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Identifying representative watershed for the Urmia Lake Basin, Iran

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Abstract Designation of representative watersheds (RWs) as a reference area representing key behavior of the whole region is an essential tool to provide a time and cost-effective basis for monitoring watershed performance against different driving forces. It is more important in developing countries facing lack of necessary investments in one hand and ever-increasing human interventions and need to assess the outcome behavior of the system in another hand. However, this serious affair has been less considered worldwide, in general, and in developing countries, in particular. Therefore, in the present study, a quantitative-based method of Representative Watershed Index (RWI) with potential range from 0 to 100 has been formulated using four important criteria and available national-wide raster data of elevation (meter), slope (%), rainfall erosivity factor (t m ha^{-1} cm h^{-1}), and land use. The approach was then applied to the data prepared for the unique and invaluable global water ecosystem of the Urmia Lake Basin (ULB), north-western Iran, as a case study. The input raster was overlaid via matrices programming in the MATrix LABoratory (MATLAB) 2016 and Geographic Information System (GIS) 9.3 software environments. The RWIs were accordingly computed for 61 sub-watersheds of the ULB. The RWIs resulted from quadri-partite dimensional matrices that varied from 5.54 to 53.46 with respective maximum dissimilarity and resemblance with the entire 61 study sub-watersheds in the region. However, the sub-watershed with RWI of 40.65 (No. 57) was proposed as the final RW for the whole ULB due to hydrological independency, appropriate locality, and existence of functioning meteorological and hydrometric stations. The identified RW would be suggested to be considered as the basis for future insight monitoring and assessing environmental issues for the region eventually leading to an appropriate adaptive watershed management.

Highlights

- Recognizing representative watershed is time and cost-effective for monitoring.
- Different combinations of data layers result in various representative indices.
- We introduced individual representative watersheds for Urmia sub-basins in Iran.

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Introduction

High population and improved technology, particularly in the developing countries and without comprehensive management policies, could damage ecosystems (Sadoddin et al. 2016; Hazbavi and Sadeghi 2017). Comprehensive and systematic management of watersheds is one of the basic strategies to achieve sustainable development (Sadeghi et al. 2009; Raum 2018; Hazbavi et al. 2018a, b). In this regard, integrated watershed management leads to effective utilization of natural resources and alleviate poverty. This key strategy improves sustainable livelihoods, determines priorities, and increases collaboration among the various stakeholders. Finally, it provides the better decisions to achieve short- and long-term development goals (Shotadze and Barnovi 2011; España-Villanueva and Valenzuela-Montes 2017; Khanna et al. 2017). Basically, the process of resources planning is based on integrated watershed resources management. Such underlying processes identify the major problems in the watershed in order to develop and implement appropriate and practical programs (Heathcote 1998; Pravongviengkham et al. 2003; Lee and Chung 2007; Sadoddin 2010; Sadoddin et al. 2010; Terefe et al. 2015; Campbell 2016). However, because of lack of comprehensive studies, no conclusion has been yet achieved about the status of watersheds at a regional scale (Thapa 2000; Sadoddin et al. 2016; España-Villanueva and Valenzuela-Montes 2017). Therefore, it is essential to develop a tool in order to continuously monitor the watersheds' behavior in response to natural and human driving forces helping to implement integrated and adaptive management measures in different temporal and spatial dimensions (Verhoest et al. 2003; Edwards et al. 2017; Nuss and Blengini 2018). To this end, identification of representative watersheds (RWs) with limited numbers and areas for a very vast and sometime inaccessible region/watershed are completely necessary to adopt monitoring system in a manageable and cost effective manner.

The RW is supposed to be a proxy for the entire study region, reference area, bearing a maximum similarity in hydrological, physical, and social-economical behaviors in terms of the number of spatial characteristics (Ebisemiju 1979; Laize 2004). The RW is a candidate for the general situation of the reference area with the most stable conditions in viewpoint of main dominant factors, including climate, land use, soil, and erosion. In addition, they can represent the essential impacts of natural changes and anthropogenic impacts on hydrological regime of the reference watershed (Subbotin 1965; Striffler 1965; Rodier 1976; Anderson et al. 1998; Bradford and Marsh 2003; Holko and Miklánek 2003; Sakthivadivel et al. 2004; Webb 2012; Hannaford et al. 2013; Montenegro et al. 2014; Arsenault et al. 2016; Hillman and Rothwell 2016). Identification of the RW is therefore inevitable for accurate and comprehensive monitoring of the watershed behavior because of the numerous numbers of watersheds, lack of facilities, time-consuming, and costly measurements (AGU 1965; Dortignac and Beattie 1965; Toebes and Ouryvaev; 1970; Laize 2004; Sakthivadivel et al. 2004; Laize and Marsh 2006; Laize et al. 2008; Whitfield et al. 2012; Montenegro et al. 2014). They are also used for intensive investigations of specific problems of the hydrological cycle under relatively stable, natural conditions and fundamental research, different aspects of environmental change effects, hydrological prediction and extension of records (Toebes and Ouryvaev 1970). Thus, identification of RWs can potentially reflect general hydrological features of a given region and their variations over large natural zones with appliances of observation and recording of hydrological and climatological phenomena and represent watersheds located in the same homogeneous or region under consideration (Montenegro et al. 2014). The RW would be used in objective of the evaluation of watersheds for demonstrating sustainable, state-of-the-art watershed planning and management practices (Arbor 2010; Whitfield et al. 2012; Dixon et al. 2013; Montenegro et al. 2014; Raum 2018).

Reviewing of literature shows that the selection of RWs, worldwide, has been often adopted based on qualitative techniques that led to prioritize watersheds. In this context, many studies have been conducted to prioritize different watersheds around the world in various fields of artificial recharge (Moradi Dashtpagerdi et al. 2013; Jaiswala et al. 2015), surface water (Toth 2013; Farsadnia et al. 2014; Naubi et al. 2017), and sediment yield (Altaf et al. 2014; Adhami and Sadeghi 2016; Fallah et al. 2016). Moreover, different tools like Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Multiple Attribute Decision Making (MADM), clustering, Decision Support System

(DSS), Analytical Hierarchy Process (AHP), Geographic Information System (GIS) and Remote Sensing (RS), hydrological models (e.g., Soil and Water Assessment Tool, SWAT; Hydrologic Engineering Center-Hydrologic Modeling System, HEC-HMS), Artificial Neural Network (ANN), Fuzzy Logic, and Reliability-Resilience-Vulnerability (R-R-V) framework were applied for watershed prioritization (e.g., Sadeghi and Singh 2001; Sadeghi et al. 2012; Erfanian et al. 2014; Abdul Rahaman et al. 2015; Erfanian et al. 2015a, b; Makwana and Tiwari 2016; Arami et al. 2017; Narimani et al. 2017; Sadeghi and Hazbavi 2017). Nevertheless, defining the specific algorithm to distinguish the RWs, which are typical in terms of a number of spatial characteristics with the same combination of classes in the region, has not received much attention yet. In this regard, only Laize (2004), Laize and Marsh (2006), and Laize et al. (2008) focused on the quantitative manner for defining RWs in the United Kingdom (UK). In these studies, three characteristics viz. elevation, land use, and soil type datasets were used to designate representative catchment index (RCI). Hereafter, in the present study, we provide RWs as a basis for running the National Mega Research Project on the Integrated Watershed Management (Sadoddin et al. 2016). The study was planned to elaborate, extend, and customize the Laize's approach (Laize 2004) for identifying the RW in the Urmia Lake Basin (ULB). The results of the study would be of great importance to decision-makers and planners at the national level.

Material and methods

Study area

The ULB as one of the most unique and invaluable global water ecosystems (Zarghami 2011; Hassanzadeh et al. 2012) is located in the northwest of Iran, containing east and west Azerbaijan and Kurdistan Provinces. It is limited in 440 7′ to 470 53′ E longitude and 350 40′ to 380 30′ N latitude with a total area of about 52,679 km^2 (Eimanifar and Mohebbi 2007). The ULB is one of the six major hydrological basins (large watersheds) in Iran (Fig. 1).

The ULB has 61 sub-watersheds (Fig. 1) which, in general, are mountainous. However, it has several vast productive lands in the valleys and around the lake. Most parts of the watershed (≈ 85%) are located at altitudes of 1280 to 4886 m above mean sea level. The climate of the study watershed is cold semi-arid climate. The high population growth rate and expansion of agricultural lands in the ULB are supposed as the main driving forces for overexploitation of the water resources and the consequent land degradation in the region (ULRP 2017; Khatami and Berndtsson 2013; DOE 2013; Fathian et al. 2015).

Research methodology

Data augmentation

In order to define the RWs in the ULB, three common, available and oft-used (e.g., Laize 2004; Ghumman et al. 2017; Naubi et al. 2017; Sieber et al. 2018) criteria, namely elevation (meter), slope (%), and land use, were initially selected for sub-watershed characterization. The initial input data were collected and managed from available sources developed for other purposes. In addition, the rainfall erosivity factor (t m ha^{-1} cm h^{-1}) of the (Revised) Universal Soil Loss Equation (RUSLE/USLE) as the most frequently used determinant to estimate rainfall potential to generate soil erosion (Brown and Foster 1987; Renard et al. 1997; Sadeghi and Hazbavi 2015; Panagos et al. 2017) was also used for further assessment due to nation-wide availability, easy accessibility, and acceptable reliability. The rainfall erosivity factor explained an interaction between the kinetic energy of raindrops and the soil surface indicating the potential ability for rainfall to cause soil loss. For the present study, the original map of the rainfall erosivity factor provided by Zabihi et al. (2016) and Sadeghi et al. (2017) and developed based on data from 70 synoptic stations throughout Iran and calculated according to the available literature (Renard et al. 1997; Banasik et al. 2001; Panagos et al. 2017) was applied.

The shapefile and GIS layers of elevation, slope, and land use were obtained from previous research conducted as part of the National Mega Project on the Integrated Watershed Management (Khaledi Darvishan et al. 2017). Additionally, the shapefiles of sub-watershed boundaries were taken from the Ministry of Energy (MOE 2012). It is worth nothing that the internal Urmia Lake water body was not considered as a sub-watershed for the representative watershed index (RWI) calculation.

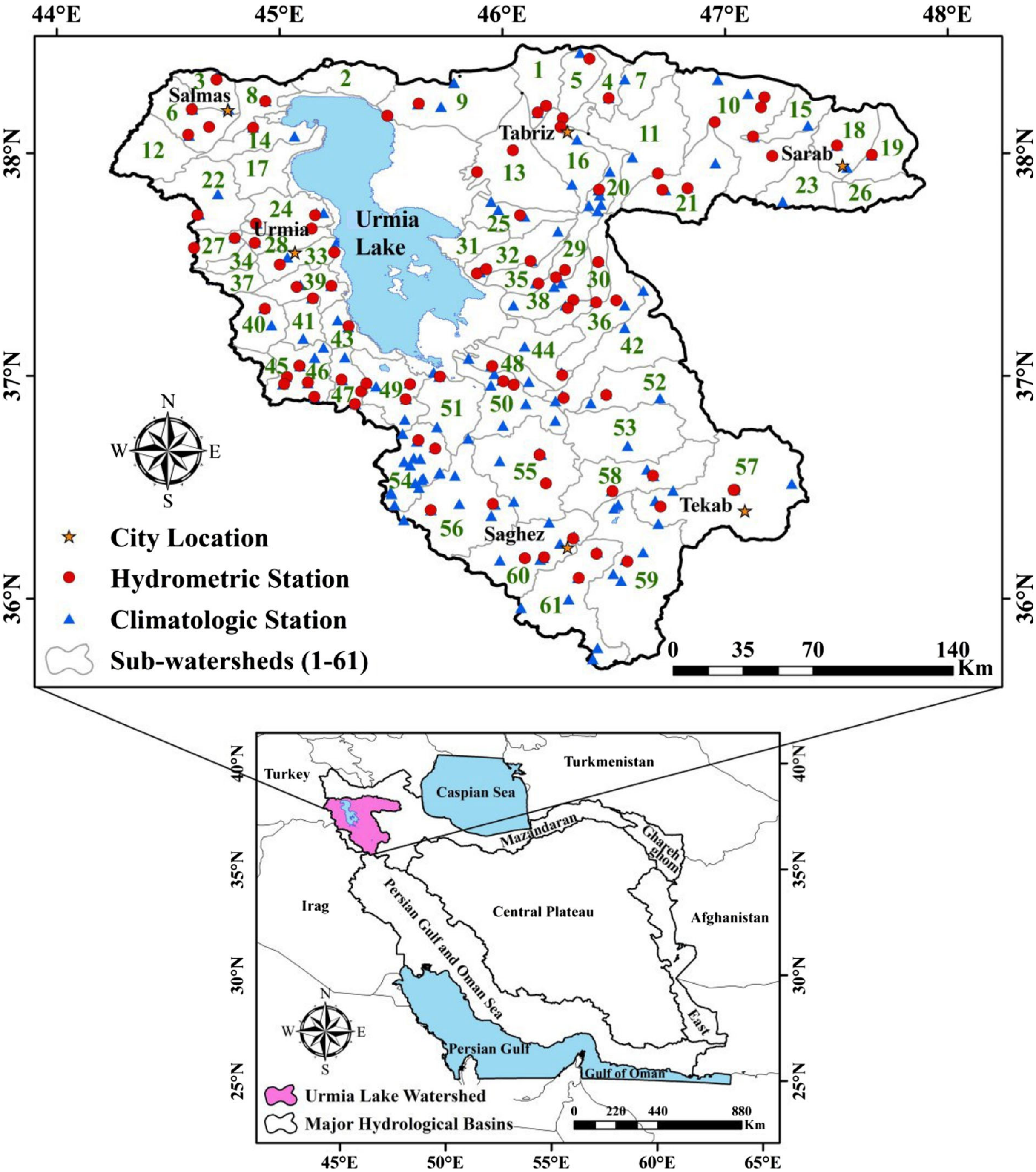

Fig. 1 Distribution of large watersheds (bottom) and distribution of sub-watersheds, climatologic and hydrometric stations (upper) of the Urmia Lake Basin, Iran

The final raster maps of elevation, slope, rainfall erosivity factor, and land use of the ULB with spatial resolution of 30 m (UTM Zone 38N) were illustrated in Fig. 2. As indicated, the elevation of the ULB varies between 1114 and 3730 m with an average of 1722 ± 397.37. The minimum and the maximum slope of the study area was 0 and 57%, respectively, with an average of 7.74 ± 7.76. The rainfall erosivity factor also ranged

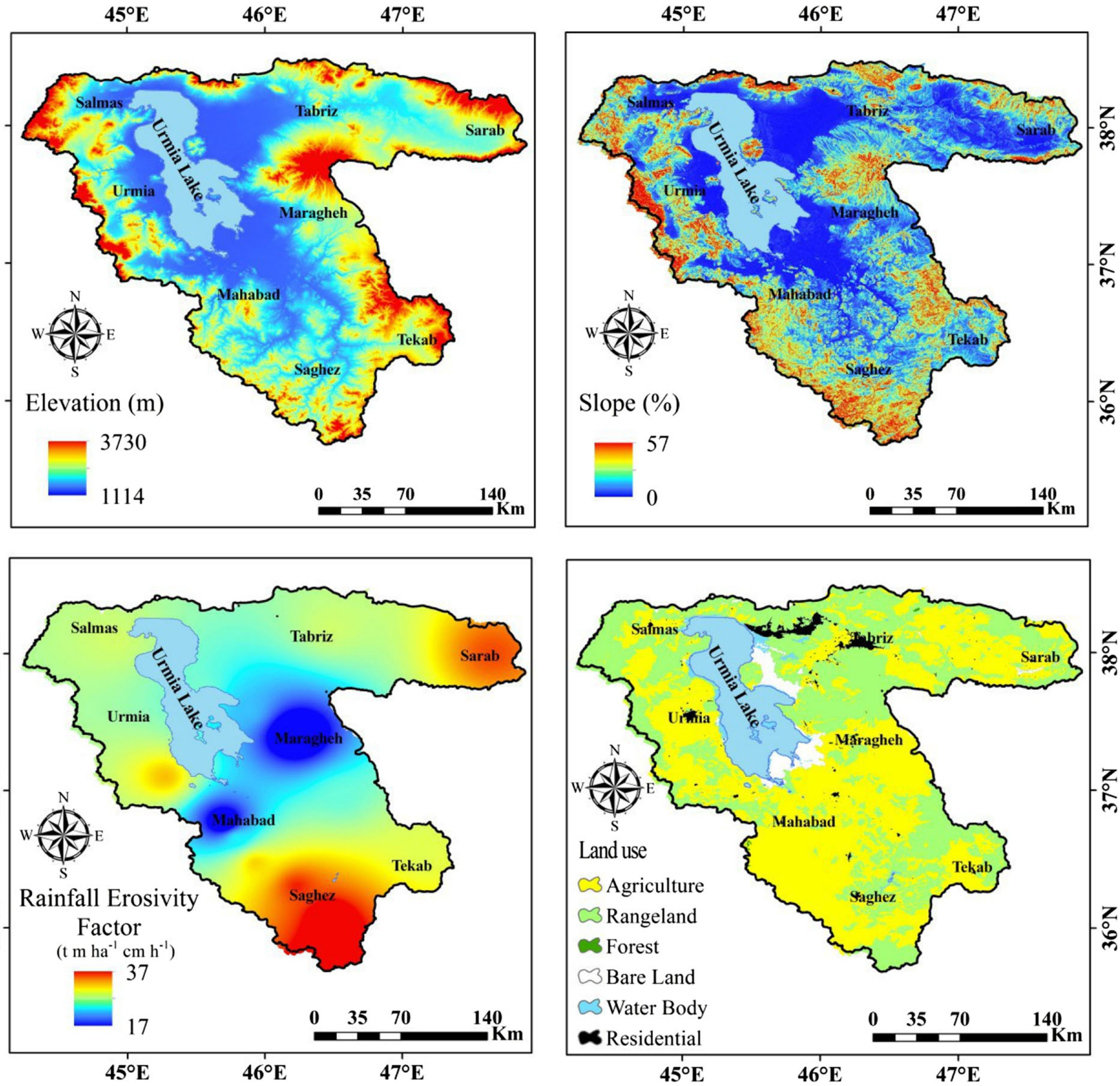

Fig. 2 Elevation, slope, rainfall erosivity factor, and land use maps of the Urmia Lake Basin, Iran

from 17 to 37 t m ha^{-1} cm h^{-1} with an average of 27.29 ± 2.95 for the study period of 1984–2004. The land use distribution of the ULB was categorized into six classes as illustrated in Fig. 2 and characterized in Table 1.

Data pre-processing

Towards identification of the RW, the map scales of all study variables were firstly changed to similar cell sizes (30 × 30 m), coordinate, and equal number of pixels. Secondly, to assess the effect of different arrangements in the dataset classification of the RW identification, the data were reclassified in different categories and methods. Three methods of equal interval, quantile, and Jenks normal breaks classification (Schiewe 2017) were tested for identifying the RWs. Towards this attempt, elevation, slope, and rainfall erosivity factor were preferably generated and categorized with equal interval method in four categories. Elevation classes (class 1: 1114–1768, class 2: 1768–2422, class 3: 2422–3076, class 4: 3076–3730), slope classes (class 1: 0–14, class 2: 14–28, class3: 28–42, class 4: 42–57), rainfall erosivity factor classes (class 1: 17–22, class 2: 22–27,

Table 1 Description of major land use types in the Urmia Lake Watershed, Iran

Land use type	Area (km^2)	Area (%)
Agriculture	24,722.72	56.58
Rangeland	17,929.45	41.03
Forest	25.48	0.06
Bare land	138.60	0.32
Water body	121.54	0.28
Residential	758.77	1.74

class 3: 28–32, class 4: 42–37), and land use layer were used with six categories as explained in Table 1. In this regard, the whole ULB was considered as a reference area (Laize 2004) containing 61 sub-watersheds.

Calculation of representative watershed index

An extended and a customized approach of proposed methodology for description of the similarity among study sub-watersheds (Laize 2004) was applied as background for the calculation of the RWI for the present study. The methodology was optimized and adopted as a pioneer endeavor in Iran with extended input data to provide basic information for other running national megaprojects. The MATLAB 2016 and the ArcGIS 9.3 softwares were used as main environments for RWI calculations and visualization, respectively. The RWI was calculated pixel by pixel for all 61 individual sub-watershed and reference area (i.e., Urmia Lake Basin) with matrix combinations of elevation, slope, rainfall erosivity factor, and land use layers. In fact, a matrix contains the proportion of any given combination of the layers relative to the watersheds and reference area.

To determine the RWI for the ULB, at first, different bi-, tri-, and quadri-partite-dimensional matrices were generated for the study layers of elevation, slope, rainfall erosivity factor, and land use. Numbers of combination of pixels in different classes of layers were then calculated. In order to obtain the value of normalized pixels of the matrices, the number of each combined class was divided by the total number pixels of corresponding layer. Accordingly, the absolute values of differences of normalized pixels for each sub-watershed (D_{sw}) were calculated between compound values of reference ($V^r_{i,j}$) and sub-watersheds ($V^s_{i,j}$) on cell basis of matrix M^s for sth sub-watershed using Eq. (1). The D_{sw} values could potentially vary from zero to two.

$$D_{sw} = \sum_{i,j}\left(\left|V^s_{i,j} - V^r_{i,j}\right|\right) \quad (1)$$

Ultimately, the percentage of the RWI was computed using Eq. (2) as given in the following:

$$RWI = (1 - 0.5 \times D_{sw}) \times 100 \quad (2)$$

The RWI values varied from zero (when the D_{sw} value is equal to two) to 100 (when the D_{sw} value is equal to zero). The RWI of 100 denotes an absolute similarity between the study sub-watershed and the reference watershed. In contrast, the RWI equal to zero shows an absolute disagreement between the sub-watershed under consideration and the main reference watershed. A sample of theoretical calculation of bi-dimensional matrices (i.e., elevation and slope) and the RWI for the sub-watershed 1 with area size of 563.55 km^2 and 621,070 pixels (Fig. 1) of the ULB with 48,743,807 pixels has been shown in Table 2.

Results and discussion

In the present study, a robust approach was developed to identify the RW for the Urmia Lake as a case study using available, easily accessible, and common criteria of elevation, slope, rainfall erosivity, and land use as described in the previous section. The results of bi-, tri-, and quadri-partite dimensional matrices for study layers were summarized in Appendix A (Tables 3 and 4). A threshold of acceptance 90th percentile was also established to examine candidates, which core above the 90th percentile of RWIs.

There were variations in spatial distribution of the RWIs in the study watershed as shown in Fig. 3. Quadri-partite dimensional matrices were used for mapping RWIs for the ULB. Out of 61 sub-watersheds, 23, 36, and 2 sub-watersheds had RWI below 25, between 25 and 50, and above 50, respectively. The highest and the lowest RWI of 53.46 and 5.54 were obtained for sub-watersheds 10 and 38, respectively (Table 4 and Fig. 3). It is further obvious from Tables 3 and 4 that the representativeness index reduced as more variables are incorporated. So, the RWI varied from 8.40 to 94.30, 7.90 to 88.86, and 5.54 to 53.46, with respective mean value of

Table 2 A sample of calculation of representative watershed index (RWI) for sub-watershed 1 of the Urmia Lake Watershed, Iran, based on elevation and slope layers

Layers		Elevation (j)							
		Number of pixels for i-j matrix							
		Reference (whole watershed)				Sub-watershed 1			
	Classes	1	2	3	4	1	2	3	4
Slope (i)	1	23,413,352[a]	8,655,445	973,697	53,884	325,800[a]	103,791	5,163	0
	2	4,870,918	6,606,662	1455329	98,495	71,757	85,820	8,563	0
	3	589,476	1,474,763	424329	34,324	6,176	12,557	1,212	0
	4	20,542	54,089	16,256	1,263	41	187	3	0
	5	250	620	105	8	0	0	0	0
Total Pixels		48,743,807				621,070			
Normalized values of pixels for i-j matrix (Vij)		0.48033[b]	0.17757	0.01998	0.00111	0.52458[b]	0.16712	0.00831	0.00000
		0.09993	0.13554	0.02986	0.00202	0.11554	0.13818	0.01379	0.00000
		0.01209	0.03026	0.00871	0.00070	0.00994	0.02022	0.00195	0.00000
		0.00042	0.00111	0.00033	0.00003	0.00007	0.00030	0.00000	0.00000
		0.00001	0.00001	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Absolute differences between Vij of the whole watershed and sub-watershed 1 (D_{SW} in Eq. 1)		0.04424[c]		0.01045		0.01166		0.00111	
		0.01561		0.00264		0.01607		0.00202	
		0.00215		0.01004		0.00675		0.00070	
		0.00036		0.00081		0.00033		0.00003	
		0.00001		0.00001		0.00000		0.00000	
Total (Σ Vij)		D_{sw}= 0.12499							
RWI using Eq. (2)= (1-0.5× 0.125) × 100 = 93.75 %									

[a] The total number of pixels in the combined layer 11 ($i = 1, j = 1$) for the whole watershed and sub-watershed 1 as exemplified by yellow block boxes

[b] Normalized value of V11 (0.48033 = 23,413,352/48,743,807) or (0.52458 = 325,800/621,070)

[c] Absolute difference between 0.48033 and 0.52458 = 0.04424

56.21 ± 21.05, 47.75 ± 18.00, and 30.41 ± 12.76, for bi-, tri-, and quadri-partite combinations of the desired variables, respectively. However, the variation rates got gradually reduced by increasing the number of variable. It simply verifies the necessity of optimization of the number of affecting factors to obtain the representative watershed for the study area under consideration. Our results demonstrated that the larger sub-watersheds were fairly allocated higher RWI score due to better representativeness for larger proportion of the reference area, i.e., the entire watershed.

For the present study, to select the RW for the ULB, in addition to numerical value of RWI, some other criteria were considered. As mentioned previously, the higher the RWI, the better the status of the sub-watershed for representing the whole watershed. Nonetheless, the RWIs with more than 90th percentile of 44.59 were considered as the basis for exploration and final selection of practically applicable RW in real condition. According to Table 4 and Fig. 3, sub-watersheds 10, 11, 43, 47, 49, and 53 with respective RWI of 53.46, 45.23, 48.30, 47.39, 46.74, and 50.93 stand at top priority of RW candidates in the ULB. Then, the criteria of hydrological independency, availability, and accessibility to hydrometric and meteorological stations and ultimately the general location of the candidate sub-watersheds were considered to select the superior RWs for the ULB. Meticulous scrutinizing Fig. 1 and considering the above-mentioned criteria, the sub-watershed 57 with RWI of 40.65 (Fig. 3) was eventually identified as the superior RW for the ULB. The proposed RW would facilitate the communication and integration for a number of governance-relevant activities at watershed scale.

Different researches approved that the use of systematic approach for RW determination and selection is highly valuable in the continuous monitoring and surveillance of watershed systems (Shotadze and Barnovi 2011; Sherafati 2016), which leads to time and cost-

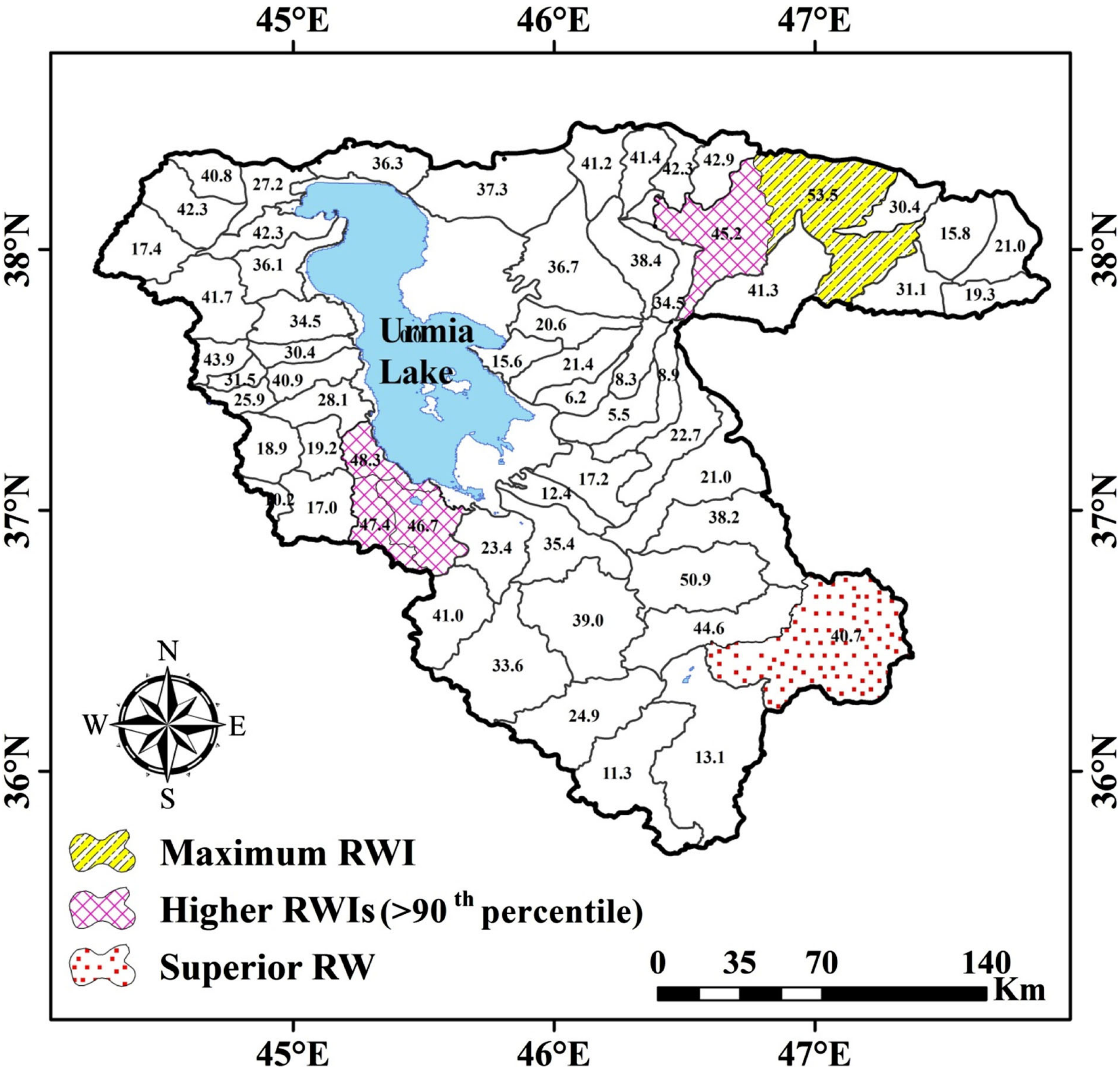

Fig. 3 Spatial distribution of the RWIs in the Urmia Lake Basin, Iran

saving of management implications. In this respect, Lee et al. (2005) used the Representative Elementary Watershed (REW) approach as a basis for hydrological modeling at the watershed scale. The REW was developed based on physically oriented balance equations governing hydrological processes initially introduced by Reggiani et al. (1998, 1999, 2000) in a mathematically rigorous and thermodynamically manner. Due to application of a set of balance equations for the physical quantities of water, momentum, and energy, the REW approach is complicated and not user-friendly. In contrary to REW, the RWI approach developed in the present study is simple, understandable, and based on few and commonly known and available data.

It is of course essential to mention that the RWI results depend on the spatial resolution of input data as highlighted in other researches (e.g., Joris and Jean 2005; Sadeghi et al. 2013; Sadeghi et al. 2015) in connection with characterization of different aspects of watershed processes. The results of the present study were based on the spatial scale of 30 × 30 m for all input maps, i.e., elevation, slope, rainfall erosivity, and land use. Hence, the spatial scale of input variables and number of used classes for each variable in RWI approach are considered as important sources of uncertainty. It is therefore suggested to develop a national data bank to exploit different spatial datasets leading to improved methodologies for selection of representative watersheds. It ultimately facilitates cost-effective, technically efficient, and sound monitoring of the watershed behaviors leading to better management of the watersheds. For continuing development of the RWI approach, it is recommended to use more important raster data, such as soil erodibility factor and geologic information, to draw more comprehensive conclusions. Nonetheless, for the ULB, due to its specific condition and regional/global importance, the results of the present study could help local and global managers, experts, and decision makers allocate appropriate technical and managerial watershed conservation measures.

Conclusion

The developed approach to identify the RWs drew attention to the links between climatologic, physical, and social characteristics in the watershed scale and offered a tool to facilitate integrated watershed management. Using the developed instruction to determine the RWs at the onset affords the monitoring of the watershed systems and successively reduces the cost and time for implementing the management treatments and implications. The RWI scores were successfully calculated based on overlaying the multi-dimensional matrices of elevation, slope, rainfall erosivity factor, and land use layers for the Urmia Lake Basin. The representative sub-watershed 57 was ultimately selected out of 61 sub-watersheds existing in the whole watershed. It is accordingly recommended that the watershed management authority in regional and national scales and even the running projects like the National Mega Project on the Integrated Watershed Management in Iran and Urmia Lake restoration programs would focus on the behavior of the selected sub-watershed as a representative of the Urmia Lake Basin to monitor and assess the effects of natural and anthropogenic driving forces on the outcome of the watershed. Further equipping and instrumentation of the representative watershed is also strongly advised for better monitoring of the watershed behavior facilitating practical adoption of adaptive watershed management.

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Appendix

Table 3 Comparison of representative watershed index (RWI %) in bi-partite dimensional matrix combinations of the study determinant variables for the Urmia Lake Watershed, Iran

Sub-watershed no.	Elevation Slope	Elevation Rainfall erosivity	Elevation Land use	Slope Rainfall erosivity	Slope Land use	Land use Rainfall erosivity
1	93.75	51.52	69.41	53.07	72.59	51.82
2	84.10	52.31	64.14	53.14	65.75	49.38
3	87.11	52.30	81.90	53.14	82.71	52.12
4	80.08	56.06	66.79	53.14	67.07	52.61
5	80.51	54.57	62.58	53.14	62.82	48.73
6	86.45	52.41	74.15	53.14	81.67	52.11
7	78.31	51.16	71.48	53.14	87.19	51.42
8	59.90	33.13	61.61	47.55	66.14	52.06
9	76.69	48.80	69.12	53.14	73.38	52.24
10	82.82	38.04	79.46	52.15	77.20	37.83

Table 3 (continued)

Sub-watershed no.	Elevation Slope	Elevation Rainfall erosivity	Elevation Land use	Slope Rainfall erosivity	Slope Land use	Land use Rainfall erosivity
11	90.72	52.44	88.72	58.36	90.20	51.80
12	43.88	25.82	28.63	53.14	42.97	27.22
13	78.34	52.44	74.94	45.78	66.18	52.24
14	84.80	49.68	77.24	53.14	84.59	51.56
15	64.48	19.76	54.45	53.14	68.65	19.69
16	87.97	52.44	55.03	72.53	56.11	39.92
17	91.57	49.55	53.48	53.14	58.39	42.04
18	66.87	19.83	63.33	69.78	91.93	19.69
19	65.44	33.04	66.13	20.75	89.65	34.80
20	68.93	52.44	56.70	69.86	76.72	52.12
21	73.69	64.38	81.10	53.13	80.38	63.67
22	82.73	52.30	82.29	53.14	85.21	51.37
23	86.29	19.83	75.41	53.14	75.53	19.80
24	67.71	38.57	66.54	54.21	72.64	51.67
25	88.88	50.62	71.46	24.43	72.86	58.38
26	75.27	31.31	62.15	37.23	73.19	33.70
27	67.16	61.72	64.79	61.26	59.07	56.39
28	60.77	32.84	56.32	59.28	66.64	39.67
29	57.92	9.66	50.07	26.39	64.08	25.54
30	82.85	15.59	81.17	26.39	87.51	18.37
31	71.97	41.27	40.95	24.43	52.15	39.94
32	83.12	11.68	58.58	26.39	58.42	11.67
33	74.65	46.64	68.04	70.17	69.40	41.81
34	82.58	54.29	74.57	59.68	75.59	41.16
35	84.44	12.61	80.58	26.21	78.14	12.57
36	81.35	18.29	65.41	24.43	65.76	18.17
37	66.93	18.48	71.00	23.87	66.77	18.35
38	65.79	12.15	66.20	25.03	63.99	12.64
39	69.19	57.52	56.23	46.39	64.63	56.22
40	83.18	34.90	85.53	20.47	86.03	34.29
41	65.14	23.54	67.11	57.36	74.56	24.50
42	73.19	57.91	62.04	28.00	62.91	39.53
43	76.39	36.54	76.46	68.48	84.19	37.61
44	52.15	11.32	53.36	21.36	52.37	12.74
45	35.24	22.14	47.24	20.47	50.47	34.56
46	94.30	19.83	90.26	72.89	90.06	19.69
47	73.40	41.31	72.82	54.96	86.76	42.45
48	48.36	8.40	44.75	19.13	38.85	10.61
49	67.02	58.63	66.60	69.79	86.04	75.38
50	56.56	42.18	57.16	38.87	59.09	46.78
51	65.95	42.63	58.75	28.18	68.76	44.86
52	70.26	52.30	69.66	57.14	82.71	51.48
53	87.91	53.42	85.76	62.84	92.52	54.44
54	66.43	73.61	59.06	58.67	37.90	50.78

Table 3 (continued)

Sub-watershed no.	Elevation Slope	Elevation Rainfall erosivity	Elevation Land use	Slope Rainfall erosivity	Slope Land use	Land use Rainfall erosivity
55	66.83	38.75	56.56	69.13	66.28	44.34
56	79.98	39.98	56.36	79.09	47.57	35.81
57	60.27	50.04	60.97	68.17	87.68	66.35
58	90.21	68.85	71.80	61.71	72.40	66.94
59	80.35	14.96	79.52	20.47	78.39	15.04
60	82.10	21.14	77.30	20.47	67.63	21.87
61	64.62	14.94	81.31	20.47	67.64	15.03
Min.	35.24	8.40	28.63	19.13	37.9	10.61
Max.	94.30	73.61	90.26	79.09	92.52	75.38
P90	87.97	57.52	81.31	69.78	87.51	56.22

Table 4 Comparison of representative watershed index (RWI %) in tri- and quadri-partite dimensional matrices combinations of the study determinant variables for the Urmia Lake Watershed, Iran

Sub-watershed no.	Area (km^2)	Elevation Slope Land use	Elevation Rainfall erosivity Land use	Slope Rainfall erosivity Land use	Elevation Slope Rainfall erosivity Land use
1	563.55	68.96	47.91	50.63	41.22
2	562.82	61.86	44.87	48.17	36.29
3	372.81	78.76	47.93	50.44	40.81
4	330.94	66.77	45.68	49.63	42.27
5	423.09	62.06	45.09	45.25	41.39
6	677.21	74.11	49.42	52.77	42.29
7	444.01	70.62	48.27	52.13	42.93
8	426.52	56.26	33.83	47.27	27.16
9	1321.99	66.73	45.58	49.25	37.28
10	1961.41	75.54	49.43	51.51	**53.46**
11	1244.78	86.01	52.79	57.72	**45.23**
12	763.02	28.58	19.33	25.99	17.38
13	1304.86	72.35	44.53	44.85	36.66
14	451.98	74.05	49.76	52.29	42.25
15	409.59	54.45	44.49	51.43	30.44
16	755.32	52.76	41.97	46.46	38.37
17	573.14	53.11	38.24	40.79	36.08
18	690.40	63.25	55.29	69.12	15.79
19	543.20	62.00	20.74	20.60	21.00
20	361.50	53.64	37.01	55.39	34.49
21	1062.21	73.36	52.68	52.46	41.34
22	946.22	79.81	49.32	52.08	41.72
23	544.74	70.65	46.22	46.24	31.14
24	584.21	63.75	39.86	53.04	34.49
25	456.06	70.03	24.40	24.40	20.64

Table 4 (continued)

Sub-watershed no.	Area (km^2)	Elevation Slope Land use	Elevation Rainfall erosivity Land use	Slope Rainfall erosivity Land use	Elevation Slope Rainfall erosivity Land use
26	422.79	62.08	33.96	31.51	19.28
27	308.91	58.12	54.30	54.66	43.92
28	289.42	56.14	35.68	44.33	30.41
29	307.84	50.04	7.90	12.31	8.27
30	496.66	79.34	25.82	25.96	8.91
31	327.88	40.01	18.00	19.26	15.65
32	592.18	58.48	23.37	23.95	21.44
33	390.99	65.33	49.57	50.47	40.89
34	152.57	70.42	44.76	46.28	31.49
35	312.88	78.92	21.05	21.22	6.15
36	723.55	64.51	22.74	23.28	22.66
37	317.99	60.72	22.95	23.70	25.89
38	541.83	62.02	23.35	24.36	5.54
39	472.83	56.19	31.94	35.00	28.14
40	555.93	81.27	20.34	20.37	18.88
41	328.89	61.82	51.90	56.90	19.22
42	1169.32	61.55	23.73	24.18	20.95
43	364.87	71.41	57.91	66.51	**48.30**
44	665.96	49.04	18.63	21.32	17.20
45	222.17	35.07	15.92	20.30	10.15
46	704.09	88.86	59.88	67.47	17.01
47	452.01	71.98	45.22	54.36	**47.39**
48	359.70	39.37	15.29	16.82	12.43
49	720.12	64.48	54.10	61.82	**46.74**
50	816.98	54.26	35.29	38.02	35.40
51	681.38	58.69	23.44	27.43	23.36
52	1089.67	69.09	44.13	53.02	38.15
53	1160.90	84.09	57.54	62.41	**50.93**[a]
54	828.85	49.98	47.01	41.02	41.02
55	1447.88	56.53	47.15	52.24	38.97
56	1441.97	53.32	44.05	45.38	33.59
57	2428.71	59.63	48.53	66.15	40.65
58	1070.33	71.80	46.53	50.10	44.59
59	2056.69	76.72	19.96	20.39	13.10
60	1184.92	75.12	18.87	20.31	24.91
61	1434.57	64.42	20.19	20.38	11.31
Min.	152.57	28.58	7.9	12.31	5.54
Max.	2428.71	88.86	59.88	69.12	53.46
P90	1333.248	78.92	52.79	57.72	44.59

[a] Bold figures are RWIs greater than 90th percentile of the highest RWI

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