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# A New Integrated Portfolio Based Water-Energy-Environment Nexus in Wetland Catchments

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**Abstract**

Increasing demand of vital resources such as water and energy will impose some overwhelming environmental degradation, particularly on wetlands as the most vulnerable bodies of the environment. Consequently, optimization of water and energy portfolios have been widely studied in order to ensure environmental sustainability and to consider the constraints simultaneously. In this study improving the security of portfolios has been performed based on resource security index to find non-dominated portfolios (Pareto Frontier). Non-dominated portfolios as scenarios to remediate water bankruptcy have been developed and probable environmental impacts have been assessed. A new Financial-Environmental Index called Water-Energy-Environment Nexus Security Index (WEENSI) have been utilized through a multi criteria decision making approach to find admiringly compatible non-dominated water and energy portfolios for environmental remediation purposes in the case of the Lake Urmia catchment as an epitome of water bankruptcy situation. Results indicate that portfolio based management approaches could be a desired solution to water bankruptcy and an inspiring option for environmental remediation, particularly in wetland catchments. It has further become known that persisting on the conventional water resources management in this catchment will increase water demand of energy sector up to more than 500 million cubic meters (MCM) in 2060, exacerbating the current critical environmental condition. Also, increasing the share of renewable energies at least up to 40% must be taken into account by managers and policy makers. Broadly speaking, any development of energy sector requires an urgent change in the currently practiced approach and considerable investment in non-conventional energy resources. The increase in primary costs of optimizing and improving the water and energy portfolios may alleviate the anthropogenic impacts with high social costs to the region.

**Keywords** Integrated water resources management · Modern portfolio theory · Multi criteria decision making · Nexus approach · Water bankruptcy · Wetlands

## 1 Introduction

Population growth as an evoking factor of socio-economic development has led to a growing consumption of vital resources such as water and energy. However, some highly overwhelming constraints are going to make serious obstacles for our abilities to keep meeting sustainable developments' goals (Rao et al. 2017). Shortcomings in resources, incompatible consumption behavior, poor decision making, thirst for development, mismanagement and also climate change are only some of the mentioned constraints.

Broadly speaking, wetlands as one of the most vulnerable bodies of the environment are prone to risks of decision makings and further developments in water and energy sectors. As a result, understanding real role of natural systems in decision making process and how they would respond to man-made changes, is one of the main responsibilities for researchers, managers and policy makers (Thorslund et al. 2017). Immediately relevant to this fact is a thought provoking question whether wetlands could survive faced with several existing difficulties, especially of anthropogenic nature (Hu et al. 2017).

To manage and control man-made stresses and climate change, long-term solutions are required to surpass water shortage as well as energy demand management (Dubreuil et al. 2013). Simultaneously, to maximize environmental-financial benefit, water-energy nexus should be considered locally and regionally in the policy making process (Lee et al. 2017). Developing nexus based management strategies needs continuing the process introduced at the United Nations Conference on the Human Environment (UN 1972) and reinforced by two decades of sustainable management experiences (Smajgl et al. 2016). According to a wealth of case studies in Australia, Europe and United States as well as other countries all over the world, recognizing the integrated links between water and energy sectors have been made in order to find regions which need integrated policy makings and have potential for implementing new management strategies (Hussey and Pittock 2012). These innovative integrated strategies have been divided to quantitative and qualitative approaches in some case studies in east Asia by Endo et al. (Endo Endo et al. 2015). California as a water scarce region has been selected as a case study to assess demand management based on improving water and energy sector's efficiency (Cutter et al. 2014). To produce highly valuable treated water from two lower valued resources (brackish groundwater-solar energy or brackish groundwater-wind energy), a new effective approach based on water-energy nexus has been developed to find optimally appropriated points to implement desalination working with wind energy (Clayton et al. 2014) and solar energy (Kjellsson and Webber 2015) in Texas. To cope with shortages, uncertainties and unreliability in availability of water and energy, structure of the proposed strategies should be evaluated in different sectors leading to short-term and long-term solutions with scope of filling unmet demand in both water and energy sectors (Malik 2002).

A wealth of studies have been done in recent years based on nexus approaches throughout the world, including in Asia-Pacific Region (Endo Endo et al. 2015), China (Li et al. 2012) (Fang and Chen 2017) (Li et al. 2016), Myanmar, Zambia and Colombia (Huber-Lee and Kemp-Benedict 2015), India (Malik 2002), USA (Liu 2016), Middle East (Dubreuil et al. 2013), Southern Africa (Conway et al. 2015) and Global (Grubert et al. 2014) (Nair et al. 2014a) (Nair et al. 2014b) (Howells et al. 2013) (Kan et al. 2016) (Garcia and You 2016). All researchers have claimed that population growth, socio-economic development, significantly growing consumption of natural resources, climate change, stress on resources supplies resulting in threats on human-environment security, are the provoking factors which made scientists to develop nexus based approaches. It seems that so many researchers have been assessed different sectors of nexus separately and evaluated existing connections between them. However, urgent need for an integrated water-energy-environment nexus approach in wetland catchments is obviously determined. Wetlands in nexus approach are playing a multiple active key role including role in generating and controlling nexus aspects and simultaneously decreasing probable impacts of them (Everard 2017).

Developing an integrated innovative approach by aggregating optimization and decision making theories would be first step in this case. Therefore, in this study, to develop a solution considering uncertainties of experts (Banihabib and Shabestari 2017), scenario ranking based on evaluative indexes (Geng and Wardlaw 2013), multi criteria decision making theory has been utilized. Also, by taking into account real worth of ecosystem resources and environmental security to evaluate efficiency of different energy sources (Hadian and Madani 2014), assessment of further water shortages (Paydar and Qureshi 2012), evaluating water and energy portfolios with a decision making toolbox (Wicaksono et al. 2017) and insuring sustainability of environment and continuity of societies' development Modern Portfolio Theory (MPT) has been utilized.

## 2 Methodology

### 2.1 Application of Modern Portfolio Theory in Resource Management

Decision making and economic sciences have been utilized to analyze and design demand management tools in integrated water resources management. Particularly, prevalent applications of economic in analysis and planning of water resources. Decisions should be made among so many alternatives based on benefit-cost analysis and multi criteria decision making. Socio-environmental impacts should be considered in a sustainable decision making process. Performance of different alternatives would be assessed by developing scenarios including a portfolio of solutions based on some aggregated evaluation tools (Grigg 2016). To supply requisite water, provide wastewater services and protect the environment, conventional approaches based on planning, analyzing and optimization have given way to holistic portfolio based approaches (Keremane, Keremane et al. 2017). Table 1 presents a brief information of modern portfolio theory applications.

It could be easily understood that the Modern Portfolio Theory (MPT) has been implemented in cases which require study, evaluation and design solutions in large scales as well as utilizing miscellaneous indexes to surpass overwhelming socio-environmental crises.

### 2.2 Schematic Model

Environmental management in catchment scale should be addressed by integration of coupled human-water systems, social issues, economic and uncertainty in decision making considerations (Liu et al. 2008), (Laniak et al. 2013). Therefore, many scientists have tried to develop inspiring approaches for integrated environmental management, especially increasingly growing nexus approaches (Al-saidi and Elagib 2017) which is characterized by interdependency of resources, growing tradeoffs, environmental considerations and so forth (Ringler et al. 2013). Although Integrated Water Resources Management considering basin scale management, stakeholder involvement, demand management and so forth has been widely implemented as a potent approach (Benson et al. 2015), an inextricably linked nexus including environment is required to enhance options to adopt to global change and to take into account miscellaneous drivers of earth systems (de Grenade et al. 2016). Therefore, in this study an integrated portfolio based water-energy-environment nexus approach has been developed and has been implemented to a lake catchment which is an epitome of environmentally degrading catchment engaging all nexus sectors.

The new portfolio based water-energy-environment nexus' schematic is shown in Fig. 1. Steam, gas and combined Cycle thermal power plants, hydro power plants, solar power plants and wind power plants are considered to fill energy portfolios and have been evaluated by some indexes such

**Table 1** A brief information of MPT application

| Case Study | Country | Problem Statement | Solution | Ref. |
|---|---|---|---|---|
| Adelaide | Australia | -Rapid Urbanization<br>-Growing Urban Population<br>-Environmental Issues<br>-Climate Change<br>-Water Delivery | -New Portfolio-Based Approach | (Keremane et al. 2017) |
| Murray-Darling Basin | Australia | -Limited Resources<br>-Climate Change and Variability<br>-Uncertainty | -A New Method Based on Modern Portfolio Theory | (Paydar and Qureshi 2012) |
| Global | Global | -Increasing GHG<br>-Impacts on Water Resources<br>-Impacts on Land Use | -A New Framework Based on Modern Portfolio Theory | (Hadian and Madani 2014) |
| Noorderkwartier | Netherland | -Flood Risk | -MPT | (C. J. H. Aerts, Botzen, and E. Werners Aerts et al. 2014) |
| Melbourne | Australia | -Rapid Population Growth<br>-Urbanization and Development<br>-Climate Change<br>-Unprecedented Drought | -An Alternative Framework to Urban Water Investment Planning, Using a Portfolio Approach | (Zhang 2016) |

as GHG Emission (Farmod 2012), Land Footprint (Hadian and Madani 2014), Water Consumption, Water Withdrawal, Primary Cost and Social Cost (Samadi 2017). Simultaneously, groundwater, surface water, reused water, brackish groundwater and diverted water (for the lake) are considered to fill water portfolios and have been evaluated by Energy Usage (Nair, George, Hector M Malano, et al. 2014) and Cost (Iran Ministry of Energy). Modern Portfolio Theory (MPT) have been used to determine non dominated water and energy portfolios. Consecutively, the produced data have been used as input data for WEAP model and finally environmental evaluation have been made to complete all considered nexus sectors.

### 2.3 Portfolio Based Nexus Model

The new portfolio based nexus model includes Portfolio Model and Water Evaluation and Planning (WEAP) Model which are producing some secondary indexes generating

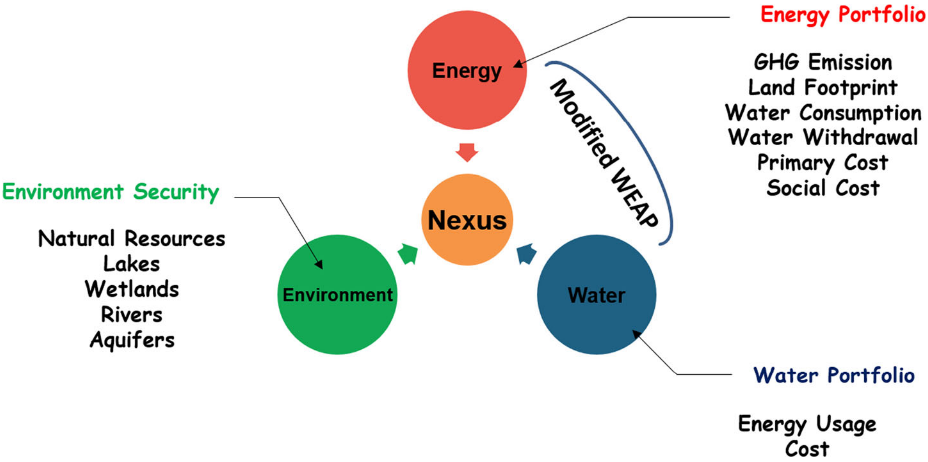


**Fig. 1** Schematic of Portfolio Based Water-Energy-Environment Nexus

final Water-Energy-Environment Nexus Security Index (WEENSI). Details of the model are shown in Fig. 2. Each part have been explained in the following sections.

## 2.4 Portfolio Model

In this model water and energy resources are considered as portfolios which are being evaluated by a new Financial-Environmental Index which is a multiple aggregated index called water security or energy security. To clarify it, an application of MPT have been used to determine non dominated water and energy portfolios as the input data of the WEAP model. In the following, required steps have been explained to determine non dominated portfolios.

First of all, the type of portfolio (water, energy, etc.) should be specified. Then some obstacles should be considered in order to take into account the natural constraints of each case study. Then some random portfolios will be created by the model. Now, each portfolio must be evaluated by the Financial-Environmental Index (resource security index).

For this purpose eq.1 is considered to normalize different indexes.

$$r_{ij} = \frac{a_{ij}}{\sqrt{\sum_{i=1}^{m} a_{ij}^2}} \tag{1}$$

In eq.1 $a_{ij}$ is the non-normalized evaluative index and $r_{ij}$ is the normalized index.

Then, eq.2 is needed to aggregate several indexes and to create resources security index.

$$RSI_i = \sum_{j=1}^{m} W_{a_j} r_j \tag{2}$$

In eq.2 $RSI_i$ is the Resource Security Index, $W_{a_j}$ is index's weight which is obtained by entropy method and $r_j$ is the normalized index.

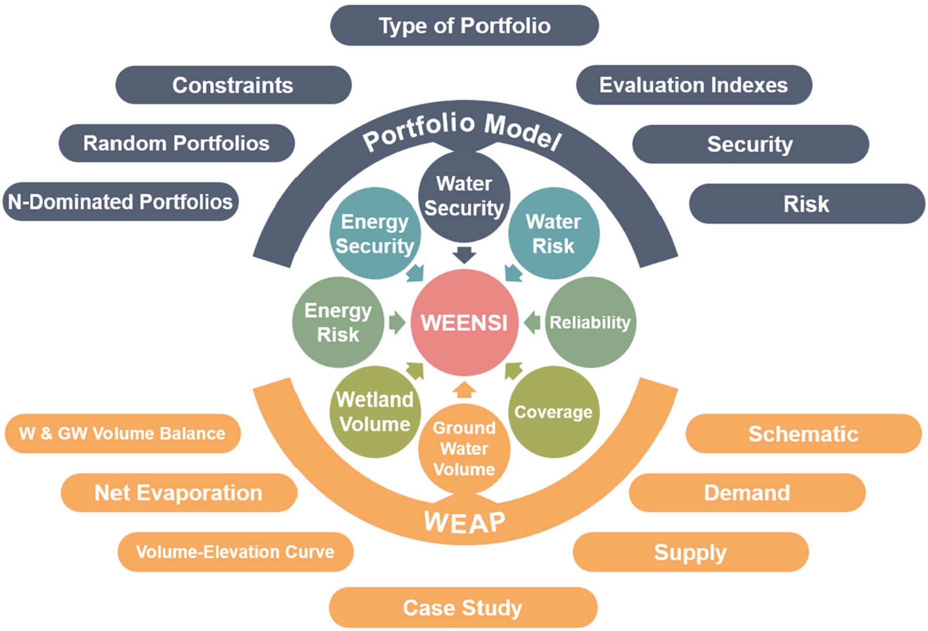


**Fig. 2** Details of the Portfolio Based Nexus Model

Finally, portfolio's security and risk will be created by eq.3 and eq.4.

$$RSI_p = \sum_{i=1}^{n} W_{E_i} RSI_i \tag{3}$$

$$SD_p = \sqrt{Var(ESI_p)} = \sqrt{\sum_{i=1}^{n} w_i^2 \sigma_i^2 + \sum_{i=1}^{n} \sum_{j=1_{i \neq j}}^{n} w_i w_j \sigma_i \sigma_j \rho_{ij}} \tag{4}$$

In eq.3 $RSI_p$ is the portfolio's Resource Security Index and $W_{E_i}$ is weight of each resource's security index. In eq.4 $SD_p$ is the risk of the portfolio, $w$ is weight of each resource in portfolio, $\sigma$ is deviation of each resource and $\rho_{ij}$ is correlation between resources.

In this step Risk-Security (Return) curve of the portfolios could be produced and non-dominated portfolios (Pareto Frontier) could be determined through dividing the length of the curve into finite elements and searching the portfolios having the most quantity of security (return) in each element. The sample Risk-Security curve of the portfolios has been shown in Fig. 3. The upper portion of the line in Fig. 3 represents the most advantageous Risk-Security (Return) combinations with point A representing the portfolio with the lowest risk. Managers and decision makers could move higher than point A to achieve higher Security (Return). However, in this case they should accept higher level of risk (Marinoni et al. 2011).

## 2.5 WEAP

First of all, the case study should be specified and an integrated modeling tool will be required to draw schematic of demand and supply chain. Herein, the WEAP software is

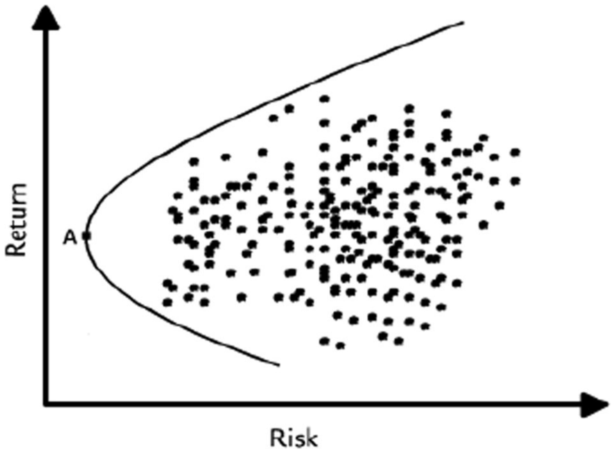


**Fig. 3** Risk-Security (Return) Curve of the Portfolio

used to simulate and consider all requisite features besides the man-made factors involved in Lake Catchment in order to improve the reliability of further decision makings. WEAP is an assistance tool for planners which can be used for different goals such as: analyzing future socio-economic development situation, water resources management (Höllermann et al. 2010) and developing a dynamic simulation in a lake catchments scale in order to evaluate human activities impacts on lakes (Alemayehu, Alemayehu et al. 2010).

After an exact assessment of Lake Catchment features, WEAP software as an integrated modeling tool is used to develop the integrated model of supply and demand chain. It is worth noting that, the lake is simulated as an endorheic one where all surrounding rivers are falling into the lake and there is no surface outflow from the basin. In other words, in this model, all the existing rivers in the basin, converge at one virtual river falling into a reservoir called Lake.

## 2.6 Water-Energy-Environment Nexus Security Index

Finally, water and energy portfolios' risk and security calculated by portfolio model, wetland and groundwater volume variation, reliability and coverage of scenarios (non-dominated water and energy portfolios) calculated by WEAP have been utilized to create Water-Energy-Environment Nexus Security Index (WEENSI), through a multi criteria decision making approach using Entropy and The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) methods, as a new Financial-Environmental Index. Then, WEENSI has been used to order preference of the selected non-dominated water and energy portfolios as scenarios in WEAP. This decision making process would evidently help managers, decision makers and policy makers to attain desired accomplishments based on environmental remediation.

## 2.7 Case Study

Lake Urmia catchment as most regions of Iran is experiencing serious water problems including, drying rivers and wetlands, declining groundwater levels, land subsidence,

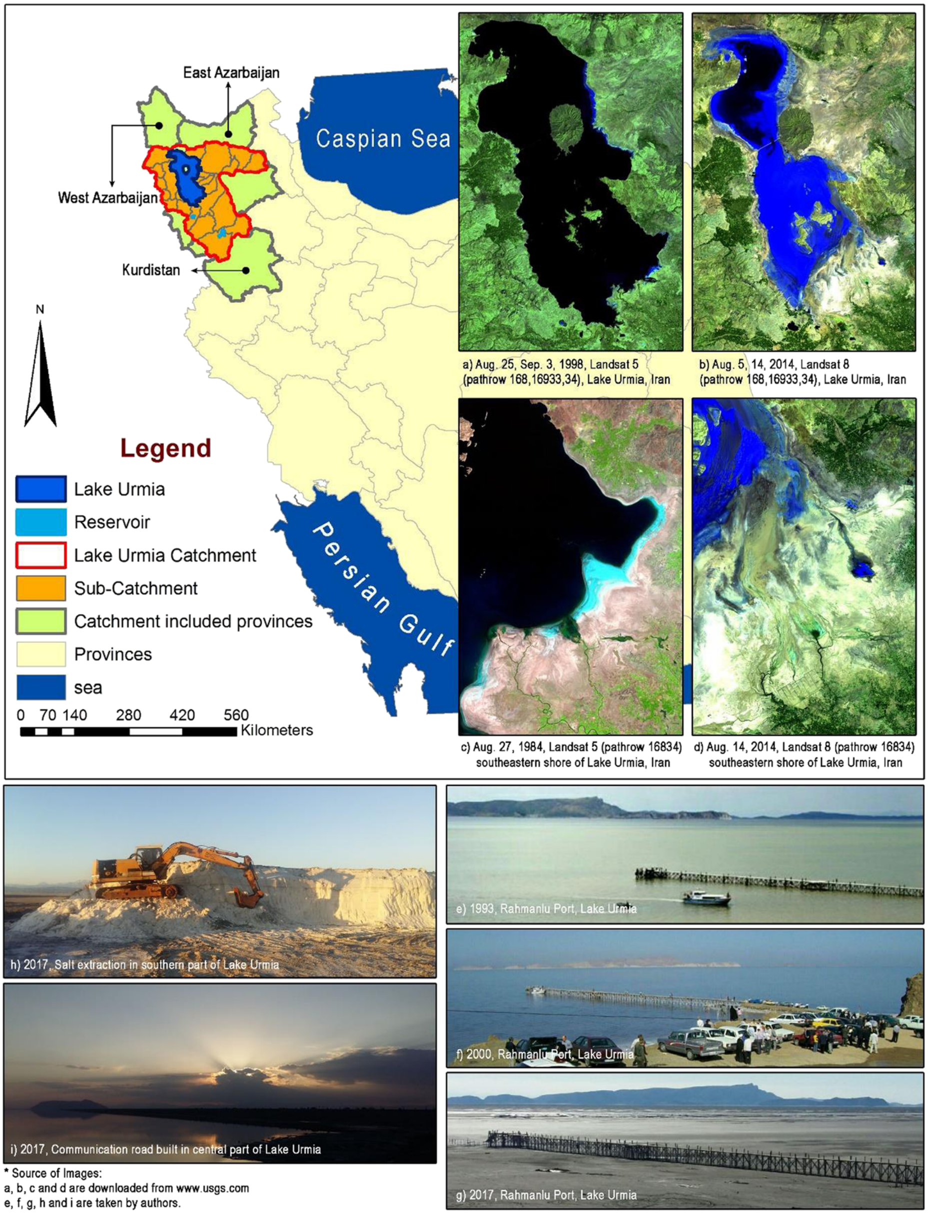


**Fig. 4** Lake Urmia catchment at a glance (*this figure is completely designed by authors)

water quality degradation, soil erosion, desertification and more frequent dust storms (Fig. 4). It could be claimed that the thirst for development in the past decades has forced this catchment to fall in a water bankruptcy (where water demand exceeds the natural water supply) situation, which could be remediated through developing additional sources of water supply and implementing aggressive water demand reduction plans (Madani et al. 2016).

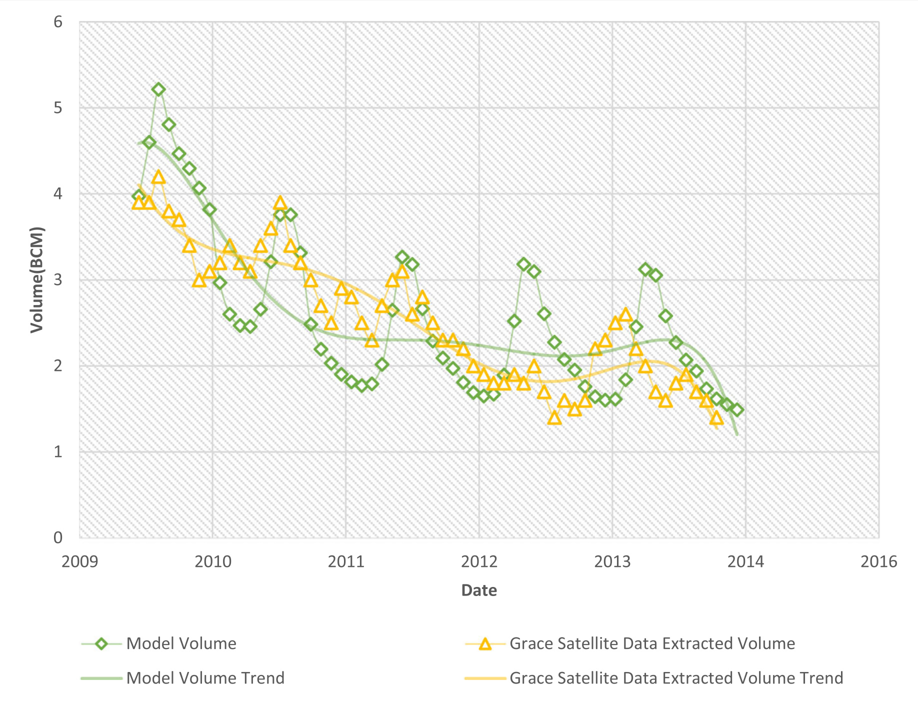


**Fig. 5** Lake Volume Verification

# 3 Results and Discussion

## 3.1 Model Verification

For the purpose of model verification, making a comparison between Lake Volume curves developed by the model and the Grace satellite extracted data (Tourian et al. 2015) is assumed

**Table 2** Results of the Evaluative Indexes of the Energy Portfolios

| Energy Source/ Index | GHG (Kg/ KWh) | Water Consumption (Litr/KWh) | Water Withdrawal (Litr/KWh) | Land Footprint (m2/ GWh) | Cost (€-cent/ KWh) | Social Cost (€-cent/KWh) | ESI |
|---|---|---|---|---|---|---|---|
| Steam | 1.2 | 3.7 | 5.4 | 623 | 6.7 | 4.9 | 46.91 |
| Gas | 1.1 | 3.7 | 5.4 | 623 | 6.7 | 4.9 | 46.91 |
| Combined Cycle | 0.6 | 0.9 | 1.1 | 623 | 6.7 | 4.9 | 56.40 |
| Hydro Power Plant | 0.02 | 0 | 20.2 | 1700 | 4.3 | 3.4 | 63.16 |
| Solar Power Plant | 0.06 | 0.12 | 0 | 1200 | 10.0 | 0.6 | 93.50 |
| Wind Power Plant | 0.015 | 0 | 0 | 2300 | 13.5 | 0.3 | 96.75 |

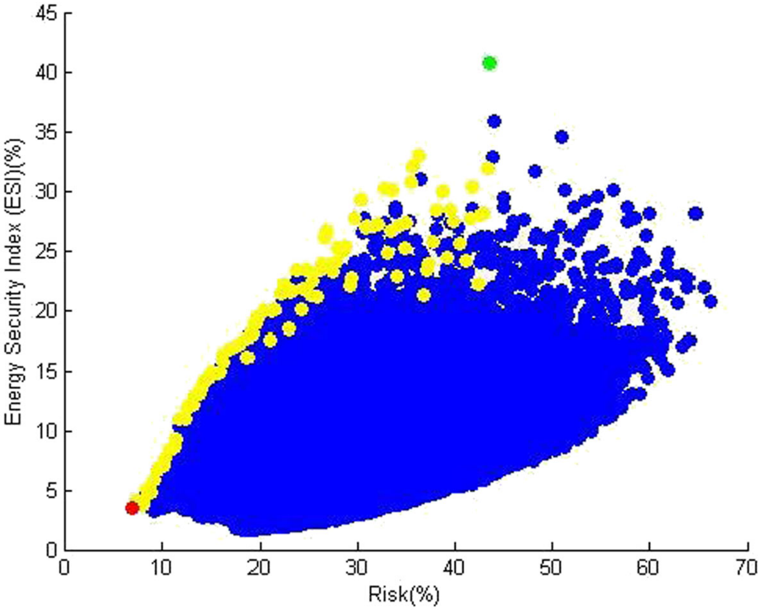


**Fig. 6** Risk-Security Curve of the Energy Portfolios

to be adequate. As seen in Fig. 5, these volume curves have acceptable consistency and the same decreasing trend.

### 3.2 Results of Water and Energy Portfolios

Results of evaluative indexes of energy portfolios show that renewables would be desired assets to modify portfolios by increasing their share. According to the calculated Energy Security Index (ESI) values in Table 2, hydro Power plants are not completely a green option due to high amount of water withdrawal in comparison with solar and wind power plants.

Risk-Security curve of the 100,000 random energy portfolios has been produced as Fig. 6. Those portfolios which have the highest security index (return) for specific quantity of risk (non-dominated portfolios) are shown in yellow. Consecutively, all non-dominated portfolios have generated Pareto Frontier of the Risk-Security curve of the energy portfolios.

To have an assessment on differences between non-dominated portfolios, 11 portfolios have been selected which are shown in Table 4. It is obvious that share of thermal power plants in

**Table 3** Results of the Evaluative Indexes of the Water Portfolios

| Water Source/Index | Energy Usage (KWh/m3) | Cost(€-cent/m3) | WSI |
|---|---|---|---|
| Surface water | 54.84 | 0.24 | 64.71 |
| Ground Water | 55.1 | 0.26 | 61.10 |
| Recycled Water | 54.81 | 0.24 | 64.73 |
| Desalination(Brackish GW) | 58.34 | 0.31 | 54.12 |
| Water Diversion (for Lake) | 54.5 | 0.4 | 40.00 |

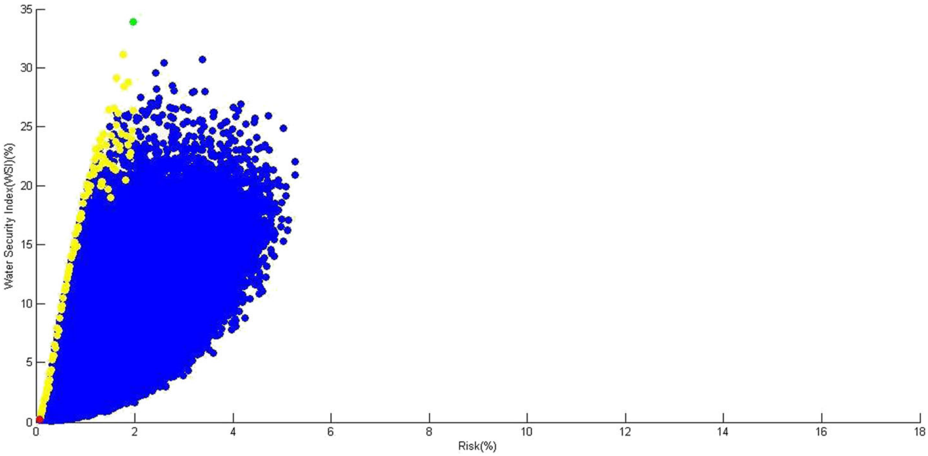


**Fig. 7** Risk-Security Curve of the Water Portfolios without Constraints

the beginning of the Pareto Frontier are relatively high and risk and security quantities are low respectively.

Simultaneously, results of the evaluative indexes, Risk-Security (return) curve and the selected non-dominated water portfolios are shown in Table 3, Fig. 7, Fig. 8 and Table 4 respectively.

In Fig. 7 the existing constraints of the Lake Urmia catchment are not considered and the results show that portfolio curve has enough diversity. However, details show that in some portfolios the share of some assets are not logical with respect to water resources concepts. For example, brackish groundwater share could not be more than 3–4%. Hence, a precise recalculation is required after implementing the constraints to the generating of random water portfolios. New Risk-Security curve of water portfolios with constraints is shown in Fig. 8. New curve shows that there is a sharp reduction in diversity of the portfolios, due to considering the constraints of the reuse water (up to 12–14%), brackish groundwater (up to 3–4%) and diverted water for the purpose of the Lake (logically low).

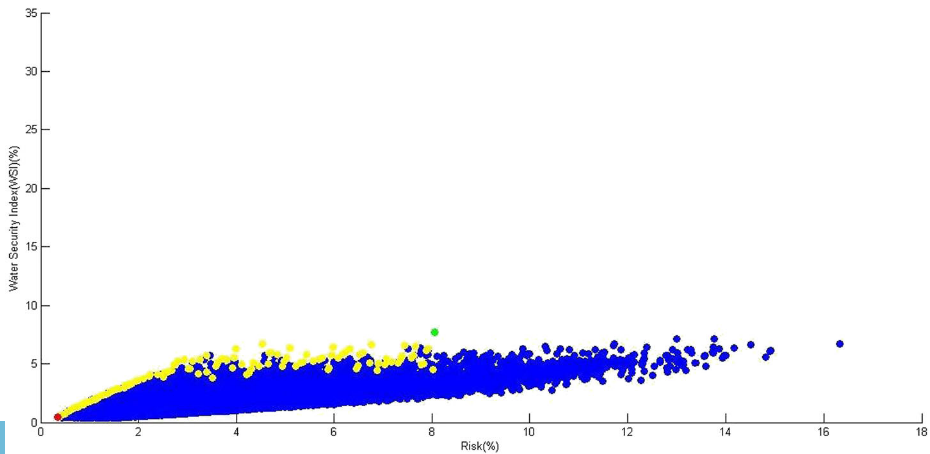


**Fig. 8** Risk-Security Curve of the Water Portfolios with Constraints

**Table 4** Scenarios

| Source\Portfolio\Scenario | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Portfolio | | | | | | | | | | | |
| Surface Water | 0.432 | 0.447 | 0.374 | 0.530 | 0.491 | 0.413 | 0.360 | 0.300 | 0.352 | 0.317 | 0.433 |
| Ground Water | 0.529 | 0.482 | 0.518 | 0.332 | 0.333 | 0.320 | 0.355 | 0.523 | 0.393 | 0.419 | 0.347 |
| Reuse Water | 0.027 | 0.021 | 0.023 | 0.029 | 0.030 | 0.137 | 0.133 | 0.028 | 0.116 | 0.110 | 0.043 |
| Desalinated Brackish Water | 0.001 | 0.001 | 0.002 | 0.003 | 0.003 | 0.006 | 0.007 | 0.012 | 0.017 | 0.020 | 0.020 |
| Diverted Water | 0.012 | 0.050 | 0.083 | 0.107 | 0.143 | 0.124 | 0.145 | 0.137 | 0.121 | 0.134 | 0.157 |
| **Energy Portfolio** | | | | | | | | | | | |
| Steam TPP | 0.3341 | 0.316 | 0.161 | 0.203 | 0.224 | 0.206 | 0.221 | 0.275 | 0.174 | 0.081 | 0.134 |
| Gas TPP | 0.3296 | 0.265 | 0.369 | 0.461 | 0.278 | 0.157 | 0.227 | 0.161 | 0.131 | 0.164 | 0.226 |
| Combined Cycle TPP | 0.2596 | 0.301 | 0.292 | 0.106 | 0.228 | 0.338 | 0.199 | 0.155 | 0.248 | 0.314 | 0.151 |
| Hydro Power Plant | 0.0022 | 0.002 | 0.002 | 0.003 | 0.002 | 0.001 | 0.005 | 0.003 | 0.002 | 0.004 | 0.003 |
| Solar Power Plant | 0.0376 | 0.037 | 0.038 | 0.049 | 0.061 | 0.079 | 0.086 | 0.093 | 0.105 | 0.153 | 0.157 |
| Wind Power Plant | 0.0369 | 0.08 | 0.139 | 0.178 | 0.207 | 0.219 | 0.262 | 0.312 | 0.34 | 0.284 | 0.329 |

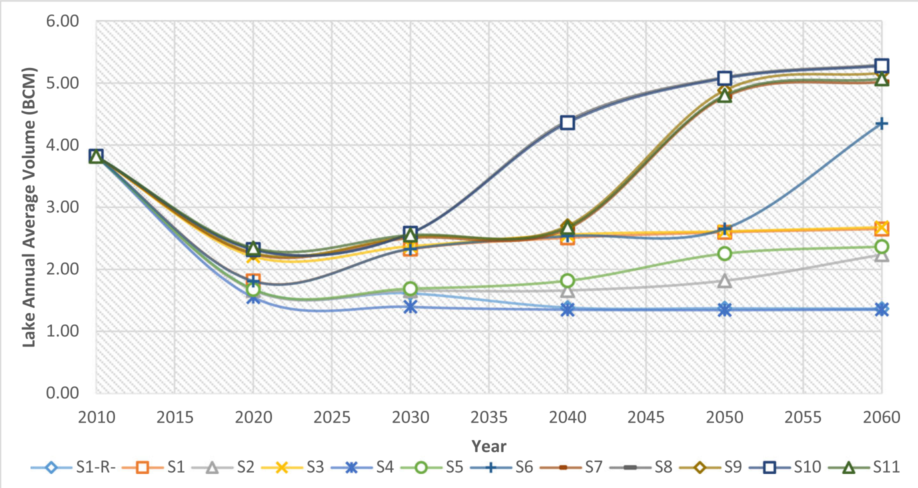


**Fig. 9** Lake Urmia Volume Variation

The reduction in diversity of portfolios has led to a limited range of security. To delineate it more, the range of Water Security Index (WSI) has changed from 0 to 34% in Figs. 7 to 0–8% in Fig. 8. Correspondingly, the range of risk has changed from 0 to 5.5% in Figs. 7 to 0–16% in Fig. 8. Broadly speaking, the low diversity in water portfolios due to water resources constraints has led to low WSI variance in portfolios where successively wider range of risk are calculated by eq.4.

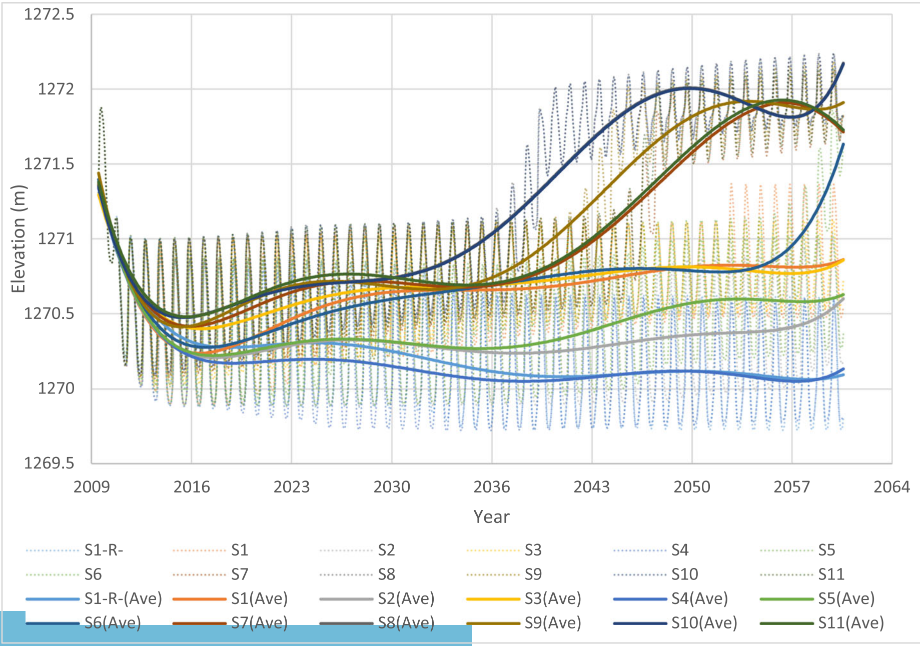


**Fig. 10** Lake Urmia Elevation

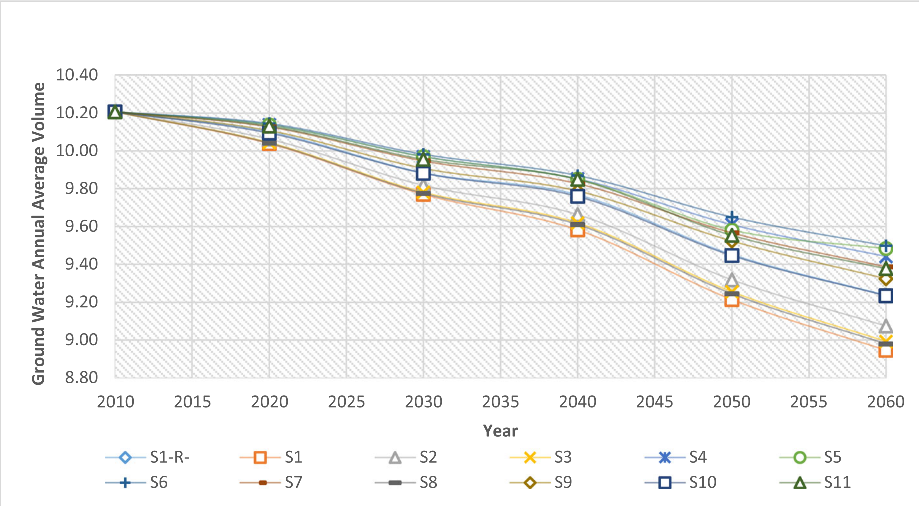


**Fig. 11** Ground water Volume Trend

Selected non-dominated water portfolios shown in Table 4 proved that there is a little asset share changing. However, the little changes in water portfolios would have knock-on effects on environmental bodies such as wetlands and aquifers.

To have an assessment on environmental impacts of water and energy portfolios, 11 scenarios are developed based on selective non-dominated water and energy portfolios which are shown on Table 4. To illustrate it more, 11 portfolio based scenarios are implemented in Lake Urmia Catchment model in WEAP to assess interactions of water-energy-environment sectors and to take advantages of the integrated portfolio management approach in an endorheic lake basin.

Lake Urmia as the biggest wetland in this catchment has been widely studied due to its crucial environment-human interactions in recent years. Lake volume is the most repeated issue in researches or between people and decision makers. Lake volume variation due to different scenarios is shown in Fig. 9.

Obviously, those portfolios with high share of surface water ($S_4$) have led to the volume reduction. In scenario ($S_3$, $S_7$, $S_8$, $S_9$, and $S_{10}$) lake volume is gradually increasing because of

**Table 5** Results of Indexes for Each Scenario

| Index\Scenario | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Security Index (WSI) | 0.49 | 1.99 | 3.32 | 4.27 | 5.74 | 4.95 | 5.79 | 5.50 | 4.86 | 5.35 | 6.29 |
| Energy Security Index (ESI) | 3.57 | 7.73 | 13.44 | 17.23 | 20.03 | 21.20 | 25.32 | 30.22 | 32.93 | 27.50 | 31.85 |
| Ground Water Index | 0.88 | 0.89 | 0.88 | 0.93 | 0.93 | 0.93 | 0.92 | 0.88 | 0.91 | 0.90 | 0.92 |
| Lake Volume Index | 0.43 | 0.58 | 0.70 | 0.35 | 0.62 | 1.14 | 1.31 | 1.39 | 1.35 | 1.38 | 1.33 |
| Reliability | 56.50 | 58.70 | 59.01 | 57.04 | 57.97 | 57.80 | 58.58 | 58.33 | 58.31 | 58.97 | 58.85 |
| Coverage | 80.05 | 80.33 | 80.72 | 80.85 | 80.24 | 79.38 | 80.04 | 79.04 | 80.40 | 80.35 | 81.13 |
| Water Portfolio Risk (W_Risk) | 0.39 | 1.11 | 1.87 | 2.60 | 3.40 | 4.11 | 4.83 | 5.76 | 6.49 | 7.35 | 7.92 |
| Energy Portfolio Risk (E_Risk) | 7.11 | 10.36 | 14.06 | 18.00 | 21.58 | 25.23 | 28.76 | 32.77 | 36.33 | 39.93 | 43.47 |

**Table 6** WEENSI Results

| WEENSI\Scenario | $S_1$ | $S_2$ | $S_3$ | $S_4$ | $S_5$ | $S_6$ | $S_7$ | $S_8$ | $S_9$ | $S_{10}$ | $S_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $WEENSI_1$ | 0.281 | 0.331 | 0.455 | 0.556 | 0.663 | 0.642 | 0.729 | 0.751 | 0.723 | 0.675 | 0.715 |
| $WEENSI_2$ | 0.463 | 0.401 | 0.448 | 0.292 | 0.378 | 0.689 | 0.746 | 0.729 | 0.694 | 0.670 | 0.643 |
| $WEENSI_3$ | 0.628 | 0.643 | 0.663 | 0.627 | 0.605 | 0.552 | 0.521 | 0.468 | 0.424 | 0.364 | 0.375 |
| $WEENSI_4$ | 0.771 | 0.773 | 0.749 | 0.678 | 0.602 | 0.520 | 0.448 | 0.360 | 0.297 | 0.229 | 0.231 |
| Average WEENSI | 0.536 | 0.537 | 0.579 | 0.538 | 0.562 | 0.601 | 0.611 | 0.577 | 0.534 | 0.485 | 0.491 |
| Total Ranking | 8 | 7 | 3 | 6 | 5 | 2 | 1 | 4 | 9 | 10 | 11 |

some modifications in portfolios, including non-conventional water and renewable energy resources' share growth.

Another index which is equally addressed is the lake elevation. Naturally, lake elevation is oscillating during a year due to seasonal inflow variation. Lake Urmia elevation variation under different water and energy portfolios is shown in Fig. 10. Different portfolios effects on the lake could be easily detected in Fig. 10.

Groundwater volume has a completely downward trend under all water and energy portfolios. Fig. 11 shows the impacts of portfolios on groundwater volume. The most important interpretation of Fig. 11 is that Lake Urmia catchment aquifers are being exploited in an unprecedented rate and urgent actions are required to balance and restore aquifers. Moreover, agriculture as the most important consumer of groundwater should be emphasized enough to cope with further conflicts. Food portfolios in the lake catchment should be modified and optimized by some precise Behavioral-Financial-Environmental studies leading to practical solutions such as crop changing scenarios, policy makings and so forth.

Results of indexes for each scenario are shown in Table 5. In order to consider different decision making situations and different priorities of indexes, four types of weighting are produced based on Entropy method. In each type of weighting some indexes have given more

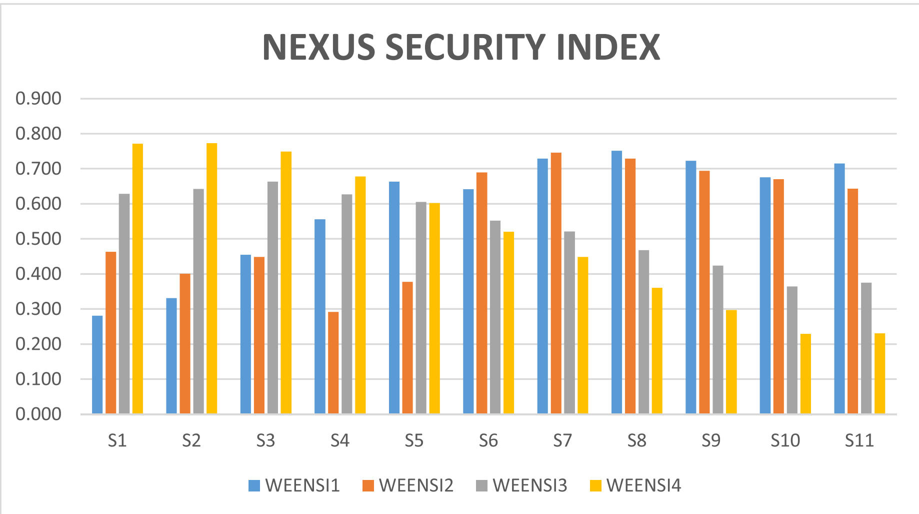


**Fig. 12** Results of WEENSI

priority (in type one RSI's, in type two ground water and lake volume, in type 3 reliability and coverage and in type 4 risks of portfolios).

Finally, WEENSI has been produced by aggregating all indexes. Results of WEENSI are shown in Table 6 and Fig. 12.

According to Fig. 12 Scenarios could be divided into two sections based on the average WEENSI result which is 0.550. Group A (scenarios with WEENSI lower than average score): scenarios $S_1$, $S_2$, $S_4$, $S_9$, $S_{10}$ and $S_{11}$ and Group B (scenarios with WEENSI higher than average score): scenarios $S_3$, $S_5$, $S_6$, $S_7$ and $S_8$. Group A has lower financial-environmental benefit in comparison with Group B. To delineate it more, there is no inspiring positive change based on environmental results. Oppositely, Group B has adequate positive environmental effects. Moreover, Scenario $S_7$ could be considered as the golden scenario in group B due to having desired results in the whole WEENSI types. It means, $S_7$ is the one that would have long-term positive financial-environmental effects with lower risk of water and energy portfolios.

## 4 Conclusion

In this paper, an integrated portfolio based water-energy-environment approach has been developed and implemented to the Lake Urmia catchment. Optimizing and improving water and energy portfolios has been performed to find non-dominated portfolios (Pareto Frontier). Then, environmental impacts of the non-dominated portfolios have been assessed through implementation of scenarios in WEAP model. Results indicate that environmental remediation in wetland catchments will be achieved through a long-term integrated holistic portfolio based management, particularly in Lake Urmia catchment. It has further become known that persisting on the conventional water resources management in this catchment will increase water demand of energy sector up to more than 500 MCM in 2060, exacerbating the current critical environmental conditions. Moreover, designing conventional solutions to surpass conflicts would no longer be effective. Innovative holistic approaches like portfolio based approaches which is suggested and elaborated in this study may be taken into account in order to achieve desired targets.

To moderate existing problems in Lake Urmia catchment and surpass the perplexing anthropogenic conflicts, some urgent actions must be taken. It is a compelling fact that current energy portfolio in the catchment depends on thermal power plants with low financial-environmental security. As a result, renewables' share must be enhanced at least by about 40%. Moreover, current water portfolio in the catchment is consuming surface water and exploiting groundwater in an unprecedented rate. To alleviate perplexing anthropogenic impacts on environmental condition, shares of surface water and groundwater must be decreased at least by 10%~20% and 2%~7% respectively.

To put in a nutshell, governors and decision makers must be aware about the risks, securities and corresponding positive and negative effects of different portfolios. Moreover, such perplexing environmental conflicts require long-term portfolio based management approaches which is utilized in this study. Absolutely, Lake Urmia restoration requires to take a logically acceptable risk of water and energy portfolios improvement to remediate water bankruptcy in this catchment. Nevertheless, the increase in primary costs of optimizing and improving the water and energy portfolios may alleviate the anthropogenic impacts with high social costs to the region.

## Compliance with Ethical Standards

**Conflict of Interest** None.

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