Nutrient Contribution

Assessment of contributions based on estimated assumptions

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Contents

Data import

File	Content
Feed composition APO-SUB-2.xlsx	Composition data of commercial and experimental fish feeds
Water quality APO-SUB-2.xlsx	Composition data of tap and rain water
IAFFD FICD.xlsx	Composition of aquafeed raw materials; data downloaded from www.iaffd.com

Data wrangling

Feed

Water

- outliers for rain water were removed

Alkalinity supplements

Results

Feed

- 82 commercial feeds
- 66 commercial feeds with data from datasheets
- 16 commercial feeds with data from literature
- 11 experimental feeds

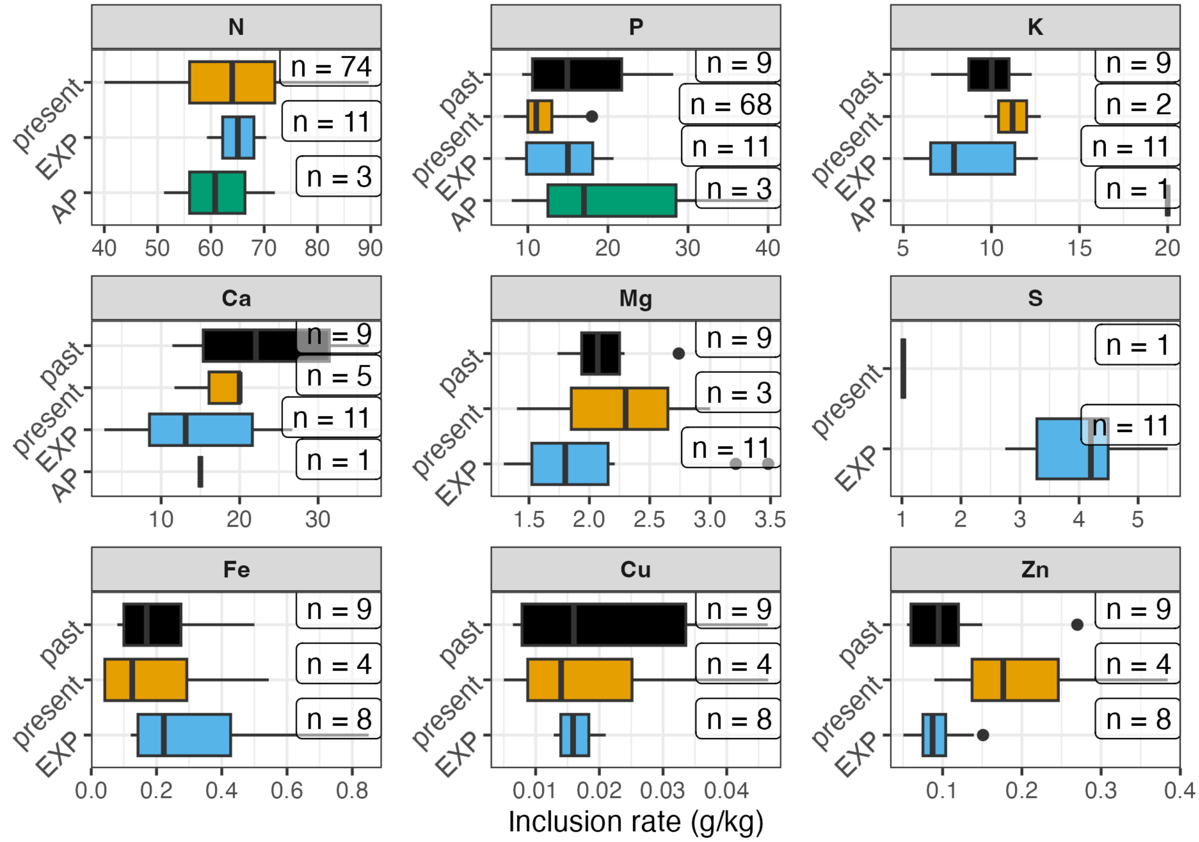
category	substance	unit	n	min	mean	sd	cv	max
aquaponic	Ca	gkg	1	15.000	15.000			15.000
aquaponic	K	gkg	1	20.000	20.000			20.000
aquaponic	N	gkg	3	51.200	61.333	10.410	0.170	72.000
aquaponic	P	gkg	3	8.000	21.667	16.503	0.762	40.000
commercial	Ca	gkg	5	11.700	17.560	3.686	0.210	20.000
commercial	Cu	gkg	4	0.005	0.020	0.019	0.933	0.046
commercial	Fe	gkg	4	0.040	0.209	0.237	1.136	0.544
commercial	K	gkg	2	9.600	11.200	2.263	0.202	12.800
commercial	Mg	gkg	3	1.400	2.233	0.802	0.359	3.000
commercial	N	gkg	74	40.000	63.862	11.796	0.185	89.600
commercial	P	gkg	68	7.000	11.662	2.444	0.210	18.000
commercial	S	gkg	1	1.024	1.024			1.024
commercial	Zn	gkg	4	0.090	0.207	0.127	0.613	0.384
experimental	Ca	gkg	11	2.760	14.646	8.410	0.574	26.710
experimental	Cu	gkg	8	0.013	0.016	0.003	0.179	0.021
experimental	Fe	gkg	8	0.121	0.348	0.297	0.854	0.850
experimental	K	gkg	11	5.000	8.633	2.762	0.320	12.630
experimental	Mg	gkg	11	1.292	2.021	0.727	0.359	3.480
experimental	N	gkg	11	59.257	64.983	4.030	0.062	70.400
experimental	P	gkg	11	7.172	14.104	4.940	0.350	20.700
experimental	S	gkg	11	2.751	4.032	0.868	0.215	5.500
experimental	Zn	gkg	8	0.050	0.093	0.036	0.385	0.151
old	Ca	gkg	9	11.429	22.676	8.952	0.395	36.429
old	Cu	gkg	9	0.006	0.021	0.015	0.728	0.046

category	substance	unit	n	min	mean	sd	cv	max
old	Fe	gkg	9	0.080	0.207	0.134	0.644	0.500
old	K	gkg	9	6.571	9.485	1.979	0.209	12.286
old	Mg	gkg	9	1.736	2.118	0.300	0.142	2.740
old	P	gkg	9	9.286	16.252	6.371	0.392	28.143
old	Zn	gkg	9	0.055	0.113	0.067	0.597	0.270

Statistics

- reliable comparison of nutrient inclusion is only possible for P, considering the number of observations in the dataset.
- comparison of commercial data with aquaponics or experimental feed is also not meaningful due to low sample size
- P: Aquaponics feeds are richer in P compared with commercial feeds and also compared with experimental diets (Tukey test: $p < 0.05$). The smallest difference was found between aquaponics and old diets. The difference between them is non-significant.

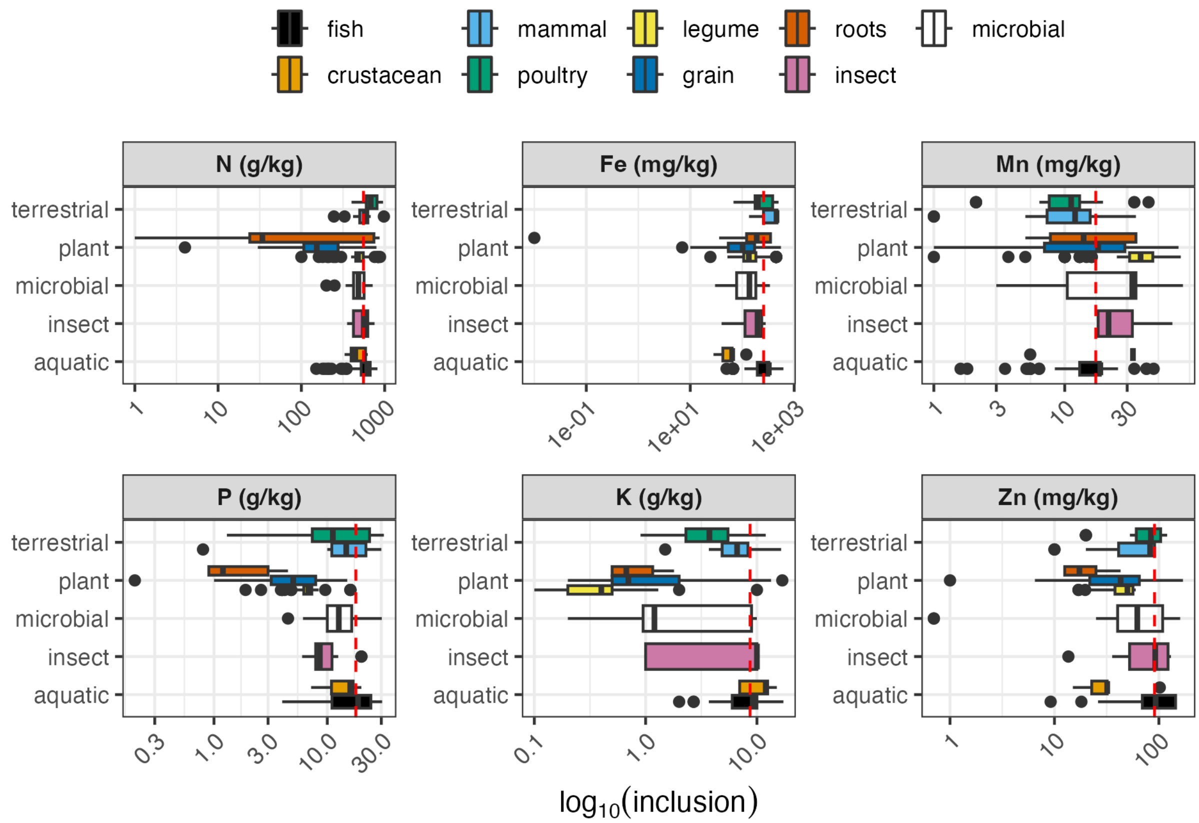
Feed composition



Feedstuff composition

cat2	analyte	n	mean	sd	cv
aquatic	N (g/kg)	86	556.81	154.06	0.277
aquatic	Fe (mg/kg)	82	258.11	132.10	0.512
aquatic	Mn (mg/kg)	84	17.26	9.02	0.522
aquatic	P (g/kg)	56	17.88	7.38	0.413
aquatic	K (g/kg)	80	8.68	3.33	0.384
aquatic	Zn (mg/kg)	84	90.88	45.03	0.495
insect	N (g/kg)	13	544.69	120.30	0.221
insect	Fe (mg/kg)	13	172.55	86.60	0.502
insect	Mn (mg/kg)	4	32.12	23.23	0.723
insect	P (g/kg)	13	10.62	4.49	0.423
insect	K (g/kg)	13	6.54	4.56	0.697

cat2	analyte	n	mean	sd	cv
insect	Zn (mg/kg)	13	83.28	42.72	0.513
microbial	N (g/kg)	19	493.26	144.74	0.293
microbial	Fe (mg/kg)	17	141.40	85.45	0.604
microbial	Mn (mg/kg)	16	30.05	23.30	0.775
microbial	P (g/kg)	18	14.02	6.55	0.468
microbial	K (g/kg)	15	3.83	4.26	1.110
microbial	Zn (mg/kg)	16	72.12	47.80	0.663
plant	N (g/kg)	192	340.35	228.27	0.671
plant	Fe (mg/kg)	191	148.49	107.09	0.721
plant	Mn (mg/kg)	171	28.28	19.09	0.675
plant	P (g/kg)	194	6.21	3.05	0.491
plant	K (g/kg)	187	1.24	2.04	1.653
plant	Zn (mg/kg)	191	45.51	24.86	0.546
terrestrial	N (g/kg)	40	649.20	171.53	0.264
terrestrial	Fe (mg/kg)	33	293.81	149.65	0.509
terrestrial	Mn (mg/kg)	40	13.21	9.69	0.733
terrestrial	P (g/kg)	27	14.31	9.95	0.695
terrestrial	K (g/kg)	38	5.53	3.45	0.623
terrestrial	Zn (mg/kg)	40	76.15	31.29	0.411



Water

Data origin

Tap water

- 71 tap water analysis reports

Table 4: Summary statistics of the chemical composition of tap water. Data was compiled from analysis reports of water supply companies (n = 71). Mean values were estimated using accepted methods for censored data (Helsel, 2012). N is the sum of all nitrogenous species.

analyte	unit	n	min	mean	sd	cv	max
N	µmolL	62	2110.073	2110.077	0.000	0.000	2110.073
P	µmolL	24	0.001	0.888	1.942	2.188	6.949

analyte	unit	n	min	mean	sd	cv	max
K	µmolL	51	2.558	65.930	66.357	1.006	358.072
Ca	µmolL	57	82.339	1484.005	815.786	0.550	3418.334
Mg	µmolL	57	37.029	462.482	333.265	0.721	1781.526
S	µmolL	58	6.746	137.463	139.926	1.018	630.839
B	µmolL	40	0.462	4.988	11.570	2.319	59.014
Fe	µmolL	62	0.000	0.581	2.975	5.117	23.637
Mn	µmolL	54	0.004	0.064	0.126	1.958	0.735
Cu	µmolL	45	0.002	0.232	0.930	4.017	4.721
Zn	µmolL	13	0.008	0.235	0.926	3.946	3.059
Ni	µmolL	40	0.003	0.033	0.051	1.534	0.235
Mo	µmolL	7	0.005	0.008	0.016	2.092	0.052
Na	µmolL	56	4.350	839.220	910.089	1.084	4697.742
Cl	µmolL	50	2.821	774.340	705.306	0.911	3300.144
Al	µmolL	50	0.041	0.651	0.919	1.410	4.485

Rain water

- 18 rain water analyses from literature
- 13 studies from which the data was derived

Table 5: Summary statistics of rainwater composition data (n = 18). Analytes with less than 5 dataset records were removed. Outliers were identified by calculating the interquartile range (IQR). Values > 1.5 x IQR were removed from the dataset.

analyte	unit	n	min	mean	sd	cv	max
Ca	µmolL	14	8.98	60.8	41.19	0.677	135.5
Cl	µmolL	14	20.14	96.5	52.18	0.541	197.4
K	µmolL	13	9.78	27.5	21.30	0.775	82.8
Mg	µmolL	13	4.59	12.9	5.44	0.421	24.7
N	µmolL	16	0.00	90.7	52.47	0.579	205.3
Na	µmolL	15	15.61	94.8	70.08	0.739	261.0

analyte	unit	n	min	mean	sd	cv	max
S	µmolL	16	16.17	44.6	24.22	0.543	88.5

Combined

analyte	unit	mean_tap	mean_rain	significance	tap:rain ratio
N	µmolL	2110.077	90.7	lower	23
P	µmolL	0.888			
K	µmolL	65.930	27.5	lower	2
Ca	µmolL	1484.005	60.8	lower	24
Mg	µmolL	462.482	12.9	lower	36
S	µmolL	137.463	44.6	lower	3
B	µmolL	4.988			
Fe	µmolL	0.581			
Mn	µmolL	0.064			
Cu	µmolL	0.232			
Zn	µmolL	0.235			
Ni	µmolL	0.033			
Mo	µmolL	0.008			
Na	µmolL	839.220	94.8	lower	9
Cl	µmolL	774.340	96.5	lower	8
Al	µmolL	0.651			

- All substance concentrations that are known for both tap and rain water are significantly lower in rain water ($p < 0.05$).

Alkalinity supplements

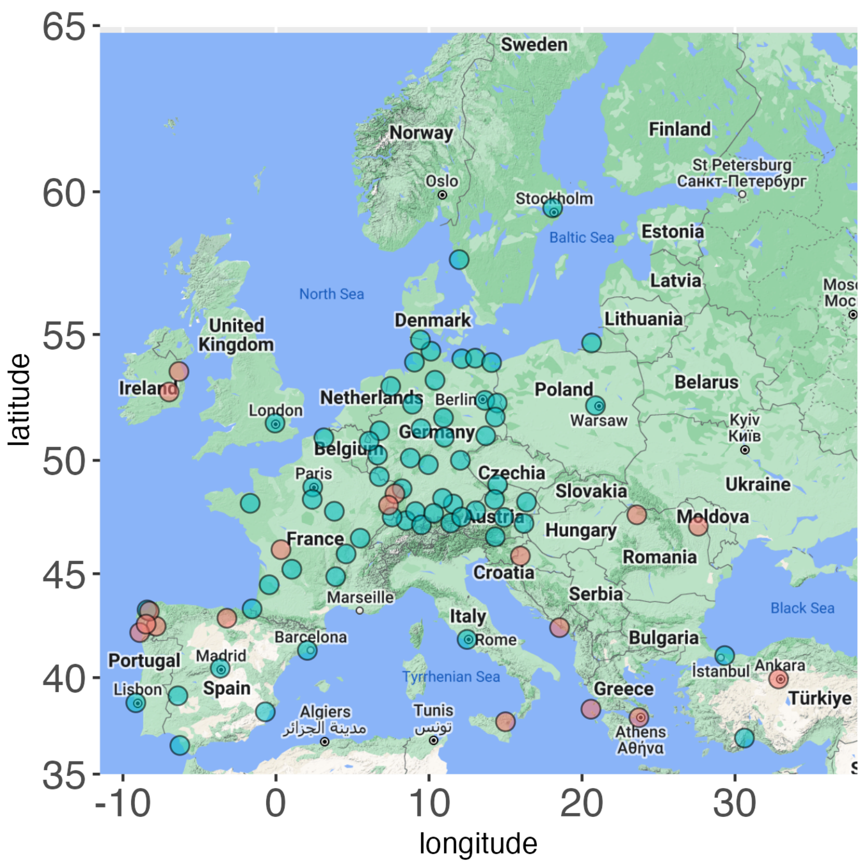


Figure 1: Origins of data included into the water dataset. Blue dots: Drinking water analysis reports. Red dots: Rain water analyses.

Nutrient contribution

Initial assumptions

We assume a recirculation aquaculture system (RAS) has a total volume of m^3 of which m^3 are used as rearing volume for the stock. Furthermore, we assume a stocking density of $kg\,m^{-3}$, referred to the rearing volume of the system. The feeding rate shall be set to $\%\,d^{-1}$ of the total biomass and a water exchange rate of $\%\,d^{-1}$ of the total system volume shall be maintained.

Based on these inputs, a biomass of kg, a total weight of kg feed fed per day, a daily exchanged volume of $m^3\,d^{-1}$ freshwater and $L\,kg^{-1}$ exchanged water per weight unit feed fed is calculated.

To estimate the mass contribution of source water and feed to the total amount of nutrients that are entering the system, it is assumed that the RAS operator is using tap water as freshwater source and analysis results from water treatment plants are thus taken as data input. Furthermore, the average of the nutrient profile of a number of commercial fish feeds is used.

Data preparation

Feed

Consideration of digestibility Assumptions with regards to the digestibility of nutrients in the feeds are the following:

- **N** ADC ranging between 85-95%
- **P** ADC ranging between 35-45% [@Sugiura2018]
- all other nutrient ADC ranging between 45-55%

Consideration of retention **Retention** assumptions are based on [@Roy2022]. These were derived from Tilapia, though.

The amount of daily feed fed was normalised to 1 kg of feed instead of going for the initial assumptions. This makes it better comparable.

Water

Tap water

Rain water

Empirical probability analysis

Without retention

Retention - Tap water

After consideration of nutrient digestibility, two scenarios occur: 1. still majority of nutrient input by feed 2.

3. equal contribution of water and feed possible

- tap water can contribute a share of N comparable to aquafeeds in some cases
- the probability that the majority of K will originate from aquafeeds is 100%
-

Retention - Rain water

Combined

```
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##
## $y
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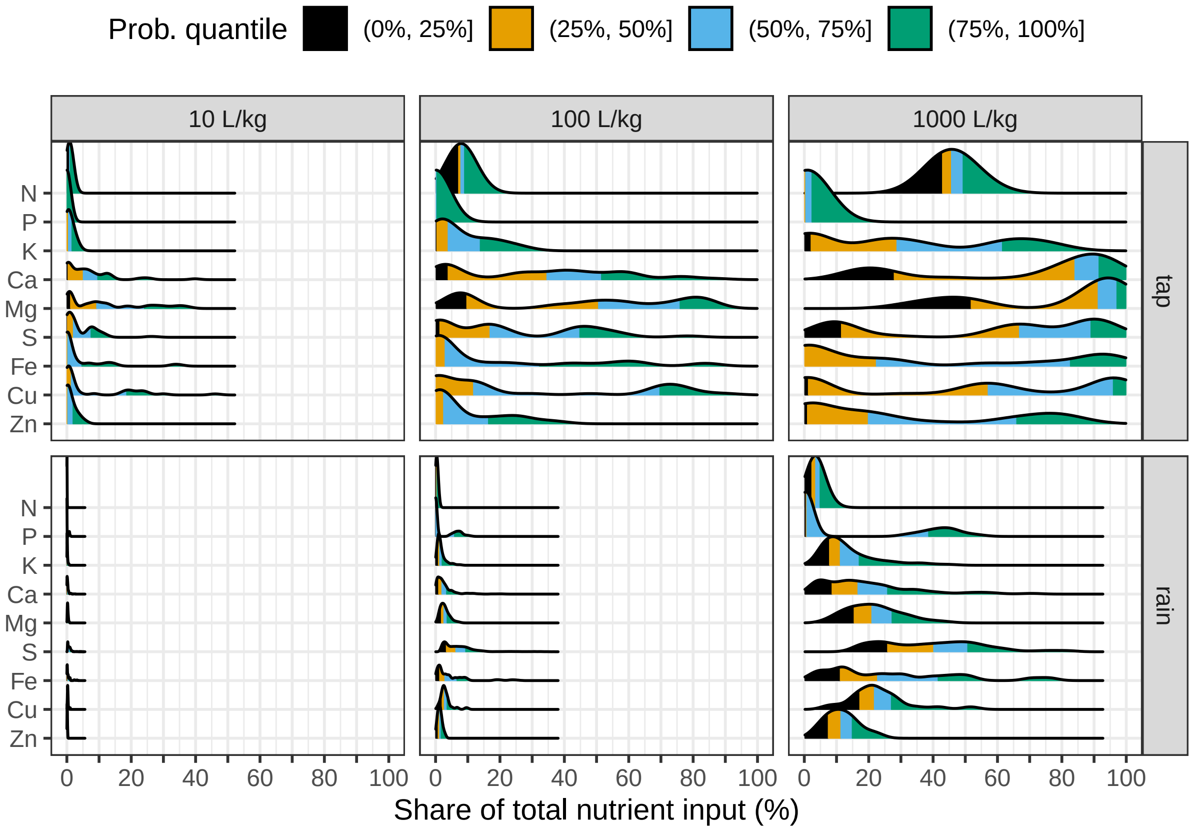
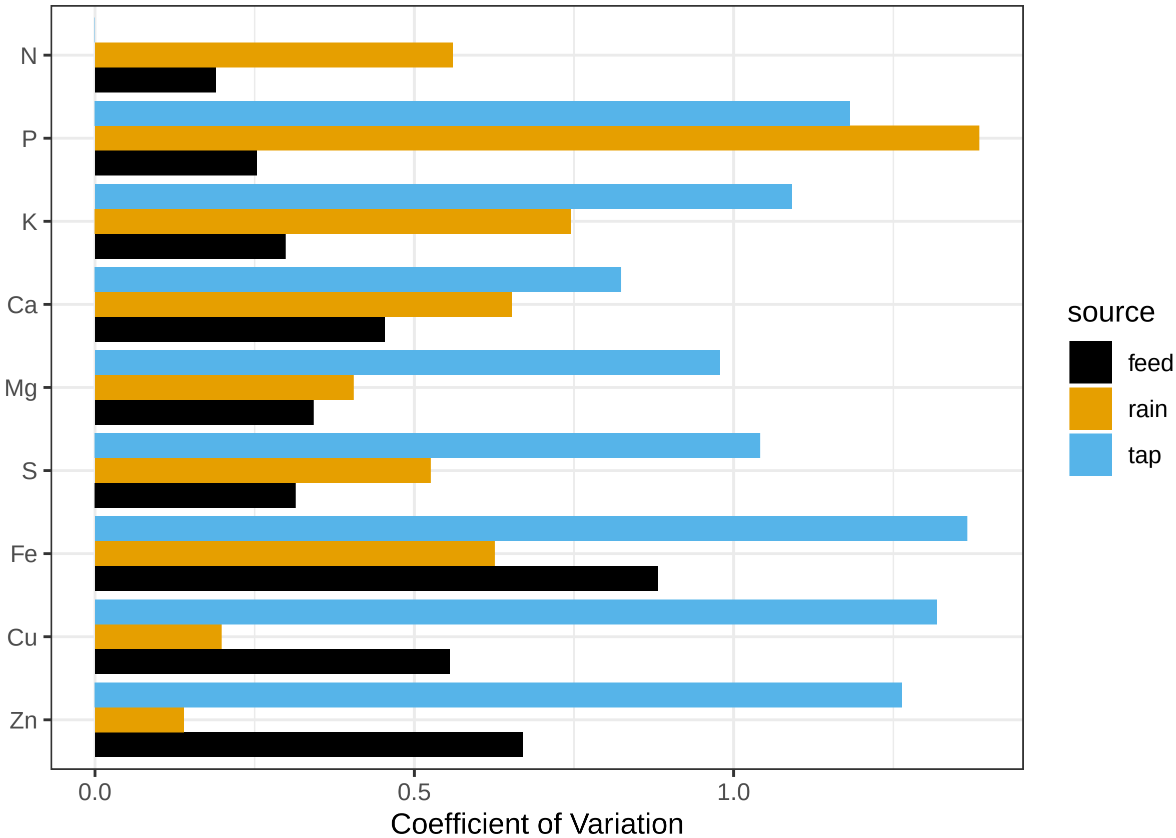


Prob. quantile
(0%, 25%]
(25%, 50%]
(50%, 75%]
(75%, 100%]
10 L/kg
100 L/kg
1000 L/kg
tap
rain
N
P
K
Ca
Mg
S
Fe
Cu
Zn
0
20
40
60
80
100
Share of total nutrient input (%)

Variability



It can be seen that tap water is the predominant source of variability in the results Feed was found to have the lowest variability (coefficient of variation (CV) < 0.5) of all nutrient sources for the major nutrients (nitrogen, phosphorus, the earth alkaline metals, potassium, and sulfur). The variability in the mass fractions of transition metals in feeds, on the other hand, is significantly higher. However, the variability is always lower than that found for tap water sources.

The highest variability in the data can be found in tap water with exception of phosphorus, which is more variable in rain

Table 7: Quantiles of percentage contribution to the total nutrient input into an aquaculture system as shown in the figure before.

substance	source2	dailyFreshwater	median	0-20	20-40	40-60	60-80	80-100
Ca	tap	10	5.007	0.332	3.595	6.424	11.830	41.577
Ca	tap	100	34.514	3.223	27.161	40.707	57.295	87.679
Ca	tap	1000	84.052	24.981	78.853	87.286	93.064	98.614

substance	source2	dailyFreshwater	median	0-20	20-40	40-60	60-80	80-100
Ca	rain	10	0.197	0.071	0.153	0.244	0.410	2.743
Ca	rain	100	1.937	0.701	1.507	2.384	3.950	22.001
Ca	rain	1000	16.494	6.591	13.267	19.630	29.138	73.826
Cu	tap	10	1.310	0.010	1.073	1.631	19.806	48.290
Cu	tap	100	11.722	0.099	9.789	14.226	71.179	90.327
Cu	tap	1000	57.040	0.982	52.042	62.385	96.108	98.941
Cu	rain	10	0.275	0.198	0.255	0.303	0.386	1.148
Cu	rain	100	2.688	1.945	2.496	2.945	3.726	10.403
Cu	rain	1000	21.641	16.552	20.383	23.279	27.903	53.727
Fe	tap	10	0.286	0.000	0.094	0.442	7.225	37.079
Fe	tap	100	2.788	0.001	0.928	4.252	43.781	85.492
Fe	tap	1000	22.287	0.005	8.568	30.753	88.620	98.331
Fe	rain	10	0.292	0.109	0.177	0.406	0.828	3.524
Fe	rain	100	2.844	1.077	1.744	3.920	7.709	26.754
Fe	rain	1000	22.641	9.815	15.077	28.975	45.514	78.507
K	tap	10	0.398	0.017	0.285	0.572	1.847	3.859
K	tap	100	3.844	0.168	2.775	5.444	15.837	28.645
K	tap	1000	28.557	1.659	22.207	36.537	65.299	80.057
K	rain	10	0.125	0.076	0.105	0.144	0.236	0.920
K	rain	100	1.235	0.754	1.041	1.417	2.314	8.493
K	rain	1000	11.111	7.064	9.520	12.565	19.151	48.137
Mg	tap	10	9.279	0.891	6.555	12.192	26.388	39.899
Mg	tap	100	50.562	8.251	41.228	58.131	78.189	86.909
Mg	tap	1000	91.093	47.350	87.523	93.281	97.286	98.516
Mg	rain	10	0.264	0.163	0.231	0.299	0.404	0.912
Mg	rain	100	2.581	1.606	2.259	2.911	3.902	8.424
Mg	rain	1000	20.947	14.035	18.773	23.070	28.881	47.914
N	tap	10	0.832	0.725	0.797	0.865	0.994	1.524
N	tap	100	7.741	6.804	7.434	8.024	9.123	13.400
N	tap	1000	45.625	42.200	44.541	46.594	50.098	60.744
N	rain	10	0.036	0.015	0.032	0.041	0.054	0.150

substance	source2	dailyFreshwater	median	0-20	20-40	40-60	60-80	80-100
N	rain	100	0.362	0.154	0.320	0.408	0.534	1.484
N	rain	1000	3.503	1.523	3.107	3.940	5.097	13.088
P	tap	10	0.003	0.000	0.003	0.004	0.025	0.048
P	tap	100	0.034	0.000	0.027	0.040	0.249	0.478
P	tap	1000	0.341	0.001	0.272	0.403	2.438	4.584
P	rain	10	0.007	0.004	0.006	0.008	0.693	1.323
P	rain	100	0.070	0.039	0.057	0.083	6.519	11.821
P	rain	1000	0.693	0.392	0.572	0.819	41.085	57.276
S	tap	10	1.972	0.110	1.655	2.687	8.038	29.263
S	tap	100	16.750	1.088	14.404	21.634	46.639	80.533
S	tap	1000	66.800	9.906	62.725	73.408	89.734	97.640
S	rain	10	0.662	0.312	0.525	0.795	1.111	5.484
S	rain	100	6.252	3.032	5.011	7.417	10.104	36.716
S	rain	1000	40.007	23.817	34.533	44.478	52.919	85.298
Zn	tap	10	0.244	0.008	0.143	0.286	2.170	6.064
Zn	tap	100	2.391	0.083	1.412	2.788	18.153	39.228
Zn	tap	1000	19.677	0.829	12.532	22.288	68.924	86.586
Zn	rain	10	0.126	0.074	0.108	0.138	0.181	0.322
Zn	rain	100	1.243	0.738	1.065	1.361	1.782	3.127
Zn	rain	1000	11.181	6.917	9.721	12.123	15.360	24.400

Table 8: Quantiles of percentage contribution to the total nutrient input into an aquaculture system as shown in the figure before.

substance	source2	dailyFreshwater	median	0-20	20-40	40-60	60-80	80-100
N	rain	100	0.362	0.154	0.320	0.408	0.534	1.48
Zn	rain	100	1.243	0.738	1.065	1.361	1.782	3.13
Mg	rain	100	2.581	1.606	2.259	2.911	3.902	8.42
K	rain	100	1.235	0.754	1.041	1.417	2.314	8.49
Cu	rain	100	2.688	1.945	2.496	2.945	3.726	10.40

substance	source2	dailyFreshwater	median	0-20	20-40	40-60	60-80	80-100
P	rain	100	0.070	0.039	0.057	0.083	6.519	11.82
Ca	rain	100	1.937	0.701	1.507	2.384	3.950	22.00
Fe	rain	100	2.844	1.077	1.744	3.920	7.709	26.75
S	rain	100	6.252	3.032	5.011	7.417	10.104	36.72

Alkalinity supplements

Table 9: Percentage contribution of selected alkalinity supplements to the nutrient budget at different levels of makeup water supplied to the system.

Substance	Makeup water	Alkalinity suppl.	Feed	Water
Ca	10	75.7	23.03	1.315
K	10	91.6	8.30	0.068
Mg	10	94.4	4.83	0.751
Ca	100	67.6	20.60	11.756
K	100	91.1	8.25	0.677
Mg	100	88.4	4.52	7.033
Ca	1000	32.9	10.01	57.122
K	1000	85.8	7.77	6.383
Mg	1000	54.2	2.77	43.071