, pesticides or fungicides in or around natural swimming pools due to the negative consequences in terms of biocenosis (Hoffman, 2013). It is understood from the interviews that there are rarely problems with plant diseases and pests. When such problems are encountered, remedies such as pruning are resorted to.

Another maintenance requirement is the need for plant fertilization. When the plants are fertilized, the nutrients in the water might increase, which may also cause an increase in algae. For this reason, fertilizer should only be given carefully in small amounts and from the leaves.

When rain water, drainage, sewage water or irrigation water are mixed with the natural swimming pool, a change in the chemistry and color of the pool water will occur. It may be necessary to intervene in these situations from time to time by monitoring the color of the water (Interview 1). It is also important to monitor the nutrient levels and chemistry of the water to ensure water quality (Dold, 2008).

According to Hoffman (2013), algae in the water create a safety hazard by reducing water clarity and visibility. Algae also competes with other plants for nutrients, inhibiting the establishment of emergent macrophytes and healthy aquatic organisms. Algae is also perceived as impure by the users, discouraging them from using the pool. For the above reasons, the algae in the water needs to be monitored. The German FLL (Landscaping and Landscape Development Research Society) guidelines for outdoor swimming pools with biological water purification, specify a secchi depth reading of three meters for clarity (Hoffman, 2013).

These guidelines further specify standards to maintain aesthetics and bacterial health of the water. While some companies use these standards, others may set their own standards (Farb, 202). Companies we have interviewed have no system for monitoring the water quality, except for visually inspecting water clarity.

Farb (2020) have provided a review of the parameters that need to be considered with the chemistry and microbiological standards of the water in natural swimming pools. In order to ensure that the natural swimming pools remain within these standards, they should be tested regularly. Public pools, in particular, require testing more often since the parameters may fluctuate between day and night (Farb, 2020).

It is also essential that there is a system for water level management, in particular, to prevent the drowning of the stems and leaves of emergent plants by keeping them above water surface level. Meanwhile, submergent plants must be kept continuously under water to sustain high survival rates (Dold, 2008).

Table 1. Water Chemistry and Sanitary Microbiological Standards for Natural Swimming Pool Water (Farb, 2020)

Parameter	*Pool water*	*Filling water*
Ammonium (NH_4^+)	≤ 0.3 mg/l	≤ 0.5 mg/l
Carbonate hardness (CH)	≥ 5.6ºdH	≥ 5.6ºdH
Conductivity (at 25ºC)	200-1000 µS/cm	≤ 1000 µS/cm
Iron (Fe^{2+} / Fe^{3+})	N/A	≤ 0.2 mg/l
Manganese (Mg^{2+})	N/A	≤ 0.05 mg/l
Nitrate (NO_3^-)	≤ 30 mg/l	≤ 50 mg/l
Nitrite (NO_2^-)	0.1 mg/l	N/A
Oxygen saturation	%80-120	N/A
pH	6.0-8.5	N/A
Sulphur (SO_4^{2-})	N/A	≤ 40 mg/l
Temperature	≤ 25ºC (long-term) ≤ 28 ºC (5-day)	N/A
Total hardness (TH)	≥ 1.0 mmol/l	≥ 1.0 mmol/l
Total phosphorus (P_{tot})	< 0.01 mg/l	< 0.01 mg/l
Escherichia coli	100 cfu/100 ml	N/A
Enterococci	50 cfu/100 ml	N/A
Pseudomonas aeruginosa	10 cfu/100 ml	N/A
Legionella	Below detection level (100 ml)	N/A

Conclusion

In this study, a fairly new concept of natural swimming pools was investigated. Initially, the existing literature on the subject was compiled. Next, the problems encountered in practice and the factors to be considered in design and implementation were determined by interviewing two companies that made natural swimming pools.

As a result of the research, it has been understood that natural swimming pools can be designed in different ways according to customer demand and needs, and the functioning of natural swimming pools may differ accordingly. This difference is closely related to how the regeneration area of swimming pools is related to the swimming area and what kind of filtration is used. These preferences may differ according to the customer or user capacity.

Factors such as the types of aquatic plants to be used in herbal filtration, the diversity of plants to be used, use of native plants, and plant size play an important role in natural swimming pool designs. In addition to these factors, factors such as nutrient removal and oxygen production capacities of plants gain importance in plant selection. Finally, pruning and fertilizing the plants at the right time in natural swimming pools is an important maintenance requirement.

Overall, the research results showed us that there is a gap between theory and practice. While research support plant-based filtration to make swimming pools more natural, they limit the use of UV radiation. In reality, phosphorus filters and UV radiation rather than plant-based filtration are preferred in terms of hygiene and customer demands. In Turkey, particularly, the demand for fully natural swimming pools is not yet high.

Acknowledgements

This research was supported by the Scientific Research Projects Coordination Unit, Çanakkale Onsekiz Mart University (Project number: FYL-2022-3883).

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