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Hydrology and Earth System Sciences Discussions

Interactive comment on "Timing of land–ocean groundwater nutrient fluxes from a tropical karstic region (southern Java, Indonesia)" *by* Till Oehler et al.

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Dear Editor,

we thank reviewer 1 for the fruitful comments on the manuscript. The major remark of reviewer 1 was that there are probably more groundwater flow paths within the karstic system. We addressed this issue and collected all information about known flow paths, as well as all negotiated flow paths, in the karstic system (Figure 1, Table 1). Based on these flow paths we give a range of nutrient fluxes at the main outlet into the ocean (Pantai Baron) in Figure 5 and Table 4. Below you can find a detailed point to point reply to the comments made by reviewer 1.

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Best regards,

Till Oehler

Reviewer

I agree with the authors that the main uncertainties in this study are the connection between the catchment area and the nutrients discharge to the coastal ocean. These two points are basically the main goals of the study and a better job must be done to justify the lack of data in this concern: As the authors mention, assuming that the discharge in Pantai Baron is the same as the flow measured in Bribin Sindon and can be directly derived from its gauge, is a major concern. In a karst system, a distance of >10Km is too large to consider a unique flow path with invariable discharge rate all the way to the coastline. Is there any flux measurement in the literature of Pantai Baron with a flow meter to be compared with the flow in Bribin Sindon? Even one measurement could give you an idea of how acceptable this assumption is.

Answer

In the previous version of the manuscript we discuss under section "5.3 uncertainties" that additional flow paths may occur, and we agree with the reviewer's suggestion that this issue can be resolved in a better way. We now include all connections which were proven by tracer tests, as well as all suspected connections, and discharge rates into Figure 1 and Table 1 and show these results in a revised version in section "2.2 Subsurface Hydrology". Based on these datasets we give a range of groundwater nutrient fluxes (Figure 5, Table 4). In general, the discharge range which was reported at Pantai Baron from McDonald&Partners 1984 is in a similar range than measured at Bribin and our data suggest that Bribin-Baron is major pathway of groundwater flow. We can assume that all water which passes by the subsurface river dam flows towards the ocean and based on all known pathways, we can also assume that most of this water discharges at Baron.

Reviewer

A second concern is the presence of other springs along the shoreline that were not considered in this study. In section 5.3 the authors mention that other small submarine and coastal springs are present in the area. Did you identify all of them? Where are they located? I understand that the two main points of discharge are Baron and Ngrumput, but when summed together the smaller springs could represent an important portion of the groundwater discharge and nutrient fluxes in the area. They could also be included in Fig. 1. Why was Pantai Sundak not included in this study if Sir MacDonald and Partners (1984) measured a higher flow here than in Pantai Ngrumput?

Answer

All springs which we were able to identify in the area are springs Baron, Ngrumput, Slili, Sundak, Ngobaran, and Pok Tunggal (Figure 1, Table 1). All known discharge rates from these springs summed up show still a much lower discharge than at Pantai Baron. Furthermore a qualitative tracer test between Seropan and Baron indicated only a connection between these two systems and not towards the springs Slili, Sundak, Ngobaran and Pok Tunggal. A connection between Pantai Ngrumput has not been considered yet, but our nitrate data at Pantai Baron and Patani Ngrumput correlates (Spearman's rank) with each other (Table 3) indicating that both springs are fed by a similar groundwater water the hinterland.

Reviewer

Were the measurements by Sir MacDonald and Partners (1984) taken during the dry or wet season?

Answer

The measurements by Sir MacDonald and Partners (1984) were taken during the dry season in August

Reviewer

Is it possible that the flux measured in Bribin Sindon feeds not only Pantai Baron but also Pantai Ngrumput and the smaller springs not considered in the study? Including this is in the discussion would improve this issue.

Answer

It is possible that Bribin-Sindon feeds also further springs at the coast, but we cannot say this for sure. We show all known pathways (and known non-pathways) which have been mapped in the area in Figure 1 and Table 1. However, the essential aim of this manuscript is to show the temporal variability of nutrient fluxes, not so much the spatial variability.

Reviewer

The authors mention that a general connection between Pantai Ngrumput and the aquifer system was deduced from the hydrochemistry temporal variability. How was this done exactly?

Answer

A Spearman's rank correlation (Table 3) of nitrate concentrations between the different springs indicates that nitrate shows a similar variability in concentrations in between Pantai Baron, Pantai Ngrumput and Gunung Kendil. This indicates that similar processes force variations in nitrate concentrations in between different springs. In a revised version we resolve this issue in more detail.

Reviewer

Furthermore, in this type of limestone diffuse discharge is also possible through the matrix. Can this also be occurring in the study area?

Answer

Matrix flow is as in any karstic region present all the time. Matrix flow is responsible for a baseline signal of the physio-chemistry of the groundwater as shown in Eiche et al 2016). However, this component is relatively small and slow compared to the piston flow. Especially for nutrients the extrema are for sure controlled by the piston flow. We can include this in the discussion of a revised paper.

Reviewer

In Fig. 3 low SST variability can also be observed along the shoreline from Pantai Baron to Pantai Ngrumput. How do you explain this?

Answer

This might be caused by longshore coastal currents and indicates the extent to which groundwater discharge affects the coastal ocean. We include this information in section "4.1 Groundwater recharge, flow, and discharge to the coastal ocean"

Minor comments

Reviewer

1) The authors mention in section 3.1 that the thermal infrared results were validated by offshore in-situ EC and temperature measurements in November of 2015 and April of 2016, however, no data is presented from these surveys. I suggest to include these data and explain the trends in the results section.

Answer

We include this data into a revised version of the manuscript and explain the trends in the results section (Figure 2).

Reviewer

2) The potential impact of excess nutrients in the coastal ocean (such as HABs) is mentioned several times in the manuscript. Has any of this issues been reported in the study area in the past by previous studies? It would be of great interest to mention in the discussion section the specific ecological implications that may arise in this particular

area. For instance, is there any vulnerable biota or seagrass species in the area?

Answer

Seagrass species were observed in a fringing reef at Pantai Ngrumput. Furthermore fishing is an important economy in the area. We can include information on the seagrass and the reef in the area, and some information about fishing.

Technical corrections

Page 2, L 16: I suggest changing “backed” with “supported”.

-Agreed for a revised version.

Page 3, L 1: I suggest adding “the” before “dry season” here and throughout the manuscript. The same for the rainy season.

-Agreed for a revised version.

Page 3, L 24: there is a typo, it should be “A decrease” not “An increase”.

-Agreed for a revised version.

Page 5, L 5: I suggest mentioning the lab at which the samples were measured and delete “In Germany”.

-Agreed.

Page 5, L 19-21: this information was already included in page 3, L 23-27.

- We will reformulate this in a revised version.

Page 5, L 29-31: this information was already included in page 4, L 3-5.

- We will reformulate this in a revised version.

Page 6, L 1-4: the description of Pantai Baron can be better explained. I suggest changing the part where you distinguish between the near shore area and the 500 m away from the shore.

-Agreed. We will change this in a revised version

Page 7, L 6: I suggest using mol/day as used in the figures instead of “mol per day”. Please correct elsewhere.

-Agreed. This will be changed in a revised paper.

Page 7, L18-19: this information is repeated, is it necessary to remind the reader?

-We can leave this information out in a revised manuscript.

Page 8, L 10: Please change “time” by “season”.

-We will change this part as suggested by reviewer 2 as well.

Page 8, L 30: be consistent, is it “Urea” or “urea”?

-We will stick to urea and change it accordingly.

Figures:

Figure 1: to improve the figure you could superimpose the ESRI World Shaded Relief layer (partially transparent) to give an idea of the topography in the area for an easier understanding. It would also be helpful to include general groundwater flow lines to indicate at least the discussed hydrogeology if possible.

-We included the ESRI World Shaded Relief layer and vectors with discharge rates and direction into the map in order to clarify the known pathways and volumes of groundwater in the area as suggested by reviewer 1 and reviewer 2 (see Figure 1 and Table 1).

Figure 3: please add a scale bar near the north arrow for reference.

-Agreed

Figure 4: in figures 1, 2, 3, and 5 you used a different font, please be consistent and

use the same font here too. I also suggest to change the axes range so the reader can see the data better. You could plot 2H only from -55 to -30 and 18O from -7.5 to -5.0.

-We can change this accordingly

Figure 6: please be consistent and use the same font here too. I also suggest to change the bars order to follow the legend, where the nitrate fluxes bar would be placed first followed by the silicate flux and lastly Bribin Sindon discharge.

-We show a new bar graph with minimum and maximum fluxes (Figure 5).

Interactive comment on Hydrol. Earth Syst. Sci. Discuss., https://doi.org/10.5194/hess-2017-621, 2017.

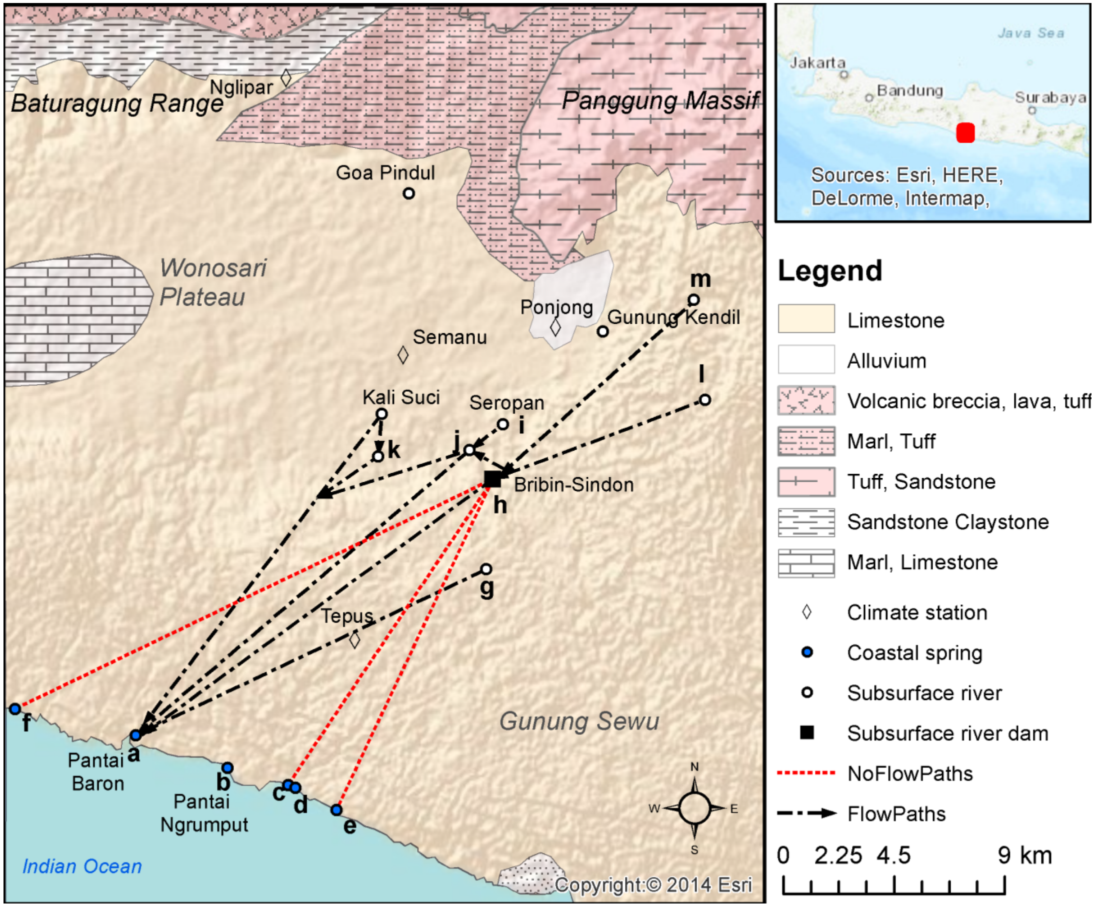

Fig. 1. All proven land-ocean groundwater connections (black lines) and negotiated connections (red lines) in the karstic region of Gunung Kidul. For respective discharge rates and names and types o

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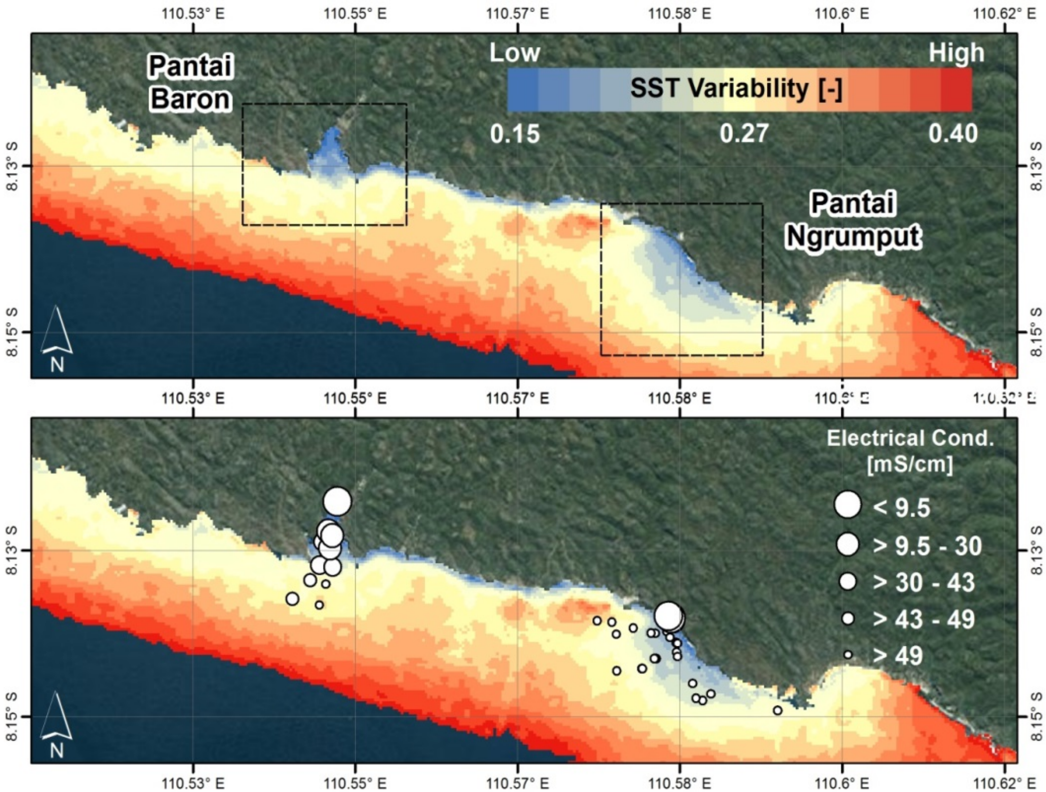

Fig. 2. TIR image of the coastal ocean showing two major sites of groundwater discharge and related electrical conductivity values which were measured in the coastal water.

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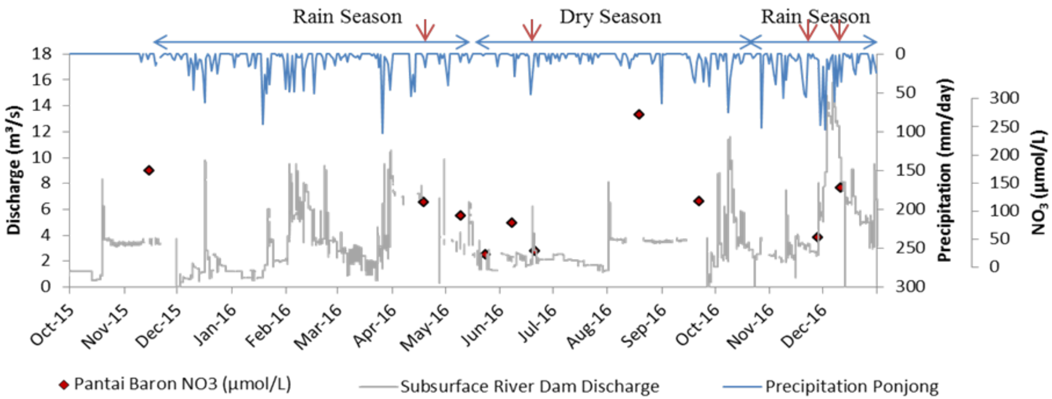

Fig. 3. Discharge at the subsurface river dam (grey) and precipitation data (blue) from the upstream located climate station Ponjong, nitrate concentrations at the coastal spring Pantai Baron (red dots). The

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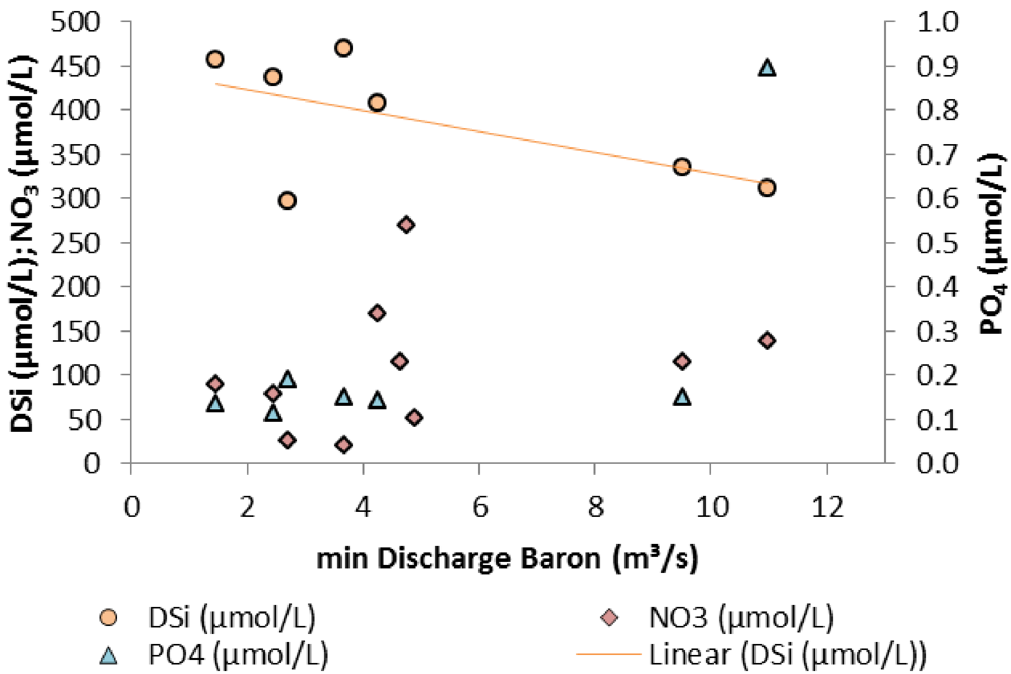

Fig. 4. Scatterplot of DSi, NO3, and PO4 in relation to the minimum discharge at Pantai Baron.

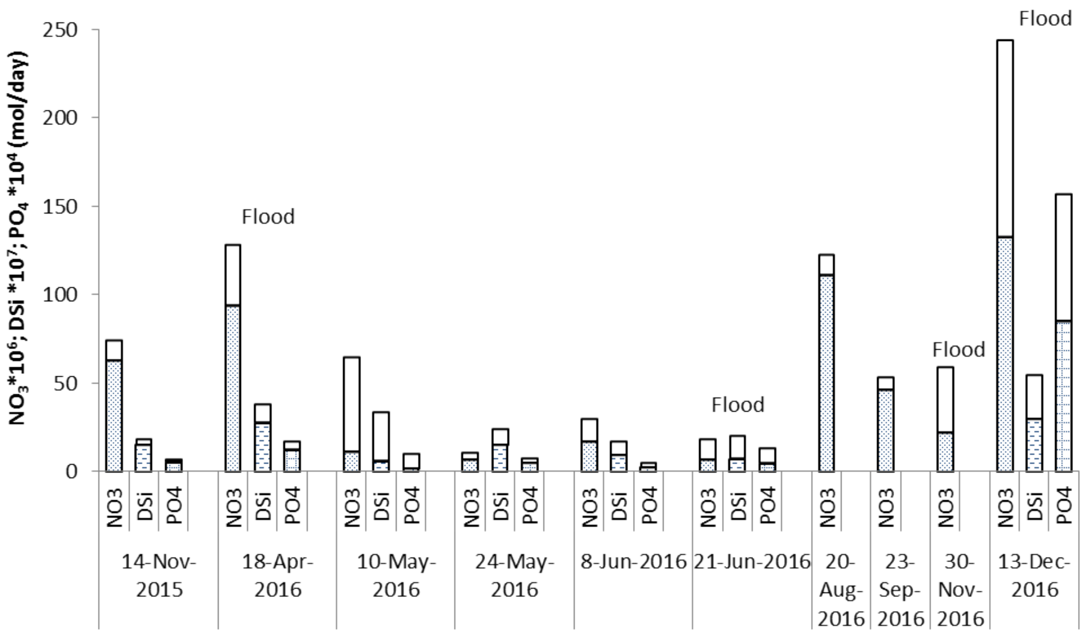

Fig. 5. Range of land-ocean groundwater nutrient fluxes estimated based on groundwater discharge rates from a subsurface river dam and nutrient concentrations sampled at Pantai Baron. The upper white part of

Site	Map ID	Type	Discharge (m³/s) dry season	Discharge (m³/s) wet season	Comment	Reference
P. Baron	a	Coastal spring	4-8.2			1
P. Ngrumput	b	Coastal spring	0.05-0.06	0.03		2
P. Slili	c	Coastal spring	0.05		No connection to Bribin-Sindon	1
P. Sundak	d	Coastal spring	0.2		No connection to Bribin-Sindon	1
Pok Tunggal	e	Coastal spring			No connection to Bribin-Sindon	
P. Ngobaran	f	Coastal spring			No connection to Bribin-Sindon	
Buhputih	g	Subsurface river	0.02		Flows to Baron	
Bribin-Sindon	h	dam	>1	<12	Flows to Baron	
Gua Bribin	h	Subsurface river	1-1.3	4-8	Gua Bribin is 2 km upstream of Bribin-Sindon	1,3
Seropan	i	Subsurface river	0.4-0.5	0.5 to <3, extreme >10	Flows via Ngreneng to Baron	3,4
Grubug	j	Subsurface river	0.7-1	2	100% flows to Baron 25% of discharge of Baron	1,3
Gua Ngreneng	k	Subsurface river	<0.1	0.2		1,3
Luweng Jomblangan	l	Subsurface river			Flows to Bribin-Sindon	1,3
Gilap	m	Subsurface river	0.003		Flows to Bribin-Sindon	1,3

* 1 = MacDonalds&Partners 1984; 2 = own measurements 2016; 3 = own measurements 2000/2001; 4 = own measurements 2008-2010

Fig. 6. Table 1: All known discharge rates measured at subsurface rivers in the hinterland and coastal springs are shown in this table. The site where the measurement was taken (Flow ID) is shown in Figure 1.

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Event	Date	Season	DO (%)	EC (µS/cm)	Temp (°C)	NO_3 (µmol/L)	NO_2 (µmol/L)	NH_4 (µmol/L)	DSi (µmol/L)	PO_4 (µmol/L)
Pantai Baron-1	14-Nov-2015	Dry	83	557	27.9	170	0.0		408	0.1
Pantai Baron-2	19-Apr-2016	Wet	85	429	27.6	114	0.3	1.3	335	0.1
Pantai Baron-3	10-May-2016	Dry	88	521	28.0	90	0.2	0.6	458	0.1
Pantai Baron-4	24-May-2016	Dry	82	541	28.1	21	0.4	3.6	471	0.1
Pantai Baron-5	8-Jun-2016	Dry	82	525	28.0	78	0.3	2.4	436	0.1
Pantai Baron-6	21-Jun-2016	Dry	77	384	27.2	27	0.2	1.2	297	0.2
Pantai Baron-7	20-Aug-2016	Dry		640	27.8	271				
Pantai Baron-8	23-Sep-2016	Dry		820	28.4	115				
Pantai Baron-9	30-Nov-2016	Wet		260	23.0	52				
Pantai Baron-10	13-Dec-2016	Wet	92	429	27.6	140	0.4		312	0.9
Gua Pindul-1	21-Apr-2016	Wet	92	533	28.6	94	0.6	1.9	320	0.1
Gua Pindul-2	11-May-2016	Dry	88	540	28.5	48	0.3	1.9	389	0.1
Gua Pindul-3	24-May-2016	Dry	87	567	27.9	72	0.3	1.4	413	0.1
Gua Pindul-4	8-Jun-2016	Dry	86	558	28.4	33	0.3	2.1	410	0.1
Gua Pindul-5	21-Jun-2016	Dry	86	413	27.3	34	0.4	3.3	303	0.1
Gua Pindul-6	20-Aug-2016	Dry		520	29.6	302				
Gua Pindul-7	23-Sep-2016	Dry		560	29.0	0				
Gua Pindul-8	30-Nov-2016	Wet		270	25.6	0				
Gua Pindul-9	12-Dec-2016	Wet	99	494	26.1	84	1.1		316	0.1
Gunung Kendil-1	17-Apr-2016	Wet	93	567	27.8	123	0.5	4.1	495	0.1
Gunung Kendil-2	11-May-2016	Dry	84	522	27.4	91	0.0	0.0	462	0.1
Gunung Kendil-3	24-May-2016	Dry	82	524	27.2	53	0.2	1.4	497	0.1
Gunung Kendil-4	8-Jun-2016	Dry	73	527	27.0	66	0.2	0.2	474	0.1
Gunung Kendil-5	21-Jun-2016	Dry	82	532	27.1	64	0.0	0.0	450	0.1
Kali Suci-1	21-Apr-2016	Wet	104	426	29.1	58	0.2	1.1	308	0.1
Kali Suci-2	10-May-2016	Dry	102	431	28.1	107	0.3	1.7	362	0.1
Kali Suci-3	24-May-2016	Dry	101	485	27.5	66	0.2	0.9	408	0.1
Kali Suci-4	8-Jun-2016	Dry	104	490	27.5	133	0.2	0.6	382	0.1
Kali Suci-5	21-Jun-2016	Dry	102	417	26.7	69	0.1	0.3	307	0.1
Kali Suci-6	20-Aug-2016	Dry		520	28.9	230				
Kali Suci-7	23-Sep-2016	Dry		490	29.2	0				
Kali Suci-8	30-Nov-2016	Wet		200	26.7	38				
Pantai Ngrumput-1	16-Nov-2015	Dry	75	8380	27.8	132	0.0		372	0.5
Pantai Ngrumput-2	19-Apr-2016	Wet	72	6300	28.4	30	0.1	7.9	350	0.1
Pantai Ngrumput-3	10-May-2016	Dry	83	9530	28.8	17	0.2	7.4	368	0.1
Pantai Ngrumput-4	21-Jun-2016	Dry	72	9450	28.4	7	0.4	5.1	391	0.1
Pantai Ngrumput-5	20-Aug-2016	Dry		7520	28.2					
Pantai Ngrumput-6	23-Sep-2016	Dry		7510	28.5					
Pantai Ngrumput-7	30-Nov-2016	Wet		8080	27.2					
Pantai Ngrumput-8	13-Dec-2016	Wet	67	5950	28.2	145	0.0		302	1.0

(white box) = base flow at Pantai Baron
(grey box) = high discharge event at Pantai Baron

Fig. 7. Table 2: The hydrochemistry of the springs which are located in the hinterland and at the coast. High discharge events at Pantai Baron are marked by the grey shaded areas.

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	P. Ngrumput	Gunung Kendil	Kali Suci	Goa Pindul
P. Baron	0.90	1.00	0.12	0.44
P. Ngrumput		1.00	-0.50	0.80
Gunung Kendil			-0.10	0.30
Kali Suci				0.54

Fig. 8. Table 3: Correlation matrix (Spearman's rank) of temporal NO3 concentration variations of the different springs which were sampled in Gunung Kidul.

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Date	P. Baron min discharge (m^3/sec)	P. Baron max discharge (m^3/sec)	NO3 (mol/m^3)	NO3 min flux (10^6 mol/day)	NO3 max flux (10^6 mol/day)	DSi (mol/m^3)	DSi min flux (10^7 mol/day)	DSi max flux (10^7 mol/day)	PO4 (mol/m^3)	PO4 min flux (10^4 mol/day)	PO4 max flux (10^4 mol/day)
Nov-15	4	5	170	63	74	408	15	18	0	5	6
Apr-16	10	13	114	94	129	335	28	38	0	12	17
May-16	1	8	90	11	65	458	6	33	0	2	10
May-16	4	6	21	7	11	471	15	23	0	5	7
Jun-16	2	4	78	16	30	436	9	17	0	2	4
Jun-16	3	8	27	6	18	297	7	20	0	4	13
Aug-16	5	5	271	111	123						
Sep-16	5	5	115	46	53						
Nov-16	5	13	52	22	59						
Dec-16	11	20	140	133	245	312	30	55	1	85	157

= base flow at Pantai Baron

= high discharge event at Pantai Baron

Fig. 9. Table 4: Range of groundwater discharge rates, NO3 fluxes, DSi fluxes and PO4 fluxes at Pantai Baron. Flooding events are marked by the grey line.

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