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## Mobile modular systems of water treatment and storage in crisis situations – review of existing solutions

### Abstract

Various methods of water purification, the aim of which is to obtain such a purity class that makes it suitable for consumption are presented in the article. It is a review of solutions, ranging from methods known and used for over 100 years, through research and experiments underway, to those that are only a concept. Some of the solutions are so effective that they should also be combined with the possibility of safe storage of purified water. Flexible tanks are used for this, which significantly improve logistics and provide a supply of water in all places where it is needed.

### Keywords:

water supply, crisis situation, safety of water supply, flood, water decontamination, water filtration, flexible tanks

### Methodology

As part of the review of solutions to provide water in crisis situations, various ways of supplying drinking water were identified, e.g. during a flood, earthquake, etc. The minimum required amount of water necessary for people for social and living purposes was also established. Several concepts of mobile filtering installations, including those transported in containers, have been described. Particular attention was paid to the system developed in Romania, which can be successfully used to ensure continuity of water supply in small groups of people. The authors' proposals are: installation of many filter sets on the chassis of a heavy off-road vehicle, which will be used to drive anywhere in the disaster, as well as a method of storing water in flexible reservoirs. The effectiveness of three water supply solutions related to moving people or staying in their place of residence was assessed. The economic aspect was emphasized by comparing the costs of transport and the time of obtaining drinking water using typical logistic methods (truck transport) and using the authors' proposals.

### Introduction

The provision of potable water is a key goal not only in emergency situations, but also in areas where there is simply no water with the right parameters. Contrary to the popular opinion resulting from a certain mental shortcut, the problem is not the lack of water in the world, because 71% of the surface of our globe is made of water. On the other hand, the real challenge for humanity is access to drinking water. Freshwater accounts for only 2.5% of global water resources, and only 1% of this part (77% glaciers and 22% groundwater) is available for consumption. However, it also requires additional treatment in many cases. In the European Union, the Water Framework Directive (WFD) is

in force, which requires the member states to develop water quality improvement programs, and in the case of water of the highest ecological purity class, not to deteriorate its parameters. The availability of water resources and the ability to renew them in the EU countries is highly uneven. Table 1 shows the 5 countries with the highest renewable water resources per capita and the 5 countries with the lowest resources in Europe, and Table 2 in the world.

Table 1. Total internal renewable water resources per capita in 2017 (Europe)

Country	Total internal renewable water resources per capita (m <sup>3</sup> /inhab/year)
Iceland	507463
Norway	72008
Russian Federation (european part)	29947
Finland	19374
Sweden	17254
...	...
Cyprus	661
Netherlands	645.7
Hungary	617.2
Republic of Moldova	399.9
Malta	117.2

Source: <http://www.fao.org/nr/water/aquastat/data/query/results.html> [8]

Table 2. Total internal renewable water resources per capita in 2017 (World)

Country	Total internal renewable water resources per capita (m <sup>3</sup> /inhab/year)
Iceland	507463
Guyana	309808
Suriname	175719
Papua New Guinea	97079
Bhutan	96582
...	...
Qatar	21.22
United Arab Emirates	15.96
Egypt	10.25
Bahrain	2.679
Kuwait	0*

\*in Kuwait the total renewable water resources (TRWR) is 10 m<sup>3</sup>/inhabitant

Source: <http://www.fao.org/nr/water/aquastat/data/query/results.html> [8]

Water purification and treatment, e.g. for obtaining freshwater from seawater, preventing environmental pollution and creating methods for removing pollutants from water and soil, can be done using nanotechnology [9]. According to some scientists, the potential of nanomaterials is so

great that it will be possible to develop large-scale water and environmental purification technology in the near future.

Ceramic filters are used in poorly urbanized and low-industrialized countries, without access to the most modern solutions, such as Guatemala, Cambodia, Nepal or Nicaragua [10-12]. They are one of the oldest water filtration methods known to mankind. In Victorian England (1827), Henry Doulton (potter and inventor), commissioned by the ruler, constructed an effective, gravitational filter, thanks to which it was possible to remove from drinking water, among others, comma cholera. Ceramic filters are still used today. The research conducted in Guatemala combined the classic technology of clay and sawdust filters with the modern one by adding silver nanoparticles to them. In the conducted field tests, the number of E. coli bacteria removed was approximately 90% [11].

The advantage of ceramic filters is their widespread availability due to the technology that has been known for centuries, and for their production all you need is clay, sawdust or rice husks. If carefully made, it can remove up to 99% of pathogenic bacteria, as well as water clouding. However, their effectiveness in relation to the needs is negligible (you can get from 0.5 to 4 liters of filtered water daily). They are easily damaged, require regular cleaning, and it is practically impossible to maintain a uniform quality standard in this type of production [12].

In the event of water shortage during natural disasters such as drought or flooding, or man-made disasters, where there is chemical or biological contamination of water resources, ensuring sufficient water for social and living purposes is one of the key tasks of emergency services. Currently, the most popular in the world are two forms of drinking water supply in emergency or crisis situations:

- bottled water that can be delivered even from long distances,
- drinking water supplied by water tankers from shorter distances, which requires the recipient to provide containers for its withdrawal [1].

This poses a great logistical challenge for emergency services due to the need to commit significant forces and resources to ensure sufficient water supply to all those in need. It requires the collection of a large number of vehicles adapted to the transport of water without unit packages or a bottled water distribution center in the affected areas, because it is often impossible for truck tractors with trailers to reach customers directly (due to the damaged road infrastructure or the lack of roads with the required load capacity).

This additionally increases the traffic in these areas, which in the event of high dynamics of events may have an adverse effect on the capacity of roads for intervention units (along with the materials and equipment necessary for these activities) to combat the effects of a disaster or prevent its extension.

Another aspect is the efficiency of the transport system depending on the distance to drinking water intakes or logistic centers with water portioned in individual containers. In the case of low efficiency of drinking water intakes, it may be necessary to ration it or create a situation of its temporary shortage for purposes other than human consumption. The solution to eliminate these disadvantages and limitations are filtration devices with high efficiency and the use of flexible tanks that require much less cargo space during transport than in the case of rigid tanks. The use of two-

phase filtration significantly speeds up the process of obtaining water for domestic purposes, i.e. activities that do not require drinking water, such as washing or hygiene.

A very precise determination of the minimum amount of drinking water needed in a given area is practically impossible, because the individual characteristics of an individual are of key importance to its demand. The selected parameters that should be taken into account when determining individual needs include: gender, age, type of diet, load resulting from physical activity and they will depend on the ambient temperature and air humidity. The higher the temperature and the lower the air humidity (water loss due to sweating) and the increase in altitude (increased water loss in the exhaled air), the greater the demand for water. Interestingly, the water balance is also influenced by low temperature due to the increased energy expenditure, and the need to use a high-calorie diet increases the need for water necessary for the metabolism of more nutrients. A diet high in fiber and sodium also contributes to increased liquid requirements [2].

Polish legal regulations define the minimum demand for drinking water depending on the time in which the water will be rationed. In the case of a short-term water shortage, the amount is 2.5 dm<sup>3</sup>/person per day, but if this time is extended, the minimums increase accordingly:

- for several days – 7.5 dm<sup>3</sup>/person per day,
- for several weeks – 15 dm<sup>3</sup>/person per day,

A sufficient amount of water for vital purposes is considered as 30 dm<sup>3</sup>/person per day [3, 4].

Water consumption related to the provision of personal hygiene, i.e. washing, showering in field conditions, washing, etc., consumes several dozen liters per person per day. However, these activities do not require the use of water of the highest purity.

As recommended by the World Health Organization, two liters is the minimum quantity required to maintain fluid balance. On the other hand, the report of the Institute of Medicine of the National Academies states that the average demand of women is about 2.7 liters each day, and that of men, on average, about 3.7 liters a day (taking into account the fluids contained in drinks and food) [14].

Providing sufficient water to meet the basic needs of people and animals in areas affected by natural or technical disasters is a huge challenge for logistics and quartermaster services. The criteria that should be followed by persons making decisions regarding the selection of the most optimal technology for emergency water supply in a given specific situation are summarized in [15]. The preliminary assessment must take into account: meteorological conditions, road availability and capacity, water quality and demand. After this pre-selection, the next components of the right choice are: costs, easy of deployment and use, environmental impact, maintenance, performance, potential acceptance, energy requirement, supply chain requirement, water filtration efficiency. For the needs of large countries such as China, due to rapid industrialization, there were major accidents leading to contamination of water bodies [16] and in the USA, where in 2007-2008 there were 36 outbreaks of infectious diseases in drinking water [17]. In extreme situations, where it is not possible to supply or activate filter systems, the simplest method of removing pathogenic bacteria is SODIS, i.e. the solar water disinfection technique using a PET bottle. The method consists in long-term exposure of water placed in a transparent plastic bottle to the influence of UV-A solar radiation. Research on the effectiveness of this method and other solutions based on UV radiation, where the main criterion



was the price, were conducted in African countries [18, 19]. Field tests of the low-pressure ultrafiltration method for the removal of solid and colloidal particles and partial disinfection of water were also carried out [20].

### 1. Mobile filtering systems

There are mobile systems on the market with a multi-stage filtration process that remove solid particles, bacteria and viruses, making the water drinkable. The end user receives water that is clean and free from biological contamination. Portable reverse osmosis systems (Fig. 1) are capable of removing hazardous substances and salts from seawater as well as from chemically polluted water.



Fig. 1. Mobile reverse osmosis systems by FUTURETECH

Source: [www.karcher-futuretech.com](http://www.karcher-futuretech.com)

According to the manufacturer's declaration, systems operating on the basis of reverse osmosis (forced diffusion of the solvent through a semi-permeable membrane separating two solutions of different concentration) provide the highest level of purity of the filtered water. The reverse osmosis membrane uses all the ultra-filtration capabilities of freshwater, and is able to remove chemicals and salt from brackish and salt water as well as chemically contaminated water. Thus, substances that are retained by the reverse osmosis membrane include: small and large solid impurities, viruses, microorganisms and various chemical compounds, including salts.

In the United States, water purification systems are shipped in 20' or 40' containers on a plug & play basis, that is, ready to go immediately after connecting the power supply. These kits are designed for

rapid response in emergency situations as supplementary or temporary sources of drinking water (Fig. 2).



Fig. 2. Container water treatment system

Source: [www.appliedmembranes.com](http://www.appliedmembranes.com)

A solution based on a water purification mechanism other than reverse osmosis is the SOWAT filtration system (System of Open Water Advanced Technology) developed by the Romanian company KHAR. It consists only of mechanical filters and works without the need for chemicals or UVC sterilization, providing drinking water without eliminating the minerals contained in it, so that the filtered water does not require additional mineralization.

Thanks to the involvement of experts from various industries in the project, it was possible to develop an effective system which, despite the fact that it was a start-up and was to serve mainly research and development purposes, has become a fully-fledged solution used practically both in Romania and after the flood caused by heavy rains in Madagascar in the Atsinanana region. The efficiency of a single module was estimated at min. 4,800 dm<sup>3</sup>/h, which in the producer's opinion will ensure the demand for water for 5,000 people a day. The great advantage is the ability to bring water of any quality (including highly contaminated) to the drinking water class. The filter system removes contaminants up to a diameter of 10 nanometers, which allows the almost complete removal of not only solid particles, but also bacteria and viruses. With such efficiency, the system can be a very interesting solution not only in crisis situations, but also in places with significant shortages of the highest quality water.

The part of the water filtration system is shown on Fig. 3.



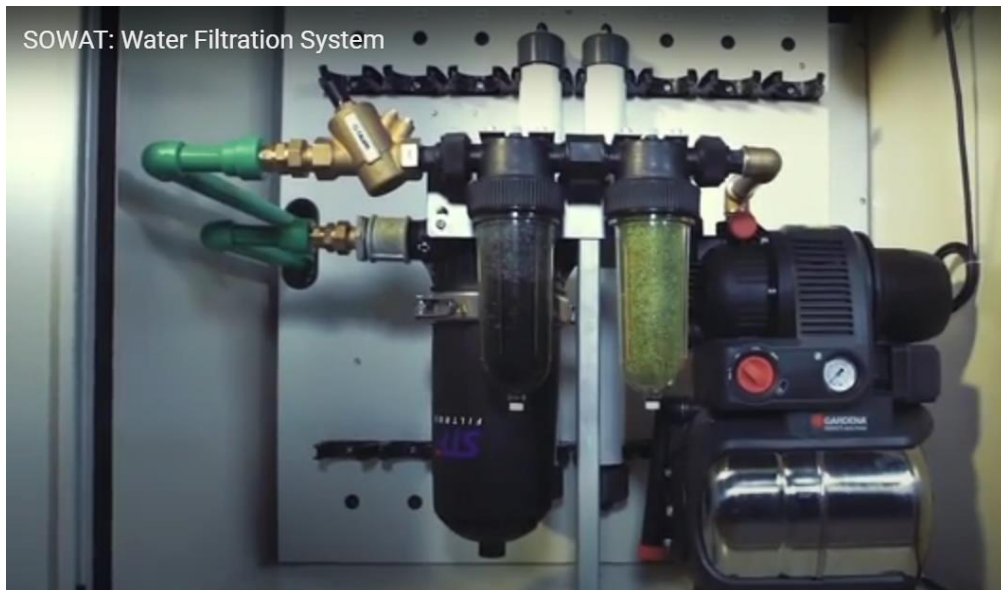


Fig. 3. Filter system: green color – polarized glass elements, black – activated carbon filter and ultrafiltration (on the back)

Source: SOWAT Water Filtration System – advertising film

A prototype installation made in Cornăţel (Romania) is shown on fig. 4 and 5.



Fig. 4. Prototype installation made in Cornăţel (Romania)

Source: SOWAT Water Filtration System – advertising film



Fig. 5. Practical use of a prototype installation

Source: SOWAT Water Filtration System – advertising film

At this stage of the project's advancement, the requirements for the installation of filter modules have emerged, the fulfillment of which is necessary for their proper operation. First of all, they should be protected against flooding, placed on a stable surface in a vertical orientation. They also require thermal protection, as they can function in a fairly limited temperature range (5-35 °C).

For the automatic cleaning of membrane filters of collected contaminants (to maintain the highest water quality and efficiency), the installation requires a connection to a waste container, because after this operation the water used for servicing is not potable [5].

## 2. Flexible drinking water tanks

As already mentioned, rigid water tanks are a great logistical problem, and they can be easily replaced with an alternative solution, which is another type, made of flexible synthetic materials. They can be transported in the form of relatively small packages. An example of such a system of tanks, used in Poland by the military for both fuel and water storage, are the products of the American company MPC Containment Systems LTD.

The tanks are equipped with filling hoses and mechanical valves with quick-connect Camlock couplings that also allow their ventilation. The use of rounded sides of the tank increases its resistance to damage during filling, thanks to a more even distribution of hydrostatic pressure. This also translates into the elimination of leaks and extension of its service life.

It is a solution used in many armies of the world, and its resistance to climatic conditions enables them to be used in combat conditions in both temperate and hot climates.

The Americans are not the only suppliers of such solutions, and the armed forces are their only recipients. Many manufacturers offer a wide range of systems for temporary storage and delivery of fuel (or water) – these are European and Asian companies.

This solution is used not only for military purposes, but also for humanitarian and commercial purposes. The modular structure of such systems enables the creation of fuel or drinking water bases



ranging from a single tank to the logistics base of large strategic operations, tailored to individual needs.

There is a wide variety of tank sizes, e.g. MPC offers capacities: 11, 25, 38, 76, 190 and 795 m<sup>3</sup>. An example of a flexible tank with a capacity of 190 m<sup>3</sup> is shown in the photo (Fig. 6).



Fig. 6. The composite flexible tank of MPC Containment Systems LTD [6]

Their transport weight is respectively: 311, 398, 414, 429, 512 and 845 kg. Folded tanks are transported in reusable wooden crates with all necessary equipment. The disassembly and assembly of all the elements of the tanks must be done by hand (Fig. 7).



Fig. 7. Preparation of flexible tanks for use [6]

### 3. Water supply systems in crisis situations

The use of mobile water treatment solutions occurs not only in the event of sudden events such as all kinds of disasters, but also when the shortage of potable water is a long-term process. An example of such a situation is the consequences of hostilities. As a result of the Second Gulf War, much of the critical infrastructure in Iraq, including the water supply, was destroyed. However, their reconstruction was a long-term process, which required finding alternative solutions implemented in a short time. A solution developed by Applied Membranes, Inc. was used to accomplish this task.

To cover the necessary minimum demand for clean water, 400 mobile units with 7-stage filtration, with a volumetric flow rate of up to 5 m<sup>3</sup>/h each, were prepared. In order to become independent from external sources of electricity, power was supplied from photovoltaic cells placed on trailers (Fig. 8). Thanks to this solution, they can be used in areas without electricity. The main threat to the population was water contamination with cholera commas. Therefore, one of the stages of water filtration and disinfection is the removal of all kinds of bacteria using ultraviolet radiation, the effectiveness of which in these modules has been confirmed by independent certified laboratories.



Fig. 8. A solar powered water treatment system to prevent the cholera epidemic in Iraq (2010)

Source: [www.appliedmembranes.com](http://www.appliedmembranes.com)

Systems for filtering and storing drinking water and delivering it to areas affected by various natural disasters have already been used many times, e.g. after earthquakes, floods and other natural disasters.

After the 2015 Nepal earthquake, Kärcher Futuretech GmbH's systems were widely used during a humanitarian operation. Two WTC 5000 UF water treatment plants operated in Kathmandu, treating 10,000 liters of water per hour for consumption, which allowed 30,000 people to have constant access to drinking water. The water was distributed directly on site or delivered using tanks on trucks. The described installation is shown in Fig. 9.



Fig. 9. WTC 5000 UF water treatment and storage system in Kathmandu  
Source: Federal Agency for Technical Relief (THW, Germany)

#### 4. Solution proposed by the authors

According to the authors, the currently presented solutions for mobile water treatment plants can be improved to some extent. The weak points of the solution using car trailers are: maximum permissible speeds with a trailer and maneuvering in difficult terrain. In the case of a container



solution, a truck with a semi-trailer is necessary, the mobility of which in wetlands or sandy areas is very limited.

Additionally, the mobility of the existing system is understood as transporting the system to designated places of providing assistance to the injured, but its frequent relocation is not expected. The authors' proposal is a truly mobile unit used to provide drinking water in many locations affected by natural or technical disasters.

The proposed solution is to install 4 or 6 sets of filters on the chassis of a heavy off-road vehicle (proposal – Fig. 10).



Fig. 10. Heavy rescue vehicle on all-terrain chassis with 6x6 drive

Source: [www.wiss.com.pl](http://www.wiss.com.pl)

This proposal solves problems related to stabilization and the required working conditions (for example, the SOWAT system should be placed vertically, on hard ground, protected against flooding, used in the temperature range from 5 to 35 °C). Flexible reservoirs of various capacities can be used to provide water supply even for small groups of people in the affected areas. Their transport can be provided by a vehicle with a tarpaulin and HDS system (Fig. 11).





Fig. 11. An example of a truck with an HDS device (Volvo FMX 66R 420 6x6, JRG Trzcianka, Poland)

Source: [www.czerwonesamochody.com](http://www.czerwonesamochody.com) (photo: Maciej Chmielewski)

The third element of a mobile drinking water supply set can be a laboratory where the water quality will be confirmed. To ensure maximum efficiency of the proposed solution, the third vehicle should be equipped (in addition to the laboratory) with additional filters and spare parts, an emergency power generator, elements of a field camp for the crew and a supply of fuel.

## Discussion

During natural or technical disasters, two approaches are practiced to strategically provide people with access to water, and the third is the authors' suggestion:

1. Movement of the population to the designated base\*
2. Remaining people on the spot, bringing water
3. Remaining people on the spot, launching a mobile modular water treatment and storage system

\*The considerations relate to the situation where the houses have not been damaged, but for logistical reasons (long distances to drinking water sources, damaged roads preventing access of ungrounded vehicles, etc.) it seems easier to build temporary bases.

The advantages and disadvantages of individual solutions are presented in Table 3.

Table 3. Comparison of three different ways of ensuring access to drinking water for people in crisis situations

	1	2	3
Construction of a base (temporary shelter) with sanitary facilities and the necessary infrastructure	YES	NO	NO
Transport of people to the base	YES	NO	NO
Stress related to changing the place of residence, lowering the quality of life (well-being)	YES	NO	NO
Water delivery by trucks (barrel vans or bottled water)	YES	YES	NO
Use of drinking water for economic purposes	YES	YES	NO
Water supplies depend on logistic possibilities	YES	YES	NO
Recovering the water that is in place	NO	NO	YES

Source: own study

For a simple cost comparison, the possibility of obtaining 25 thousand. liters of water, which provides the daily demand for 833 people (the required amount of water for life purposes – 30 dm<sup>3</sup>/person per day, half of which does not have to be drinkable).

The assumed amount of water corresponds to the maximum logistic possibilities of transport in a standard set with a semi-trailer (commonly known as a TIR): 34 euro pallets, 504 bottles each, with a capacity of 1.5 dm<sup>3</sup>. Such amount of water to the drinking water purity class can be obtained during 5 hours of operation of the WTC 5000 UF set (effectiveness confirmed during the Nepal earthquake).

The fully mobile solution proposed by the authors, equipped with the SOWAT INOVAYA C1000 system (with a capacity of 20 m<sup>3</sup>/h), requires 1 h 15 min for decontamination of this amount of water (even of the lowest quality).

There is no emergency service in the world with a sufficient number of tractor units with semi-trailers to ensure the transport of water on its own. This means that it is necessary to hire commercial forwarding companies (the cost depending on the EU country is 0.5-1 €/km). It should be taken into account that the return of an unloaded truck also costs money and it is unlikely that a return order will be obtained.

It should be remembered that a 40-ton truck will not enter a wetland or most local roads, which requires organizing a logistics center, unloading and reloading to smaller, preferably off-road vehicles, which also increases costs.

According to the manufacturer's declaration of the SOWAT system, one set is able to provide enough water for 5,000 people. people at a monthly cost of just 0.05 €/person. The proposed decontamination unit in the number of 3 cars alone should not constitute a significant burden on the budget of any national fire service in the European Union countries. Building several such units in each country would constitute a central operating reserve for the countries of the community in the case of the described events. Even a single unit at the disposal of the chief fire brigade significantly improves the effectiveness of the rescue system in the event of a disaster and can be disposed of with one order. In fact, you need to equip one car from scratch – the one with a filter kit and a laboratory.

The greatest advantages of mobile systems are the guarantee of the continuity of water supply, as the filtration systems can even handle heavily polluted water – whether fresh or from the seas or oceans. The proposed set is fully autonomous and can be used in any place where it is necessary. The efficiency of the SOWAT filter system is so great that it will take 15 hours to provide water in a group of people reaching, for example, 10,000 people (assuming the demand in crisis conditions – 30 dm<sup>3</sup>/person per day). To provide the same amount of water, it is necessary to engage 12 tractor units with trailers fully loaded with water.

## Summary and Conclusions

In the authors' opinion, the presented proposal significantly improves logistic efficiency, simplifies and reduces the number of necessary vehicles, such as cisterns, cars for transporting bottled water, etc. Reaching even small groups of people whose homes are not directly exposed to flooding and only lacking drinking water, can be retrofitted with such a kit, leaving a flexible tank with a capacity of e.g. 190 m<sup>3</sup> and refilling it if necessary.

The conducted analysis allowed to highlight the following advantages of the presented solution:

1. Real mobility. Other applied solutions require the fulfillment of the basic conditions for the functioning of the water treatment, which are provided for the system installed on the truck.
2. The use of flexible tanks allows for their relocation in a very short time and providing access to drinking water even for small groups of people without the need to build camps, if people's homes are not threatened.
3. It greatly simplifies the logistics, there is no need to involve significant forces and resources.

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