Derivation mathematical equations to estimate water surplus and groundwater recharge in Iraq

Hussein Ilaibi Zamil Al-Sudani¹

Received: 12 June 2019 / Accepted: 13 March 2020 / Published online: 23 March 2020
© The Author(s) 2020

Abstract

Climate and hydrological conditions in any hydrological basin are multi-combined reflection of natural factors of morphology and soil nature, as well as the changing in climate factors that affect directly the hydrological cycle. The water balance equation for any natural area or water body indicates the relative values of inflow, outflow, and change in water storage for the area or water body. Estimation of water surplus and natural groundwater recharge in Iraq depending on water balance equation and meteorological data was the aim of this research. Corrected potential evapotranspiration were compared with annual and monthly rainfall in (32) meteorological stations to obtain actual evapotranspiration using water balance equation. Water surplus was divided into runoff and natural groundwater recharge where runoff coefficient method was used to estimate runoff. The obtained mathematical relationship between rainfall with both water surplus and actual evapotranspiration can be used to estimate these two parameters directly from rainfall. The results indicate that water surplus increased toward northeast direction of Iraq, while the minimum values of runoff and groundwater recharge located in western desert of Iraq. The climate conditions of desert were the major influence on reducing rainfall and rising temperature resulting decreasing water surplus, runoff, and groundwater recharge.

Keywords Derivation mathematical equations · Water surplus estimation · Runoff and groundwater recharge · Iraq

Introduction

Climate and hydrological conditions in any hydrological basin are multi-combined reflection of natural factors of morphology and soil nature, as well as the changing in climate factors that affect directly on hydrological cycle (Al-Sudani 2018a).

The hydrology section is divided into two main components, surface water and groundwater, where hydrologic cycle which occurs continuously in nature is the water transfer cycle (Subedi and Chávez 2015).

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by

the change of water storage (UNESCO 1971). Knowledge of the water balance assists the prediction of the consequences of artificial changes in the regime of streams, lakes, and groundwater basin (Sokolov and Chapman 1974). Classical method of water balance calculations considers precipitation on the input side and runoff, evaporation, and infiltration on the output one. It aims at the best estimate possible of the water balance components with the simplest formulation and the minimum set of input data (Al-Sudani 2019a). The water balance equation can be expressed as follows (Domemico and Schwartz 1998):

$$\text{Input} - \text{output} = \text{change in storage.} \quad (1)$$

Rainfall is the only input element in the water balance, where set of outputs as evaporation, transpiration, and consumption. Evaporation reflects the loss of water from water surfaces or soil, while transpiration and consumption are a process of water evaporation from plants, these two processes are called potential evapotranspiration (PE), which reflected the water losses with abundant quantity of water that exist in the basin area, and it can be calculated by specific equations, while actual evapotranspiration (AE) can be

✉ Hussein Ilaibi Zamil Al-Sudani
dr.hussein_alsudani@yahoo.com;
150098@uotechnology.edu.iq

¹ Petroleum Technology Department, University of Technology, Baghdad, Iraq

determined when quantity of water is limited (Al-Sudani 2018b). The second element of the water balance is soil moisture content, which depends on soil type, texture, and depth. This element affects on surface runoff and ground-water recharge, which represent the last elements of the water balance (Al-Sudani 2018b). One of the most important outcomes in water balance equation for any natural area or water body is evapotranspiration, and it is also a crucial component of hydrologic cycle (Abdullah et al. 2014). It can be defined as combination of two separate processes through which, water is lost from the soil surface via evaporation process and from the crop by transpiration (Allen et al. 1998). Thornthwaite method is one of the significant methods used to estimate the potential evapotranspiration (PE) that is based on the monthly average temperature. This method can be appropriately used in arid and semiarid regions (Henderson 2012). Potential evapotranspiration can be calculated by applying following formula (Al-Sudani 2018b):

$$PE = 16 \left[\frac{10tn}{J} \right], \quad (2)$$

$$J = \sum_{i=1}^{12} j, \quad (3)$$

$$j = \left[\frac{tn}{5} \right], \quad (4)$$

$$a = 0.016J + 0.5, \quad (5)$$

where PE is potential evapotranspiration, J heat index, j coefficient monthly temperature ($^{\circ}\text{C}$), a constant, and tn average monthly temperature ($^{\circ}\text{C}$).

Prediction of monthly evapotranspiration can be obtained depending on observed monthly average temperatures at a meteorological station in each year, despite the fact that this formula is shown by many researches to underestimate (PE), and it has been accepted widely around the globe (Vangelis et al. 2013).

Using meteorological data to calculate water balance in Iraq depending on Thornthwaite method is the aim of this research. The water balance will predict water surplus and water deficit. The calculation of water balance will facilitate hydrological studies of lakes, river basins, and groundwater basins outcomes as well as reducing cost and time.

Iraq is sited between latitude (29.00° – 37.22° N) and longitude (38.45° – 48.30° E), while climate of Iraq is generally as continental and subtropical semiarid type, whereas the mountainous regions are classified a Mediterranean climate. It is characterized by a very hot summer and a short cold winter and also by the breadth of the daily and annual temperature because of the lack of large water bodies that reduce the coldness of winter and summer heat (Al-Sudani 2019b).

Several pervious studies and researches were used meteorological data within Iraqi locations either for estimating water balance or other different purposes. Some of these researches were applied locally, while others researches were applied in large basins of Iraq as mentioned below:

- Hydrogeological System of Debagah Basin In North of Iraq (Al-Sudani 2003).

Table 1 Geographical position of meteorological stations in Iraq (Al-Sudani 2019a)

Location of stations		Name of station	Station no.	Location of stations		Name of station	Station no.
Long.	Lat.			Long.	Lat.		
444300	323300	Ainaltamer	1	433600	354500	Makhmoor	17
471000	315100	Amarah	2	430900	361900	Mosul	18
415700	342800	Anah	3	441900	315900	Najaf	19
450400	325500	Azizyah	4	421500	320200	Nukhaib	20
414400	360200	Baaj	5	461400	310500	Nasiriyah	21
455700	330600	Badra	6	410100	342300	Qaim	22
441400	331400	Baghdad	7	420600	364800	Rabiah	23
432900	345600	Baiji	8	430900	332700	Ramadi	24
474700	303400	Basrah	9	401700	330200	Rutba	25
445900	315900	Diwaniyah	10	435300	341100	Samaraa	26
460300	321000	Hai	11	451600	311800	Samawah	27
442700	322700	Hilla	12	415000	361900	Sinjar	28
440100	323700	Karbalaa	13	422900	362200	Tel-Afer	29
443200	335000	Khalis	14	434200	343400	Tikrit	30
452600	341800	Khanaqin	15	443900	345300	Tuz	31
442400	352800	Kirkuk	16	360900	440000	Erbeel	32

Fig. 1 Distribution map of meteorological stations in Iraq

- Water Balance of North Erbeel Basin (Al-Shamma et al. 2007)
- Calculating of Groundwater Recharge using Meteorological Water Balance and Water level Fluctuation in Khan Al-Baghdadi Area (Subedi and Chávez 2015).
- Climatic Water Balance and Hydrogeological characteristics of Lailan Basin, Southeast Kirkuk, North of Iraq (Al-Kubaisi and Rasheed 2018).
- Study of Morphometric properties and Water Balance using Thornthwaite method in Khanaqin Basin, East of Iraq (Al-Sudani 2018b).
- Investigation of Water Balance Methods of Haqlan Basin in the Western Region of Iraq (Saud et al. 2016).
- Groundwater system of Dibdibba sandstone aquifer in south of Iraq (Al-Sudani 2019c).
- Assessment of groundwater resources in Iraq and management of their use (Jawad and Ridha 2008).
- Temperature—Potential Evapotranspiration Relationship in Iraq Using Thornthwaite Method (Al-Sudani 2019a).
- Hydrogeological Investigations for sector 9.5th Stage, Badra-Jassan Region, East of Iraq (Al-Sudani et al. 2000).
- Derivation Mathematical Equations for Future Calculation of Potential Evapotranspiration in Iraq, a Review of Application of Thornthwaite Evapotranspiration (Al-Sudani 2019b).
- Estimation of Water Balance in Iraq using Meteorological Data (Al-Sudani 2019d).
- Rainfall Returns Periods in Iraq (Al-Sudani 2019e).

Material

The materials used in this research were:

1. Annual and monthly temperature and rainfall records for (32) meteorological stations with their geographic coordinates from date of station operation until 2016 (Iraqi Meteorological Organization and Seismology 2015).

Table 2 Mean rainfall, (PEc), (AE), and (WS) in meteorological station in Iraq

St. no.	Ave. sum of rainfall (mm)	Ave. sum of potential evapotranspiration (mm)	Ave. sum of actual evapotranspiration (mm)	Ave. sum of water surplus (mm)	water surplus %	Duration (years)
1	92.469	1579.066	72.88234	19.58666	21.18	20
2	178.687	2318.14	103.6623	75.02467	42	35
3	142.529	1388.118	97.11806	45.41094	31.86	38
4	117.814	2014.677	82.7288	35.0852	29.78	15
5	229.04	1361.543	112.2714	116.7686	50.98	17
6	204.843	2330.101	108.4218	96.42122	47.07	15
7	136.702	1674.369	92.2237	44.4783	32.5	66
8	199.6981	1697.278	116.6699	83.02824	41.57	30
9	144.805	2132.123	102.3255	42.47953	29.33	67
10	112.441	2033.104	84.34017	28.10083	25	38
11	139.17	2139.199	96.59776	42.57224	30.6	68
12	108.981	1773.72	80.0853	28.8957	26.51	25
13	103.4592	2087.377	76.60349	26.85571	25.95	38
14	162.6836	1511.515	106.5557	56.12789	34.5	17
15	308.659	1751.833	140.8596	167.7994	54.36	60
16	376	1662.425	152.2042	223.8048	59.52	68
17	306.914	1792.035	143.459	163.455	53.2	19
18	372.995	1327.295	148.0522	224.9428	60.3	70
19	94.05	2185.641	73.0197	21.0303	22.36	40
20	72.1554	1579.066	63.18704	8.96836	12.42	20
21	119.4807	2257.156	90.5997	28.881	24.17	73
22	140.624	1383.538	98.24673	42.37727	30.13	20
23	367.12	1122.652	160.1051	207.0149	56.39	31
24	110.512	1515.101	86.3939	24.1181	21.82	25
25	116.65	1182.171	93.06902	23.58918	20.22	35
26	151.5433	1845.079	101.488	50.05526	33.03	26
27	104.682	2242.733	78.98249	25.69951	24.55	38
28	389.308	1399.499	153.8117	235.4963	60.5	42
29	322.8445	1464.71	139.7751	183.0694	56.7	25
30	181.878	1910.049	104.8913	76.9867	42.32	24
31	254.026	1768.054	136.522	117.504	46.25	17
32	449	1488.116	305.302	143.697	32	40

2. Thornthwaite formula (Thornthwaite 1948).
3. Water balance equations (Al-Sudani 2018b, 2019a; Domemico and Schwartz 1998).
4. Runoff coefficient method (Garg 2013).
5. Excel, Grapher, and Surfer programs demonstrating tables of results and contour maps and figures.

The method adapted in this article depends on empirical methods belong to Thornthwaite formula. The basic assumption considered that temperature is an excellent parameter of the evaporative influence of the atmosphere. This method became very common due to limited data requirements (Mohammed and Scholz 2017).

Annual and monthly air temperatures of 32 meteorological stations distributed in Iraq used to calculate potential evapotranspiration (PE) using Thornthwaite method. These stations were divided according to Iraqi geographic latitude from (30–31) in the south to (36–37) in the north of Iraq, Table 1 Fig. 1. Calculated potential evapotranspiration (PE) was compared with temperature in all stations located in the same sector. Statistical approach was used to identify the types of equations for each group of stations using Grapher program. Finally, Surfer program was used to demonstrate contour map of heat and corrected potential evapotranspiration (PEc) in Iraq.

Fig. 2 Contour map of annual summation of rainfall in Iraq

Methodology

Temperature as a key factor controlling on potential evapotranspiration (PE) can be obtained by using data recorded in meteorological stations. Thirty-two stations were used all over Iraq, where annual and monthly air temperatures were adopted to calculate potential evapotranspiration (PE) using Thornthwaite method. The results of corrected potential evapotranspiration (PE_c) were compared with annual and monthly rainfall in each station to obtain actual evapotranspiration (AE) using water balance equation. Water surplus was divided into runoff and natural groundwater recharge where runoff coefficient method was used to estimate runoff depending on Eq. (1) mentioned above which can be rewritten as follows:

$$\begin{aligned} \text{Rainfall (P)} - [\text{evaporation (E)} + \text{transpiration (T)} \\ + \text{evapotranspiration (ET)} + \text{soil moisture (So)} \\ + \text{runoff (Rof)} + \text{groundwater recharge (GWR)}] \\ = \text{change in storage } (\Delta S). \end{aligned} \quad (6)$$

Finally, excel and Surfer programs presented results and demonstrate contour map of rainfall, water surplus (WS), runoff, and natural groundwater recharge in Iraq.

Results and discussion

Using Thornthwaite formula (Thornthwaite 1948) given in Eqs. (2–5) previously, the monthly corrected potential evapotranspiration (PE_c) was calculated after using correction factor of sunlight duration and number of day light according to latitude. Table 2 shows the mean annual rainfall, (PE_c), (AE), and water surplus (WS) in each meteorological station in Iraq. Depending on Table 2, the mean annual summation of rainfall in (32) stations is demonstrated in Fig. 2, while Fig. 3 shows the distribution of actual evapotranspiration (AE) in Iraq.

It seems that mean annual summation of rainfall has a symmetrical increasing pattern from southwest toward northeast according to increasing ratio of rainfall due to

Fig. 3 Contour map of actual evapotranspiration (AE) in Iraq

impact of Mediterranean climate condition on Iraq. On the other hand, the distribution of actual evapotranspiration (AE) as shown in Fig. 3 has a similar pattern of rainfall distribution. Since actual evapotranspiration depends directly on water excess during calculating water balance, and whenever potential evapotranspiration was less than rainfall, the actual evapotranspiration will be equal to potential evapotranspiration which will produce water surplus. Whenever potential evapotranspiration was greater than rainfall, the actual evapotranspiration will be equal rainfall producing water deficit (Subedi and Chávez 2015; Al-Sudani 2018b, 2019a, d).

Figure 4 shows the obtained water surplus contour map in Iraq depending on water balance equation. The map shows the same pattern of rainfall distribution and actual evapotranspiration regarding increased values toward northeast

direction of Iraq. The water surplus depends directly on both rainfall and actual evapotranspiration.

A mathematical relationship between mean annual of rainfall with both annual summation of water surplus and annual summation of actual evapotranspiration was obtained as shown in Fig. 5. The coefficient of determination were (99.2%) and (95.37%) for the first and second relationship, respectively. These two relationships can be used to obtain water surplus or actual evapotranspiration directly from mean annual rainfall as they are the major outputs of water balance equation.

Runoff coefficient method (Garg 2013) was used to calculate runoff by applying following formula:

$$Q = KP, \quad (7)$$

Fig. 4 Contour map of annual water surplus (WS) in Iraq

Fig. 5 The relationship of rainfall versus (WS) and (AE)

where Q runoff P precipitation and K a constant having a value less than (1) or at most equal to (1).

The value of K depends upon the imperviousness of the drainage area. Its value increases with the increase in imperviousness of the catchments area and may approach unity (1.0) as the area becomes fully impervious. The value of K depended on roof type and was estimated as (0.1) depending on Muhaimed et al. (2014). Table 3 shows water balance components as actual evapotranspiration (AE), water surplus (WS), runoff, and groundwater recharge. Figure 6 shows contour map of annual runoff, while Fig. 7 shows contour map of annual groundwater recharge in Iraq.

As shown in both Figs. 6 and 7 the minimum values of runoff and groundwater recharge located in southwest direction of Iraq (western desert). These values were calculated depending on water balance and water surplus which indicate that climate conditions of desert area. These conditions

Table 3 Water balance component as (AE) and (WS), runoff, and groundwater recharge

St. no.	Ave. sum of rainfall (mm)	Ave. sum of actual evapotranspiration (mm)	Ave. sum of water surplus (mm)	Ave. sum of runoff (mm)	Ave. sum of ground-water recharge (mm)
1	92.469	72.88234	19.58666	9.2469	10.33976
2	178.687	103.6623	75.02467	17.8687	57.15597
3	142.529	97.11806	45.41094	14.2529	31.15804
4	117.814	82.7288	35.0852	11.7814	23.3038
5	229.04	112.2714	116.7686	22.904	93.8646
6	204.843	108.4218	96.42122	20.4843	75.93692
7	136.702	92.2237	44.4783	13.6702	30.8081
8	199.6981	116.6699	83.02824	19.96981	63.05843
9	144.805	102.3255	42.47953	14.4805	27.99903
10	112.441	84.34017	28.10083	11.2441	16.85673
11	139.17	96.59776	42.57224	13.917	28.65524
12	108.981	80.0853	28.8957	10.8981	17.9976
13	103.4592	76.60349	26.85571	10.34592	16.50979
14	162.6836	106.5557	56.12789	16.26836	39.85953
15	308.659	140.8596	167.7994	30.8659	136.9335
16	376	152.2042	223.8048	37.6	165.7935
17	306.914	143.459	163.455	30.6914	132.7636
18	372.995	148.0522	224.9428	37.2995	187.6433
19	94.05	73.0197	21.0303	9.405	11.6253
20	72.1554	63.18704	8.96836	7.21554	1.75282
21	119.4807	90.5997	28.881	11.94807	16.93293
22	140.624	98.24673	42.37727	14.0624	28.31487
23	367.12	160.1051	207.0149	36.712	170.3029
24	110.512	86.3939	24.1181	11.0512	13.0669
25	116.65	93.06902	23.58918	11.665	11.92418
26	151.5433	101.488	50.05526	15.15433	34.90093
27	104.682	78.98249	25.69951	10.4682	15.23131
28	389.308	153.8117	235.4963	38.9308	196.5655
29	322.8445	139.7751	183.0694	32.28445	150.7849
30	181.878	104.8913	76.9867	18.1878	58.7989
31	254.026	136.522	117.504	25.4026	92.1014
32	449	305.302	143.697	44.9	98.79771

was the major influence on rising temperature resulting increased values of potential evapotranspiration which effect directly on actual evapotranspiration. The opposite influence of these conditions leads to reducing rainfall which is the only input component of water balance.

Conclusions

1. Actual evapotranspiration depends directly on water excess during calculating water balance.
2. Water surplus contour map indicates increased values toward northeast direction of Iraq, where water surplus depends directly on both rainfall and actual evapotranspiration.
3. The minimum values of runoff and groundwater recharge located in western desert of Iraq.
4. The obtained mathematical relationship between rainfall with both water surplus and actual evapotranspiration can be used to estimate these two parameters directly from rainfall.

Fig. 6 Contour map of annual runoff in Iraq

5. The climate conditions of desert were the major influence on reducing rainfall and rising temperature resulting decreasing water surplus, runoff, and groundwater recharge.
6. Iraq can be divided into five distinguished hydrological zones, where topographical, geological, and climatic characteristics of these zones produced distinguished hydrological and hydrogeological conditions (Al-Sudani

2019f). Depending on these zones characteristics, future local studies in each zone will be done depending on results of this research as well as all data collected related to geological, hydrological, and hydrogeological investigation and local climate condition in order to optimize the results of water surplus and natural groundwater recharge.

Fig. 7 Contour map of annual groundwater recharge in Iraq

Compliance with ethical standards

Conflict of interest The author declares that he have no conflict of interest.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

Abdullah SS, Malek M, Mustapha A, Aryanfar A (2014) Hybrid of artificial neural network-genetic algorithm for prediction of reference

evapotranspiration (ET) in arid and semiarid regions. *J Agric Sci* 6(3):191

Al-Kubaisi QY, Rasheed AA (2018) Climatic water balance and hydrogeological characteristics of Lailan Basin, Southeast Kirkuk—North of Iraq. *Iraqi J Sci* 59(1A):105–118

Allen RG, Pereira LS, Raes D, Smith M (1998) Crop evapotranspiration—guidelines for computing crop water requirements—FAO irrigation and drainage paper 56. FAO, Rome

Al-Shamma A, Taqa ES, Saeed MAH (2007) Water balance of North Erbil Basin. *Iraqi J Sci* 48(1):124–134

Al-Sudani HI (2003) Hydrogeological system of Debagah basin in North of Iraq. PhD thesis, University of Baghdad, College of Science, p 153

Al-Sudani HIZ (2018a) Calculating of groundwater recharge using meteorological water balance and water level fluctuation in Khan Al-Baghdadi Area. *Iraqi J Sci* 59(1B):349–359

Al-Sudani HIZ (2018b) Study of morphometric properties and water balance using Thornthwaite method in Khanaqin Basin, East of Iraq. *J Univ Babylon Eng Sci* 26(3):165–175

Al-Sudani HIZ (2019a) Temperature—potential evapotranspiration relationship in Iraq using Thornthwaite method. *J Univ Babylon Eng Sci* 27(1):16–25

Al-Sudani HIZ (2019b) Derivation mathematical equations for future calculation of potential evapotranspiration in Iraq, a review of

- application of Thornthwaite evapotranspiration. *Iraqi J Sci* 60(5):1037–1048
- Al-Sudani HIZ (2019c) Groundwater system of Dibdibba sandstone aquifer in south of Iraq. *Appl Water Sci* 9(4):1–11
- Al-Sudani HIZ (2019d) Estimation of water balance in Iraq using meteorological data. *Int J Recent Eng Sci* 6(5):8–13
- Al-Sudani HIZ (2019e) Rainfall returns periods in Iraq. *J Univ Babylon Eng Sci* 27(2):1–9
- Al-Sudani HIZ (2019f) Groundwater zones in Iraq. No 4. <https://www.researchgate.net/publication/336497608>
- Al-Sudani HIZ, Jawad SB, Jawad MA (2000) Hydrogeological investigations for sector 9.5th stage, Badra-Jassan Region, East of Iraq. Report no 1. <https://www.researchgate.net/publication/319665617>
- Domemico PA, Schwartz FW (1998) Physical and chemical hydrogeology. Wiley, New York, p 506
- Garg SK (2013) Irrigation engineering and hydraulic structures, 27th edn. Khanna Publishers, New Delhi
- Henderson A (2012) The future of the world's climate, 2nd edition. Henderson-Sellers A, McGuffie K (eds). Elsevier, Boston, pp 531–621
- Iraqi Meteorological Organization and Seismology (2015) Meteorological data of (32) meteorological station for different periods. Internal report. Ministry of Transportation, Baghdad
- Jawad SB, Ridha SA (2008) Assessment of groundwater resources in Iraq and management of their use. General Commission of Water Resources Management. Ministry of Water Resources, Baghdad, 19 p
- Mohammed R, Scholz M (2017) Impact of evapotranspiration formulations at various elevations on the reconnaissance drought index. *Water Resour Manag* 31:531–548. <https://doi.org/10.1007/s11269-016-1546-9>
- Muhaimeed AS, Saloom AJ, Saliem KA, Alani KA, Muklef WM (2014) Classification and distribution of Iraqi soils. *Int J Agric Innov Res* 2(6):997–1002
- Saud A, Azlin Md, Said Md, Abdullah R, Hatem A (2016) Investigation of water balance methods of Haqlan Basin in the western region of Iraq. *World Appl Sci J* 34(5):652–656
- Sokolov AA, Chapman TG (1974) Methods for water balance computations, an international guide for research and practice. UNESCO Press, Paris, p 127p
- Subedi A, Chávez JL (2015) Crop evapotranspiration (ET) estimation models: a review and discussion of the applicability and limitations of ET methods. *J Agric Sci* 7(6):50
- Thornthwaite CW (1948) An approach toward a relation classification of climate. *Geograph Rev* 32(55):3–30
- UNESCO (1971) Scientific framework of world water balance. Technical papers in hydrology, no. 7, Paris, 27 p
- Vangelis H, Tigkas D, Tsakiris G (2013) The effect of PET method on reconnaissance drought index (RDI) calculation. *J Arid Environ* 88:130–140

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.