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Multi-objective optimization for solving water shortage issues in arid zones via the analytic hierarchy process (AHP): the Israeli case

Sivan Jan[a], Asaf Cohen[b], Gideon Oron[c,d,*]

[a]*Vernit Company, Mascit Street 33, Herzlia, Israel 4673300, Tel. 050-797-2133; email: sivi77@gmail.com (S. Jan)*
[b]*Intel, Shederot HaAvatz 2, Kiryat Gat, Israel 8258113, Tel. 052-368-1618; email: casafc@gmail.com (A. Cohen)*
[c]*Zuckerberg Institute for Water Research, Blaustein Institutes for Desert Research, Kiryat Sde Boker, Israel 8499000*
[d]*The Department of Industrial Engineering and Management and The Environmental Engineering Program, Ben-Gurion University of the Negev, Beer-Sheva Israel 8410500, email: gidi@bgu.ac.il (G. Oron)*

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ABSTRACT

Water scarcity along with the continuing decrease in its quantity and quality continues to be one of the major challenging threats on human survival in many parts of the world. Advanced technologies are required for testing the alternatives for solving water scarcity issues. Testing the alternatives should be carried out in several directions and taking into account several considerations: theoretical models allowing examining different options and physical-algorithms emanating in the field leading options. This work is based on screening the option of solving water shortage issues as faced in the Mediterranean Basin. Modelling of the alternative is based on the analytic hierarchal process as a general screening method. Selecting the preferable solution is based on the opinion of a group of experts and turning their ideas into a mathematical model that will be demonstrated here within.

Keywords: Analytic hierarchy process (AHP); Alternative screening; Water shortage; Water resources management

1. Introduction

The most essential needs of human society are water and sustainable agricultural food products. The human population is increasing at an alarming rate, along with groundwater shortage due to intensive depletion. The worldwide birth rate is around 2.5×10^5 new-borns babies per day. It means that the world population will expand to around nine billion people towards the year 2050 [1,2]. The existing agricultural production systems that provide an abundant, affordable and safe food supply, as well as many industrial and consumer products face dramatic challenges in meeting the increasing needs for safe and nutritious food for the growing population of the world. The consequences are an increase in food production by 25%–70% in the next three decades, which means higher water production and consumption rates. However, it is more than just agricultural productivity that is involved, because the system must function within finite lands. This source availability is also decreasing at an alarming rate. Land that was considered marginal about a decade ago must be revived and protected.

The hypothesis of this work is based on three pillars: (i) shortened sea strip that allows comfortable recreation however, the community needs it for tourism and refreshment due to climate changes during hot periods. The new water has to be produced by desalination seawater probably several km in the sea; (ii) the options of reclaiming and transporting treated wastewater is a challenging task, and; (iii) supplying water via transboundary water is an acceptable solution for countries not having access to the ocean [3].

The purpose of this work is to show how to solve water shortage issues, to maintain the environment, and to provide

* Corresponding author.

solutions for the expanding phenomena of sinkholes in the Dead Sea. The method presented here within is part of the water policy that should be employed in water-scarce regions. Therefore we first provided optional solutions for closing the gap between supply and demand and subsequently followed with the application of the analytic hierarchal process (AHP) process. The AHP is not a new innovation however, a procedure that can as well be applied to water issues, as given here step by step.

1.1. Potential of water technologies for efficient use

Efficient water reuse in many countries in the Mediterranean Basin, the USA (California, Texas) and Africa use extensive extraction of groundwater however, they suffer from frequent drought events [4]. These phenomena are due to prominent hydrological events causing floods on one hand and increasing drought events on the other side which are due to climate changes [5]. This has led to environmental awareness and intensive efforts in the treatment and reuse of nonconventional water resources, primarily wastewater, grey water and runoff [6,7].

Essentially there are four main directions to add extra waters to existing systems: (i) reuse of wastewater (including industrial wastewater and greywater); (ii) reuse of runoff water which is associated with increased standard deviations in appearance that are due to dramatic climate changes; (iii) expanded use of desalinated water pumped from the sea or/and saline groundwater (reverse osmosis (RO) and/or forward osmosis (FO)) although some limitations are involved with the FO method [8,9], and; (iv) use analytical methods for synthesizing water from hydrogen and oxygen [10]. This last topic will not be discussed in the current work.

1.2. Wastewater reuse

A possible direction for solving water shortage is to reuse treated domestic wastewater (TDW) and industrial wastewater. This approach can simultaneously solve water shortage and is a contributive approach to controlling the environmental risks of pollution due to disposal. Instead of disposing of it freely, the TDW can be reused for diverse purposes. Moreover, the nutritious content is of great advantage for agriculture [11–13]. However, the nutrient content in the treated effluent can as well be of adverse effect due to the increased concentration of certain nutrients during specific growing periods of the agricultural plants. The increased content of nutrients and micro-elements enhances eutrophication processes and generation of nitrates in the groundwater, hindering further use of water for drinking purposes [14]. In some cases trying to solve health aspects and pathogen content was associated with aggravation of the water quality [15,16]. A great deal of works is associated with salinity and other micro pollutants removals [17]. No doubt that salinity removal has to be tackled with nanotechnological methods.

The nutrient content of TDW has imposed many problems related to the treatment level of the wastewater. It is mainly due to the seasonal nature of the crop cultivated and the residual nutrients content from the TDW remaining in the soil after harvesting. In arid regions, the soil is hardly leached by precipitation, as common in rainy regions. Salts and micro pollutants are accumulated, causing a reduction of crop yield and ultimately in food production and leading to human health risks [16,18].

1.3. Runoff water reuse

Subject to climate changes and extreme hydrological events, large amounts of runoff water can be accumulated in arid regions. Flood is a major natural disaster factor that causes enormous damages annually including loss of human lives. Flood modelling has been an area of active research since the inception of engineering hydrology [19,20]. Globally, it has recently come into focus because of the numerous devastating floods that have swept across many countries. Recent episodes of flooding have been attributed to global warming [21]. In order to decrease flood damage and save human lives, flood modelling is undertaken in order to assess the instantons huge amounts of water on time and space scales. There are several methods available for flood estimation and assessing the available waters for reuse [22]. Flood frequency analysis (FFA) is the most direct method and serves as a benchmark to assess the accuracy of the regional flood estimation approach and rainfall-runoff modelling [23]. FFA is an active area of investigation in statistical hydrology of assessing water caption options.

The primary objective of FFA is to relate to the magnitudes of extreme events and to their frequency of occurrence using probability distributions [24,25]. FFA determines the relationship between flood quantiles and their non-exceedance probability. FFA is a major component of hydrological surveys, as it is the basis of hydraulic design for infrastructures such as dams, spillways, diversion canals, dikes, river channels, urban drainage systems as well as cross-drainage structures (e.g., culverts, bridges, dips), and flood risk mapping. The social and economic implication of FFA requires incorporating accurate statistical procedures. For example, in order to provide a value for the accepted risk of constructing dams and spillways, the design discharge should be estimated as accurately as possible. The accuracy is required due to flood quantiles estimated below the real value will increase the costs of the spillways unnecessarily [26].

Due to climate changes and frequent drought events, flood control is receiving increasing attention these days. It is subject to the increase in the standard deviation of rain events and the option to better harvest the flood water [27]. It is also due to the expansion of paved roads that allow less water to infiltrate into the groundwater and increase in water accumulation in closed sites for future use.

1.4. Desalination of sea and brackish groundwater

Intensive work is undergoing worldwide for desalination of low-quality waters. The general idea is to produce more potable water that can easily be used for drinking and for irrigation of crops. Various levels of desalination are used, subject to the purpose of use [8]. RO is the primary acceptable nano-technology for desalination, although FO is gradually becoming popular as well. RO is widely used to treat wastewater and saline waters and removes most of the constituents, including the micro pollutants.

FO is a novel and emerging low energy demand technology for desalination. The application of the advanced concept is briefly described in desalination works of saline and sea waters applied for irrigation, using fertilizer as a drawing agent (e.g. ammonia) [28,29]. Instead of separating the draw solution from the desalinated water, the diluted fertilizer draw solution can be directly applied for fertigation. They indicate that most soluble fertilizers can generate osmotic potential much higher than the seawater. The draw solutions of KCl, $NaNO_3$ and KNO_3 performed best in terms of water flux while $NH_4H_2PO_4$, $(NH_4)_2HPO_4$, $Ca(NO_3)_2$ and $(NH_4)_2SO_4$ have the lowest reverse solute flux.

A summary of anticipated development in the area of water resource shortages is given in the anticipated Fig. 1. It is a combination of environmental issues and techno-economic considerations. The graph (Fig. 1) describes the general tendencies of the theoretical development directions to be undertaken in the next 30 years and the related obstacles.

2. Water quality issues can be solved by nanotechnology processes

2.1. Nanotechnology for water quality control

A nanotechnology-based filtering system installed at the head control of any water system can dramatically improve effluent quality. The question arises to which level one has to bring the effluent quality: should it be a technology based on microfiltration, nanofiltration or RO. This work combines aspects related to water quality, environmental issues, as well as economic aspects [30–33]. An additional important issue refers to the fate of the brine disposed of by desalination plants, primarily it is relevant to inland water resources (currently, most of the desalination plants are installed along the sea-shore). RO can remove most contaminants from the wastewater to an acceptable level (the acceptable level should be defined) and prevent health and socio-economic risks. That includes the micro pollutants, personal care and hormones that can be removed by the RO processes [34].

Three cardinal drawbacks are noteworthy in reference to membrane technology, although the structure and materials composing the membranes themselves is another one. These pillars include (i) fouling of the membrane causing a decline in flux (a lot of works have dealt with this issues in recent years) [31]; (ii) the energy required to operate the systems [35,36], and; (iii) the brine disposal, primarily in the in-land regions where the release of the water to the sea is hardly economically feasible [37].

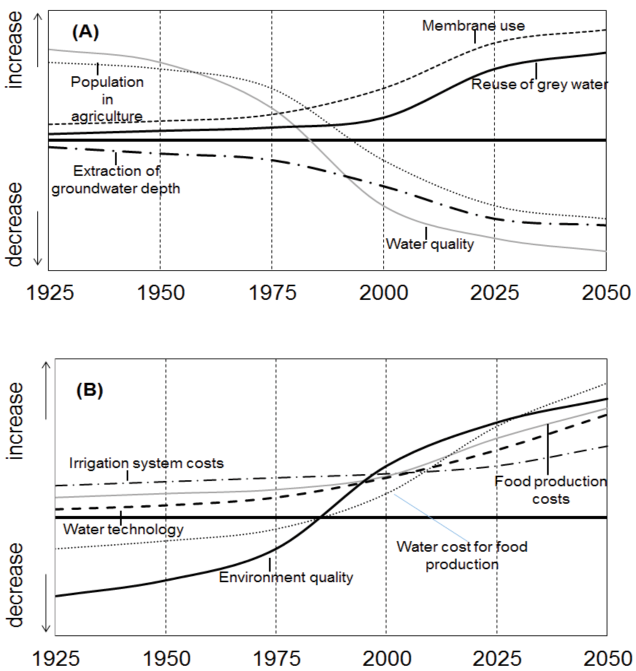


Fig. 1. Anticipated technical and other aspects of reusing of different waters and related developments subject to development: (a) technical aspects and (b) environmental and other issues.

2.2. Synthesizing hydrogen and oxygen to produce new waters

Water can be synthesized by combining hydrogen and oxygen. With a spark, the two elements can react and produce water, and possibly-a big explosion. This topic, of producing new water by a chemical reaction will be discussed only very briefly. The balanced chemical reaction is given by Eq. (1):

$$2\,H_2 + O_2 \rightarrow 2\,H_2O + \text{Heat Demand} \tag{1}$$

3. Screening alternatives for enriching the national water potential

3.1. Alternative solutions to water resources

There are a large number of alternatives to enrich the national water sectors. These alternatives are derived from theoretical studies subject to different developing fields. These fields are based on the anticipated future urban and agriculture demands. The selection of the new water resources to be developed is conventionally based on the severances and possibilities of the expert to assess the control options of these issues. In screening the alternatives for solving water shortage, two main methods are noteworthy: (i) the series of ELECTRE methods, which consists

Bottom of Form

In theory, it is a very simple process to produce water from the combination of hydrogen gas and oxygen gas. "Simple" mixture the two gases together, add a spark or sufficient heat to provide the activation energy and to start the reaction. Mixing the two gases together at room temperature will not do anything; just like hydrogen and oxygen molecules in the air do not react to produce water. Energy must be supplied to break the covalent bonds that hold the H_2 and O_2 molecules together. When the chemical bonds are at adequate conditions to form water, additional energy is released, propagating the reaction, which is a typical exothermic process. Currently, this reaction is in the focus of theoretical studies however, it is not discussed in this work as a practical alternative to produce new waters.

actually from four sub procedures, and; (ii) methods that are based on AHP. Each method has its' own advantages and limitations.

3.2. ELECTRE-III method

The ELECTRE methods (I, II, III, IV, and V (TRiangular Intuitionistic, TRI)) were developed in Europe, mainly by [38]. All methods are based on similar principles however, they differ in types of decision-making and operational aspects. The ELECTRE methods consist of five sub-methods that consider different types of problems to be solved: (i) ELECTRE I, is utilized for adequate decisions selection, for gradual decision-making when the relative importance of the criteria is given; (ii) ELECTRE II, III and IV are applied for ranking problems. ELECTRE II is a relatively old version, ELECTRE-III is applied when it is possible to quantify and to emphasize the differences and importance among the alternatives. ELECTRE III however, is the most popular one and is a mathematical method allowing to outbreak and support solutions in infrastructure engineering projects [39–41]. ELECTRE IV when it is hardly possible to quantify between alternatives [42] and: (iii) ELECTRE V (TRI), is used for assignment problems. In this work ELECTRE-III will be reviewed only shortly for general knowhow however, the AHP method will be elaborated in more details.

3.3. ELECTRE-III procedure

The ELECTRE-III is one of five different ELECTRE methods that were developed by [43]. ELECTRE-III differs from the AHP used in this work, which is based on defining threshold values, which allow blurring the boundaries among competing alternatives ELECTRE-III will be a review shortly:

$$A = A\left(a, b, c, \ldots, n\right) \tag{2}$$

where a, b, c, …, n are the set of finite alternatives (four in this case).

The comparison criteria series is given by (six in this study):

$$G = G\left(g_1, g_2, g_3, \ldots, g_j, \ldots, g_m\right) \tag{3}$$

It is assumed that $m > 3$.

$g_j(a)$ defines the effect of alternative "a" on criterion $g_i \in G$. The greater the value of the criteria the better is the final result. In addition, a performance matrix "M" is defined for $A \times G$. In this matrix $g_j(a)$ is the performance in a row "a" and column j. Actually, $g_j(a)$ expresses the value of alternative "in regards to a specific criterion". It represents the evaluation of the alternative where $a \in A$ for the specific criterion and $g_j(a) \in G$. The calculation depends on the goal of the problem if it thrives to a maximum or a minimum.

The evaluation procedure according to ELECTRE-III is based on a series of functional stages, taking into account threshold values. A binary outranking relation "Z" model is defined. If one assumes (for example) that two alternatives "a" and "b" exists, taken from the set "A", namely four situations can be identified:

- aZb and not bZa: aPb ("P" is for "preferred") ("a" is definitely preferred on "b").
- bZa and not aZb: $aP^{-}b$ ("b" is definitely preferred on "a").
- aZb and bZa: aLb ("a" does not differ from "b").
- Not aZb nor bZa: aRb ("a" cannot be compared to "b")

"L" and "R" indicate no difference and incomparable conditions, respectively.

The outranking relationship Z is constructed considering the set G, Every criterion can be defined for or against the statement aZb. This definition allows defining pseudo criteria with two thresholds which are used for identifying the final preference [38]. The procedure continues, implementing several stages, based on the problem characteristics a series of assumptions and related mathematical equations:

- q_j – the indifference threshold which is defined by a weak value among the alternatives. For example, when one examines the damage due to a strong noise, there exists the lowest value that can be identified.
- v_j – a preference threshold value is defined by a given clear and strong difference between alternatives. If alternative "a" is preferable over the "b" one for a given criterion "g_1", then alternative "a" will be selected.
- The veto threshold is the value at which the given alternatives cease to be relevant for a given criterion. For example, if one has a specific amount of money and the cost of the alternative are above it then this option becomes non-relevant.

With the help of the threshold values the ELECTRE-III defines a series of preference ratios that allow selecting the preferable ones. Different ratios are defined between the alternatives, enabling them to select the intensiveness and preferred alternatives.

3.4. Analytic hierarchy process

The AHP procedure selects the best alternative out of several options, subject to a series of criteria. A group of experts from various disciplines is choosing the preferable alternative subject to a finite number of criteria (e.g. economic; environmental, others). The process allows managers and decision-makers to compare all weighted variables and factors that are involved in the resolutions and to produce a hierarchy of priorities. The procedure takes the views of managers who come from different disciplines and having various views. The AHP also allows the managers to take their independent decisions, regardless of their neighbors, It will ensure that the decision will be hopefully be based on a broad picture of the project under discussion.

The AHP method is based on the outranking of alternatives. Essentially it is based on comparing pairs of values and ranking them in a ladder from one (almost no difference between alternatives) to nine (extremely preferred). Other rankings levels are given according to the following [44]: (2) equally to moderately preferred; (3) moderately preferred; (4) moderately to strongly preferred; (5) strongly preferred; (6) strongly to very strongly preferred; (7) very strongly preferred, and (8) very strongly to extremely preferred. Actually, the use of this ladder is subject to personal background and expertise and her/his personal attitude to the problem under consideration. A group of experts is commonly asked to evaluate the different approaches, each having his own ideas and views, subject his life experience.

Thus AHP is actually a multiple objective optimization approach: a decision-making process that provides a systematic method of considering all the elements of a problem. The method was used to a large extent in different areas of technology [45–49]. It organizes the problem into smaller parts and then only calls for simple pairwise judgments to develop a hierarchy. This hierarchy is subsequently manipulated analytically to produce a final matrix, representing the overall priorities of the alternatives relative to each other. One can make a logical decision based on the pairwise comparisons made between the alternatives and the criteria being used during the decision-making process. It allows managers to make simple comparisons of the factors involved in a decision, thus producing a hierarchy of alternatives. It provides managers with logical and rational decision-making tools based on analytical methods. This eliminates much of the chance that is often confronted with decision-making. It also enables managers to consider both tangible and nontangible factors when constructing the hierarchy. It guarantees that the decision will be based on more than just financial or other measurable characteristics.

This work focuses on the need to produce new waters and to transfer them to fill natural storages (the Sea of Galilee and the Dead Sea) and to produce hydro energy as an alternative green energy source. To some extent, it is associated with different water qualities application (the different qualities correspond to various levels of desalination wastewater treatment). The nanotechnology emphasizes the issues related to sustainable food production and the level of treatment, the best technology for the target country and what is the adequate treatment level subject to the hydrological conditions [11].

3.5. Alternative solutions according to the AHP

The goal of the work is to choose the project that has the best chances to be successful in enriching the Sea of Galilee with high-quality water due to increasing salinity and solving the sinkholes problem in the Dead Sea, jeopardizing the communities in this part of Israel. The method was developed around 30 years ago and the main purpose that it can be applied successfully also to worldwide water resources issues. The six main criteria that were selected for current project evaluation are: (i) cost of project; (ii) benefits of producing new waters; (iii) benefits of producing energy; (iv) benefits from tourism; (v) benefits of regional development, and; (vi) benefits of maintaining natural ecological equilibrium. This selection is conducted in view of the main issues that bother the Israeli general community.

Four options were suggested for solving the issues of water supply in Israel and the Dead Sea sinkholes issue: (Fig. 2): (i) Desalinating seawater within the ocean on special-purpose islands or abandoned ships near the City of Acre (Kibbutz Shomrat) and transporting it to the Sea of Galilee

Fig. 2. Schemes of the alternatives solutions for new water production, energy generation, and the sinkholes issues in the Dead Sea.

(Kinneret), and subsequently releasing water partially into the Dead Sea [50]. This alternative will also enable to generate environment-friendly hydroelectricity near the Sea of Galilee, using sections of the National Water Carrier and will be called "Shomrat–Kinneret, (ShK)"; (ii) Desalination of water from the Mediterranean Sea and transporting it from the City of Haifa via the Beit-Shean Valley to the Jordan River, subsequently via the Jordan River to the Dead Sea and titled "Haifa–Beit Shean, (HaB)"; (iii) Transporting desalinated seawater from an area in the vicinity of the City of Ashkelon via the mountainous area of Judaea directly into the Dead Sea, allowing also to generated hydro energy and titled "Ashkelon–Dead Sea, (AsD)", and; (iv) Transporting desalinated seawater at the Red Sea and transporting it via the rift valley ("Arava") to the Dead Sea, titled "Red Sea–Dead Sea, (ReD)". Alternatively [for option (iv)], the seawater can be desalinated in a middle location within the rift valley ("Arava") (between the Red Sea and the Dead Sea) and the brine can be disposed into the Dead Sea. If only the desalinated brine is disposed into the Dead Sea it might create deposits of choke and gypsum and other problems due to the content of different salts in the Dead Sea and disposed concentrate. Several main advantages and limitations of each alternative are listed in Table 1.

4. Implementation

Modelling with AHP is considered a powerful and flexible multi-objective tool for decision-making that helps in setting priorities and preferences. It allows taking experts from different disciplines and setting them the criteria and letting them make their own decision subject to their experience, understanding and background. This approach allows experts to prioritize quantitatively and enhanced analytical thinking. AHP is designed for the subjective evaluation of a set of alternatives based on multiple criteria and is arranged in a hierarchical structure. At the top level, the criteria are evaluated, and at the lower levels, the alternatives are estimated according to each criterion. The purpose is to provide a vector of weights expressing the relative importance of the elements, helping people to cope with the intuitive, the rational and the irrational, as well as with risks and uncertainties in complex settings.

The decision-maker performs four steps. The first step's setup consists of defining the hierarchy of criteria and elements for evaluation and arranging them as input data for the problem. The second step consists of weighting the alternatives and conducting pairwise evaluation comparisons. It is based on pairwise comparison subject to each single one which is involved in the process. Ratio scales are implemented to represent experts' judgments by integrating values of levels 1 to 9 and their reciprocals (Table 2). The comparisons are placed in a positive reciprocal matrix ($a_{ij} = 1/a_{ji}$), and the comparisons are evaluated in terms of their contribution or effects on the elements in the immediately higher level.

Table 1
Advantages and drawbacks of each alternative of solving the water problems and sinkholes problem in Israel (beyond the costs of the systems)

Name of alternative	Advantages	Limitations
Shomrat–Kinneret (ShK)	• Sea of Galilee (Kinneret) will be filled. • Energy can be generated via hydro-power stations. • Parts of the Water National Carriers can be used.	• Water losses due to transpiration. • Medium cost due to the need to construct some tunnels.
Haifa–Beit Shean (HaB)	• Probably the less expensive option. • Flow by gravitation – less energy demand.	• No filling of the Sea of Galilee. • Poor option for producing energy. • Poor option for energy generation.
Ashkelon–Dead Sea (AsD)	• Strong option for generating energy. • Relatively short distance.	• No filling of the Sea of Galilee. • Very hilly area to pass. Tunnelling will be probably required.
Red Sea–Dead Sea (ReD)	• Flourish the rift valley. • Desalination options and water transfer to Jordan. • Option for producing energy.	• If desalination is maintained along the rift valley and brine is disposed into the Dead Sea there is risk of deposition in the Dead Sea. • High risk of earth quakes. • No filling of the Sea of Galilee. • Damage to the Red Sea.

Table 2
Pairwise comparison of the water quality issues

Criterion	Cost of system	Benefits from water production	Benefits from energy generation	Benefits from tourism maintenance	Benefits from regional development	Benefits from ecological equilibrium	Geometric mean (GM)*	Percentage (fraction)**
Cost*	1.00	0.33	0.50	0.33	1.00	0.20	0.47*	0.067**
Benefits from water production	3.00	1.00	3.00	5.00	1.00	0.50	1.68	0.239
Benefits from energy generation	2.00	0.33	1.00	3.00	0.50	0.50	0.89	0.127
Benefits from tourism maintenance	3.00	0.20	0.33	1.00	0.33	0.20	0.49	0.068
Benefits from regional development	1.00	1.00	2.00	3.00	1.00	1.00	1.35	0.193
Benefits from ecological equilibrium	5.00	2.00	2.00	5.00	1.00	1.00	2.15	0.306
Total	15.00	4.86	8.83	17.33	4.83	3.40	7.03	1.000

* Geometric mean: $GM = (1.00 \times 0.33 \times 0.50 \times 0.33 \times 1.00 \times 0.20)^{1/6} = 0.47$
** Percent (fraction) = (0.47)/(7.03) = 0.067

This is also the ladder of values given to the variables. In the third step, statistical ranking methods are implemented to yield priorities (weights for criteria and for elements). The decision-maker assesses the pairwise comparison matrix $a_{i,j}$, and similarly calculates the eigenvector of the elements v_j. of the matrix. Each eigenvector is normalized so that the sum of entries within it becomes 1.0. In the fourth and last step (evaluation, after recording the preference), the priorities of the elements are arranged by the criteria into composite measures to arrive at a set of ratings for the elements alternatives. Lower level priorities are weighted by comparing to the higher-level priorities until the bottom level is reached. At this stage, the composite priorities (i.e., the overall relative weights of the alternatives, where these weights add up to one) are calculated using the linear additive model.

Subject to available information, talks among stakeholders and available data, a pairwise comparison table related to the Dead Sea and the Sea of Galilee (Kinneret) (Table 2) was generated. The pairwise comparison is based on the ladder as suggested by Saaty (44). According to this ladder, it is obvious that the selection of each alternative depends on a series of personal characteristics of humans, consequently taking a large group of different experts might strengthen and doom the various ideas.

- The first stage is to construct a "pairwise table" comparing the relationship between variables for the various options (Table 2) (note the reciprocal values). This table is constructed according to the tendencies, beliefs, and experiences of each professional involved.
- In the second stage, six tables were defined (in this case according to the number of parameters evaluated) with values according to the parameters which will be used for the comparison of the alternatives. In the above stage, each of the six tables was constructed from the six different points of view. Thus six tables were constructed with pairwise data, comparing the input according to the six parameters, namely the cost of rehabilitating the system, benefits from production of new waters, benefits of generating energy ("green energy"), benefits from creating an advanced system for tourism, benefits from regional development and advantages from creating an improved ecological balance.

Similarly to the data presented herein, six tables were prepared that refer to the variables of characterizing the project (i) cost of project (Table 3); (ii) benefits of producing new waters (Table 4); (iii) benefits of producing energy (Table 5); (iv) benefits from tourism (Table 6); (v) benefits of regional development (Table 7), and; (vi) benefits of maintaining natural ecological equilibrium (Table 8). Each parameter was evaluated according to the four alternative suggested solutions.

- The third stage is to combine all six Tables, 3–8, with the weights as suggested in Table 2. It allows constructing the AHP final summary table (Table 9). It is conducted by taking the last column of each of Tables 3–8 and combining with the related weights which enable us to find out the final priority of each alternative. The preferred alternative receives the value of 0.391 where the second one gets a value of 0.282. The Ashkelon–Dead Sea option is the least preferable option.

5. Conclusions

As indicated, the best alternative for producing new waters, generating hydro energy, recovering the sinkholes

Table 3
Comparison of alternatives under the criterion of system cost

Benefits from costs of system	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	8.00	2.00	7.00	3.25	53
ReD	0.13	1.00	0.14	0.50	0.31	5
ShK	0.50	7.00	1.00	6.00	2.14	34
AsD	0.14	2.00	0.17	1.00	0.47	8
Total	1.77	18.00	3.31	14.50	6.17	100

Table 4
Comparison of alternatives under the criterion of water production benefits

Benefits from new water production	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	6.00	0.50	8.00	2.21	35
ReD	0.17	1.00	0.14	3.00	0.52	8
ShK	2.00	7.00	1.00	9.00	3.35	53
AsD	0.13	0.33	0.11	1.00	0.26	4
Total	3.29	14.33	1.75	21.00	6.34	100

and closing the gaps of water shortage in the Sea of Galilee is to transfer desalinated water from the Shomrat site to the Sea of Galilee. This will allow generating energy subject to the difference in elevation of the Sea of Galilee and the highest point above it (around 370 m). Water from the Sea of Galilee can be subsequently being released into the Jordan River in the direction of the Dead Sea. The water release from the Sea of Galilee will be the trigger to reduce the number of sinkholes and the associated risks. Also, the quality of the water of the Sea of Galilee will improve significantly (salinity reduction) due to the fact that the incoming water is desalinated.

According to Table 9, the best alternative is the link Shomrat–Kinneret (ShK). It is far higher (0.391) than the two closest ones which are around 0.282 and 0,229 for the HaB and the ReD alternatives, respectively. The AHP result even

Table 5
Comparison of alternatives under the criterion of benefits from energy generation

Benefits from energy generation	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	0.11	0.33	0.13	0.26	4
ReD	9.00	1.00	8.00	3.00	3.83	58
ShK	3.00	0.13	1.00	0.14	0.48	7
AsD	8.00	0.33	7.00	1.00	2.08	31
Total	21.00	1.57	16.33	4.27	6.65	100

Table 6
Comparison of alternatives under the criterion of benefits from tourism

Benefits from tourism maintenance	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	5.00	0.33	7.00	1.85	29
ReD	0.20	1.00	0.14	2.00	0.49	8
ShK	3.00	7.00	1.00	9.00	3.71	58
AsD	0.14	0.50	0.11	1.00	0.30	5
Total	4.34	13.50	1.59	19.00	6.34	100

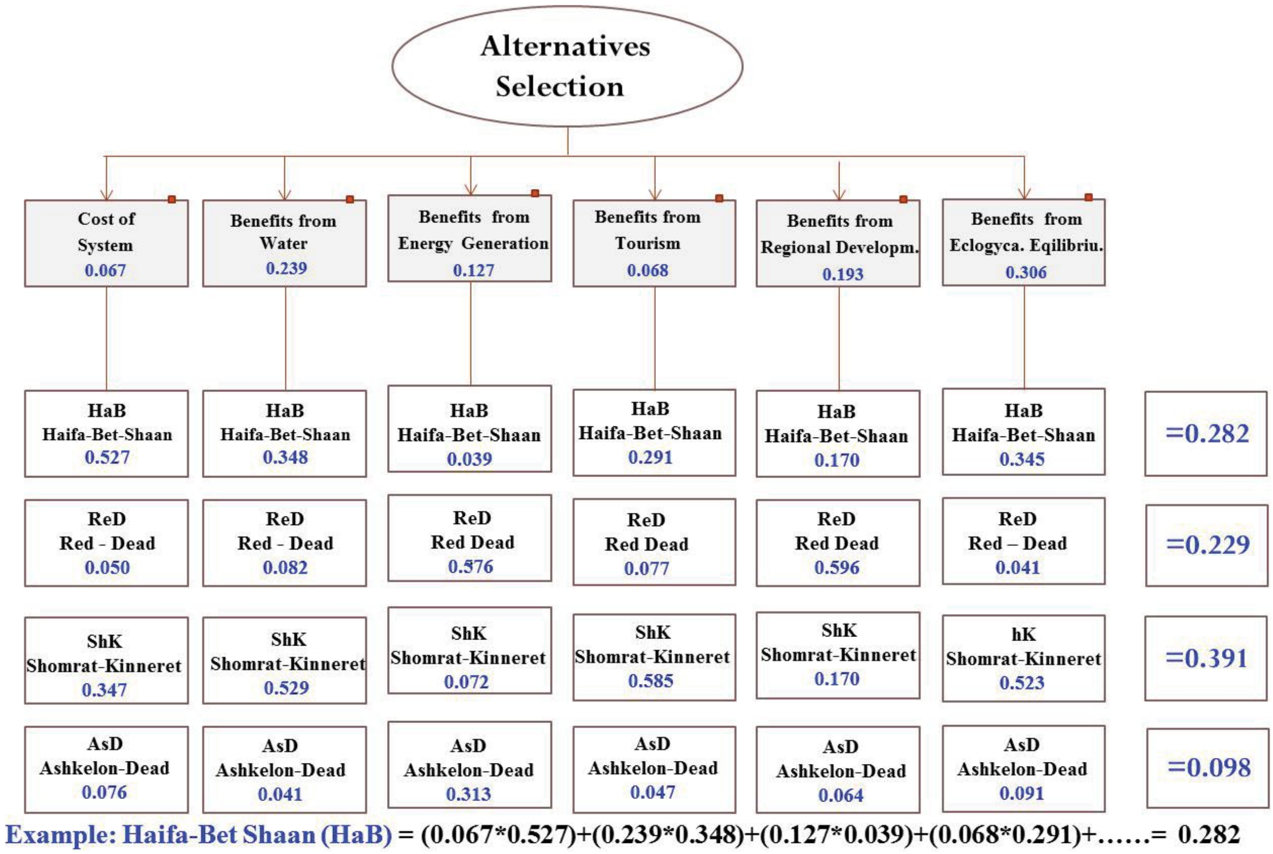
Table 7
Comparison of alternatives under the criterion of benefits from regional development

Benefits from regional development	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	0.25	1.00	3.00	0.93	17
ReD	4.00	1.00	4.00	7.00	3.25	59
ShK	1.00	0.25	1.00	3.00	0.93	17
AsD	0.33	0.14	0.33	1.00	0.35	6
Total	6.33	1.64	6.33	14.00	5.47	100

Table 8
Comparison of alternatives under the criterion of benefits of maintaining ecological equilibrium

Benefits from ecological equilibrium	HaB	ReD	ShK	AsD	Geometric mean (GM)	Percentage
HaB	1.00	8.00	0.50	6.00	2.21	35
ReD	0.13	1.00	0.11	0.33	0.26	4
ShK	2.00	9.00	1.00	7.00	3.35	52
AsD	0.33	3.00	0.11	1.00	0.58	9
Total	3.46	21.00	1.72	14.33	6.40	100

Table 9
Results of the AHP analysis



indicates why the idea of transferring water from the Red Sea should be ruled out. It should not even be considered due to the anticipated damage that might be caused by most of the natural precious objects of the sea of the City of Eilat.

An additional imported result emerges from the work. The issue of trans-boundary water transfer can be treated relatively easy by the AHP. If one takes a group of experts and quantifies the options then it allows treating the low-quality water (by desalination) and transferring it to a neighboring country that suffers from water shortage.

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