Technical Note December 2024

Groundwater Quality Risks in Indonesian Cities

1 PURPOSE

This technical note provides background information for the Policy Brief "*Groundwater Quality Risks in Indonesian Cities*" The Policy Brief contains five policy recommendations and refers readers to this Technical Note for further information on the following two recommendations:

Recommendation 2 – Risk Ranking Tool

Recommendation 4 – Using Sanitary Inspections to Reduce Risk

Hence, this Technical Note comprises two parts covering each of these recommendations.

2 Part A: RISK RANKING TOOL

2.1 Background

The purpose of the risk ranking tool is to assist in identifying cities where the greatest benefit could be achieved by providing pipe water, and to provide information to assist decision making on the types of investment that reduce health risks. A key objective of the risk ranking tool is that it makes use of existing data so that it does not require new sampling of household water supplies which would be costly and time consuming.

The policy brief explains that we began with an understanding (conceptual model) of how pathogens enter household water sources[1] and used this to identify the factors expected to affect the likelihood of finding *E. coli* in groundwater sources. Data on each of these factors was gathered where possible. We obtained data from the "Studi Kualitas Air Minum Rumah Tangga" (SKAM-RT) survey, which was conducted over November to December 2020. This provided measurements of *E coli* at the water sources of 622 households that are both located in an urban area[2] and use a bore or well as their main drinking water source. We used statistical methods to determine which factors are associated with *E coli* > 100 CFU/100mL and so created a model that aims to estimate in which cities household groundwater sources are more likely to have high *E coli.* Each of these steps is explained in more detail in the following sections.

Because we have chosen to use only available data and are simplifying a very complex real world, the aim is not to achieve an accurate predictive model, but rather a method to rank cities.

2.2 Conceptual Model

A conceptual model of how pathogens enter groundwater supplies in urban areas of Indonesia was developed using a review of the academic literature (Mbae et al., 2024) as illustrated in Figure 1. The approach was to consider pathogens as moving from a source via a pathway to a receptor. Various

[1] The ranking is based on pathogens as indicated by *E coli* at the water source. It does not consider further contamination or treatment that may occur between the source and use of the water.
[2] In this study we took urban area to mean the household is located within the administrative boundaries of a kota. An alternative approach used by the Central Bureau of statistics is to define each Kelurahan/Desa as urban or rural. We did not do this as our purpose was to rank at a kota (city) level.

barriers exist to limit pathogen emission from sources and transport along the pathways and into receptors.

In urban Indonesia we expect to find the following sources, pathways, and receptors with their associated barriers to pathogen transport.

Sources:

- Onsite sanitations systems.
- Leaks from sewers.
- Livestock.
- Greywater that does not connect to the onsite sanitation system and directly infiltrates into groundwater.

Pathways:

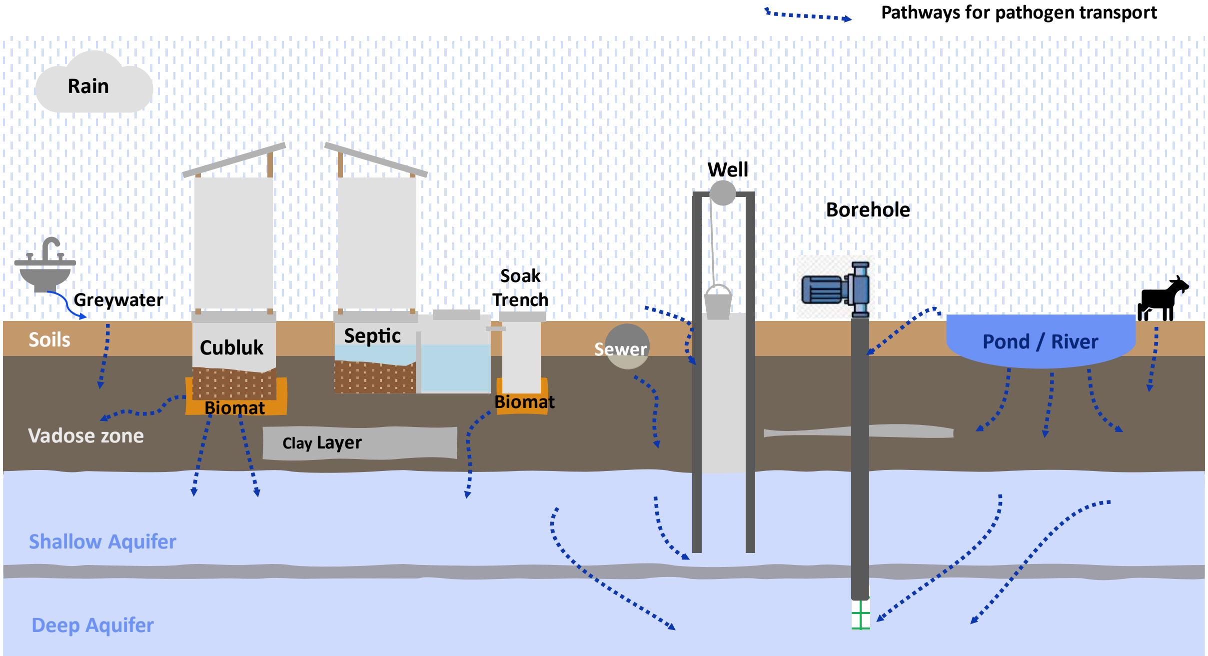
- Aquifer pathway – contaminants travel through an unsaturated zone into an aquifer and then flow towards the water source (receptor). The presence of multiple aquifers separated by aquitards can complicate this pathway.
- Localised pathways – contaminants enter the receptor without flowing through the aquifer, for example surface runoff entering through cracks in a well wall.

Receptors

- Boreholes (drilled wells, usually with a protective casing and typically with an electric pump to extract water)
- Dug wells (shallow dug wells with protective plaster only in upper portion, may have an electric pump or use a bucket and rope).

Each of these sources, pathways and receptors create barriers that reduce pathogen transmission. In addition to these sources, pathways and receptors, rainfall and subsequent flow of water from the surface to aquifers and receptors can be considered an enabler that may enhance pathogen flows along the pathways.

Figure 1 Conceptual Model



2.3 Data Collected on Risk Factors

Table 1 presents a list of factors for which data can be obtained for most Indonesian cities and that may represent the various sources, pathways, receptors and associated barriers to transmission of faecal pathogens. For some barriers, there are several possible data sources that could be used (e.g. quantity of pathogens being discharged from onsite systems and sewerage could be represented by population density or proportion of land that is built up or even by the intensity of light emissions at night), while for others no data exists (e.g. depths of household bores and which aquifer they are accessing is largely unknown).

Table 1 Risk Factors where data is available for expected sources, pathways, receptors and their associated barriers.

Risk Factor	Potential Data to quantify risk factor	Used in model?	Explanation
Sources			
Load (amount of E Coli applied to catchment) from - Onsite sanitation systems. - Leaks from sewers. - Livestock. - Overflows from poor or blocked sanitation systems. - Grey water contaminating surface	Population density	Yes	Significant association at 95% confidence
	% land area built up	No	Population density provides better correlation
	Areas covered by piped sewerage	No	Only a small % of households are serviced by piped sewerage and data was not easily available.
	Toilet within 15m	No	No significant association found.
	% households in city that do not have any of WWTP; septic; cubluk	No	No significant association found.
	HH sanitation type	No	No significant association found.

Risk Factor	Potential Data to quantify risk factor	Used in model?	Explanation
water that subsequently infiltrates into groundwater.			
Pathways			
Aquifer pathway.	land slope	No	No significant association found.
	Depth to groundwater	No	Poor association. Available data does not represent actual groundwater depth with sufficient accuracy
	Lithology	No	No significant association with the data available.
	Aquifer lithology	Yes	Significant association at 90% confidence
Localised pathways	Sanitary inspection score	No	Significant association at 95% confidence but lack data to know what typical sanitary inspection scores would be for each kota. (SKAM-RT has too few samples for this)
Enabling impact of rainfall	Rainfall in 2 months before sampling (Oct/Nov 2020).	Yes	Significant association at 95% confidence
Receptor			
Type	Drinking water source type (well or bore)	Yes	Significant association at 95% confidence

2.4 Method for Estimating Risk

A common method of thinking about risk is:

RISK = CONSEQUENCE x EXPOSURE

Translating this to the specific situation of households using groundwater in urban Indonesia, we can say:

CONSEQUENCE is the impact on human health. The health impact of pathogens in drinking water are typically diseases such as diarrhea and chronic effects such as childhood stunting[3]. We can't easily measure the human health impacts as there are too many different causes of poor health, hence we looked at how likely groundwater sources are to be contaminated with pathogens. *E coli* is the most used indicator of whether water is likely to be contaminated with faecal matter and hence may contain pathogens.

EXPOSURE in this context can be measured by the number of households using groundwater as their main drinking water source

So, the risk for a particular city becomes:

Risk = (level of groundwater contamination as indicated by E coli) x (proportion of households using groundwater for drinking)

[3] Drinking-water (who.int)

Data from SUSENAS (BPS-Statisitics Indonesia, 2020) was used to estimate the proportion of households in each Kota using groundwater (wells, bores or springs) as their main drinking water source.

2.5 Estimating E Coli in Groundwater

The SKAM-RT survey conducted in 2020 (Irianto, 2020) provides the most comprehensive assessment of *E coli* in household drinking water supplies. It has data on 847 households in cities (within Kota administrative boundaries) that use groundwater from a bore or well as their main drinking water source. Of these, for 619 households have a complete set of data, including the location with sufficient accuracy to match the household data with location specific factors such as population density or aquifer lithology. For each of these households, a single sample was taken of their water source and analysed for *E coli* and the results recorded in the following categories:

- Safe: 0 CFU/100mL
- Low Risk: 1 – 10 CFU/100mL
- Medium Risk: 11 – 100 CFU/100mL
- High Risk > 100 CFU/100mL

The number of samples is not large enough to use the results to rank cities directly from the data (many cities do not have any samples). But the data provides an opportunity to use multivariable regression techniques to generate a model that predicts *E coli* by using the risk factors in Table 1.

Method for Developing Correlation

The *E coli* data was grouped into two categories to create a binary variable. This enables a binary logistic regression model to be used to predict a probability of *E coli* being in one or the other category. The cutoff was chosen as " > 100 CFU/100mL" because it is a common cutoff used in literature e.g. (Bain et al., 2021) and some trials with the data showed using this cutoff gave better association between *E coli* and the explanatory factors than the other commonly used cutoff of "> 0 CFU/100mL".

The purposeful selection method (HOSMER et al., 2013) was used to choose which risk factors in Table 1 should be used in the model. Information for each of the factors was entered into a geographic information system[4] which enabled values such as population density and lithology to be obtained at the location of the households, thus creating a dataset suitable for statistical analysis.

The SKAM-RT survey sampled clusters of ten nearby households in each Kelurahan (Urban Village) included in the survey. The statistical analysis needs to take account of this clustering as, particularly when considering groundwater contamination, there is likely to be some level of correlation between households within a cluster, hence a Generalised Estimating Equation was used with SPSS software (IBM, 2021).

Logistic regression fits an equation of the form:

$$logit(P) = \ln\left(\frac{P}{1-P}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_n X_n$$

Where:

P = probability of *E coli* being > 100 CFU/100mL

β_0 = intercept

β_1 = coefficient for risk factor 1

X_1 = value of risk factor 1

The generalised estimating equation method provides a predicted average probability for each

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[4] QGIS software was used

sampling cluster. To provide a risk ranking we wanted to estimate the average probability of *E coli* > 100 CFU/100mL across a Kota. To do this we used the data on each chosen risk factor in QGIS to calculate the logit(P) for small areas (aprox 280m by 315m "pixels") that approximate a household scale. Because the logit regression model is linear, the mean logit(P) for all pixels within a kota administrative boundary will represent the kota mean. Many kota boundaries include areas of low population density, so a simple area average does not reflect the fact that most people live in the higher population density areas. To address this, we calculated a population weighted average of the logit and then calculated the "P" (probability of *E coli* > 100 CFU/100mL). This "P" represents how likely a groundwater source is to have *E coli* >100 CFU/100mL and so we used this as the "consequence" term in the risk equation.

2.6 Results

Table 1 summarizes which factors we were able to obtain data that had a statistically significant association with *E coli.* Water source type; aquifer lithology, rainfall in the two months prior to sampling and population density were sufficiently associated to be used in the model. The best fit model found was:

Logit(P) = -2.882 + 1.063 * (1 if water source is a well, else 0) - 0.461 * (1 if aquifer lithology is solid or volcanic rock, if limestone or unconsolidated sediment, 0) + 0.129 * (October + November 2020 rainfall in mm / 100) + 0.673 * (popn density – people per $km^2/10{,}000$[5]).

This equation is often more readily understood when expressed as odds ratios. The odds ratio (OR) for each variable is calculated as $OR = e^{\beta i}$. Using this approach we can say:

The odds of *E coli* > 100 are:

2.9 times greater if the water supply is a dug well rather than a borehole.

1.6 times greater if the aquifer lithology is unconsolidated sediment or limestone as compared to volcanic or solid rock.

1.14 times more likely for every 100mm increase in October to November rainfall.

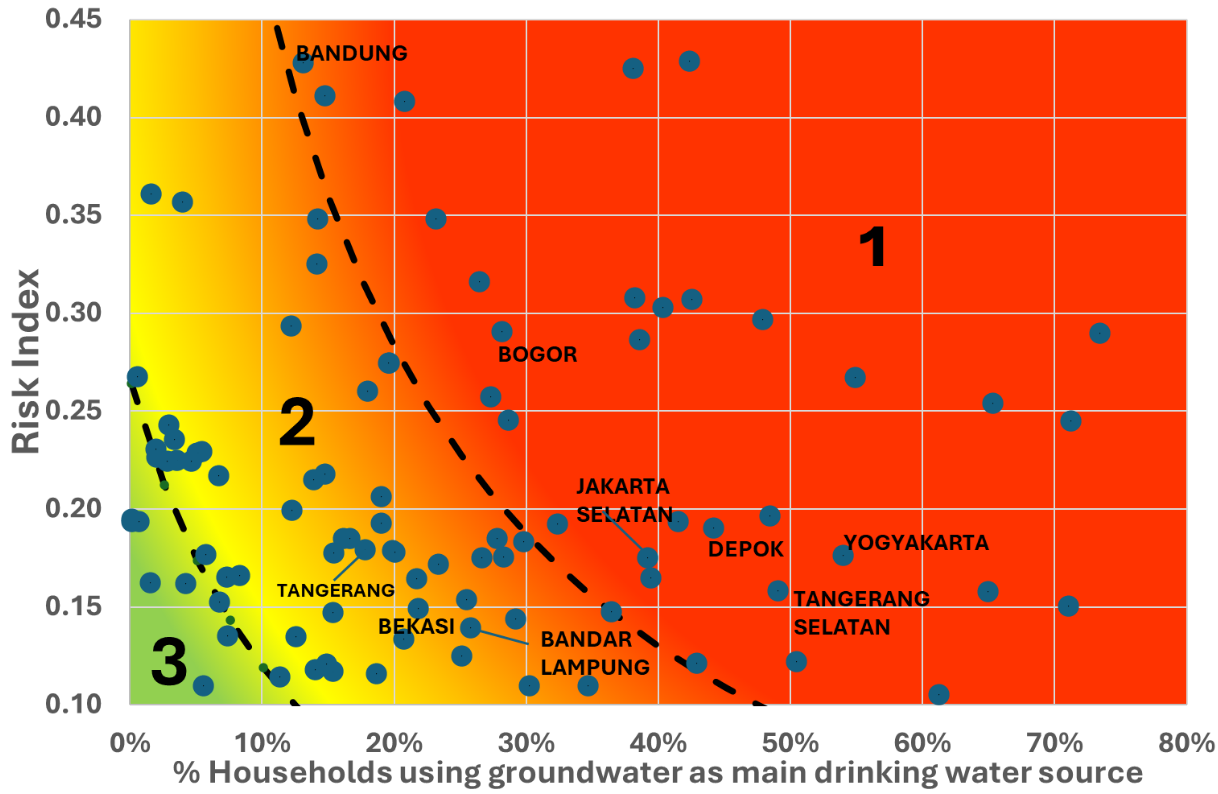
1.8 times more likely for every 10,000 people/km^2 increase in population density.

Using this equation and calculating population weighted average probability of *E coli* >100 CFU/10mL for each Kota gives the results summarized in Appendix: Output of Kota Risk Ranking.

A graphical representation of risk is shown in Figure 2 by plotting "P" (the likelihood of a groundwater sampling having *E coli* > 100 CFU/100mL) against the proportion of households using groundwater. Three zones are depicted with zone 1 highest risk cities (more contamination and high use of groundwater for drinking), zone 2 medium and zone 3 lower risk. The colour graduation shows red (highest risk) to green (lowest risk).

[5] The values in this term were calculated on a pixel of approximately 280m by 315m and then the values ratioed to express the result as population per km^2 divided by 10,000 for ease of understanding)

Figure 2 Risk vs Groundwater Use



A map view is provided in Figure 3.

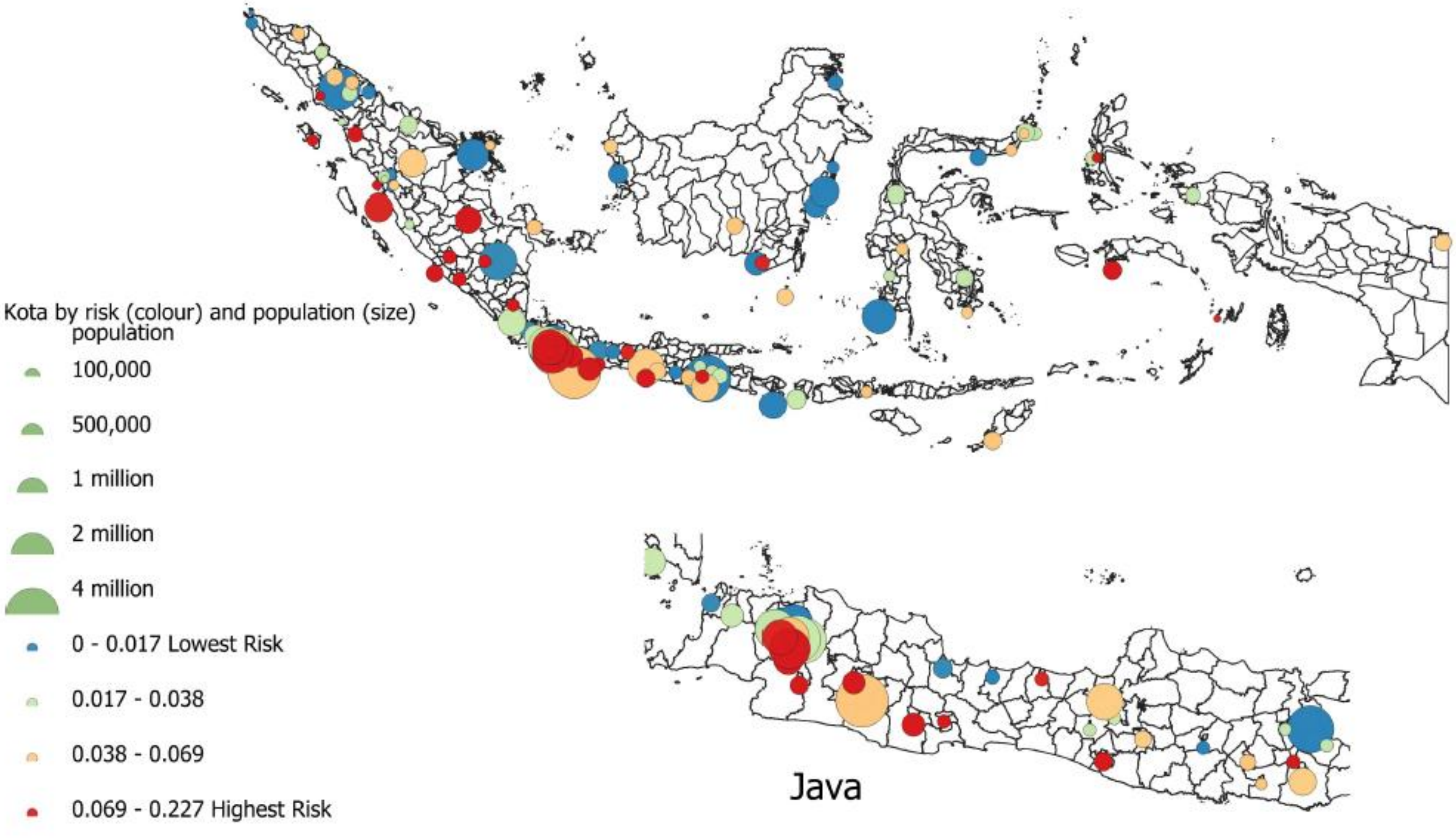
2.7 Conclusion

The risk ranking model can provide insights into locations that are expected to have higher risk, i.e. areas with high population density, higher proportions of wells and to some extent areas with unconsolidated sediment. We believe this is sufficient for ranking cities, while recognizing that health risk is only one factor that needs to be considered when making investment decisions.

There are some key limitations that should be kept in mind:

- The model is based on *E coli* which is a reasonable predictor of faecal contamination in groundwater (Atherholt et al., 2003), but viruses are known to travel longer distances in groundwater than bacteria, and so health risks can exist even when *E coli* is not detected (Mbae et al., 2024).
- The risk ranking is based on the average risk for a city. Within a city, some locations will have higher risk than others. Breaking the risk down to smaller areas can be considered in future work if deemed useful but is likely to be limited by data availability.
- The model is missing some explanatory factors we know are important, particularly depth to groundwater, due to a lack of sufficiently accurate available data. So, the model should just be used for ranking but with recognition that circumstances, such as a city with very shallow groundwater, may cause that city to have a different risk than the model estimates. We hope to produce an academic paper that will look more at comparing the model to other data.

Figure 3 Map of Cities by risk and population



3 Part B. USING SANITARY INSPECTIONS TO REDUCE RISK

The SKAM-RT survey included an environmental health inspection, or sanitary survey of water sources, which aimed to identify hazards that might cause contamination such as faults in barriers (eg cracks in the well wall) for each water source or the presence of sources of contamination. The questions used in the survey are shown in Table 2. As noted in Table 1, we did not use sanitary inspection results in the risk modelling because the only source of data we had is the SKAM-RT survey which does not have sufficient results for all cities to be able to rank cities. Nonetheless, receptor barriers are important in preventing contamination and so we decided to investigate the relationship between *E coli* and sanitary inspection results.

Table 2 Sanitary Survey Questions for Bores and Wells

Bores	Number "Yes"	Wells	Number "Yes"
Total Number of Cases	**358**		**261**
Is there a latrine/sewer/septic tank within 15 m of the bore?	189 (53%)	Is there a latrine/sewer/septic tank within 15 m of the well?	181 (69%)
Is there a latrine/sewer/septic tank that is higher than the bore, within 30 m of the bore?	43 (12%)	Are there sources of pollution in the upstream areas such as wastewater from livestock activities, animal/poultry slaughterhouses and the like that could contaminate dug wells?	15 (6%)
Are there other sources of pollution at a distance/radius of 15 meters from the bore, such as animal waste/garbage/stained pools of dirty water and the like?	46 (13%)	Are there other sources of pollution at a distance/radius of 15 meters from the dug well, such as animal waste/garbage/stained pools of dirty water and the like?	59 (23%)
Is the pump damaged or loose at the bottom connection that abuts the floor, allowing contaminants to enter the bore?	19 (5%)	Is the rim/ring of the dug well not plastered perfectly, thereby allowing wastewater to seep into the dug well?	37 (14%)
Is there a crack in the floor covering the well so that contaminants can enter?	47 (13%)	Is the cement wall inside the well 3 meters deep from the top surface not plastered perfectly/tightly enough?	68 (26%)
Do you see any cracks or damage to the top of the bore wall?	19 (5%)	Does the cement/plaster floor surrounding the dug well have a radius/width of less than 1 meter?	85 (33%)
Is the wastewater drainage channel missing or damaged, causing water to stagnate around the bore?	16 (4%)	Is the wastewater drainage channel missing or damaged, causing water to stagnate around the well?	19 (7%)
If the bore is outside the house, is there no fence around the well so that animals (such as birds) can reach the bore?	33 (9%)	Is there standing water at a distance of 2 meters around the dug well?	24 (9%)
		Is there standing water on the cement floor around the dug well?	18 (7%)
		Are the buckets and bucket ropes for collecting dug well water placed haphazardly, thereby allowing contamination of the dug well water?	17 (7%)

The sanitary survey is set up such that a "yes" answer indicates either a barrier fault or a contaminant source close to the water source. There are eight questions for boreholes and ten questions for dug wells. Adding the number of yes answers gives a "sanitary score". There is a significant association between sanitary scores and *E coli* for wells, but not for bores.

The sanitary survey includes a question about presence of toilet/onsite sanitation within 15m of the bore or well. There was no statistically significant association between this question and *E coli* >100 CFU/100mL.

Conducting a sanitary inspection for bores in urban areas is more difficult than for wells because often all that is visible is head of the bore, which can sometimes be located inside the house. Many faults in the bore casing cannot be seen. In an urban area with limited space, a household cannot usually take any corrective action if a toilet/sanitation system is too close. So, a "controllable sanitary score" was calculated by including only those things that a household may be able to fix and so improve their water quality. The questions in Table 2 highlighted in yellow were excluded for the "controllable sanitary score". A plot of this score against the proportion of results with high-risk *E coli* is shown in Figure 4. This suggests water sources with a controllable sanitary score greater than 1 have a higher likelihood of E coli > 100 which may be due to faults in the protective barriers.

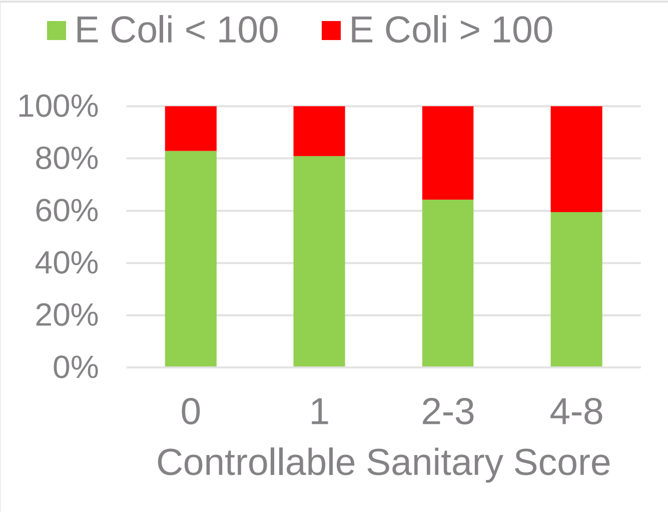


Figure 4 Controllable Sanitary Score - Bores & Wells combined.

When all cases with a score > 1 are removed and logit equation for predicting the probability of *E coli* being greater than 100 CFU/100mL recalculated, the odds of *E coli* being > 100 CFU/100mL when the source is a well compared to a bore drops from 2.9 times more likely for a well to 2.1 times more likely for a well. In other words, removing water sources that are known to have faults makes the difference between wells and bores a bit smaller, which suggests part of the reason that wells have higher levels of contamination than bores are greater contamination from surface sources entering through faults (or absence of protective barriers).

It has been argued that combining questions to create a "score" is not the best approach (Kelly et al., 2020) and the latest WHO guidelines do not include a scoring system (WHO, 2024). Hence, we also looked individually at the questions to determine which have a statistically significant association with *E coli* > 100 CFU/100mL and the questions that had a statistically significant association are show in Table 3.

Table 3 Association Between Individual Sanitary Survey Questions and E coli > 100.

Question	Odds Ratio	"p" – statistical significance
Bores		
Is there standing water on the cement floor around the dug well?	3.1	0.028
Wells		
Is the rim/ring of the dug well not plastered perfectly, thereby allowing wastewater to seep into the dug well?	2.3	0.001
Is the wastewater drainage channel missing or damaged, causing water to stagnate around the well?	2.5	0.029

All these questions imply that faults in the protective barriers of either a bore or a well are associated with, and so might be the cause of, some contamination, and hence we made recommendation 4 in the policy brief that “Sanitary inspections of wells and boreholes could be used to help reduce risk”.

4 Appendix: Output of Kota Risk Ranking

The risk score in Table 4 is the “consequence” x “exposure”, i.e. “estimated probability of *E coli* >100” x “proportion of households using groundwater as their main drinking water source”.

Table 4 Kota Risk Ranking

Kota Name	Population (2020)	% groundwater sources that are wells	Rainfall in Oct to Nov 2020	Mean probability of *E coli* > 100 CFU/100mL	% HH using groundwater for drinking	Risk Score
Kota Pagar Alam	144,000	56%	747	0.251	91%	0.227
Kota Lubuklinggau	234,000	77%	787	0.290	73%	0.213
Kota Gunungsitoli	136,000	39%	625	0.429	42%	0.182
Kota Prabumulih	193,000	98%	628	0.245	71%	0.175
Kota Subulussalam	91,000	76%	624	0.254	65%	0.166
Kota Ambon	347,000	33%	249	0.425	38%	0.162
Kota Padangsidimpuan	225,000	84%	488	0.267	55%	0.147
Kota Pariaman	94,000	51%	975	0.297	48%	0.142
Kota Tasikmalaya	716,000	54%	1,019	0.307	43%	0.131
Kota Bengkulu	374,000	80%	938	0.303	40%	0.122
Kota Banjar	201,000	53%	829	0.308	38%	0.118
Kota Sukabumi	346,000	32%	896	0.286	39%	0.111
Kota Batu	213,000	60%	412	0.151	71%	0.107
Kota Metro	169,000	69%	386	0.158	65%	0.103
Kota Yogyakarta	374,000	37%	465	0.176	54%	0.095
Kota Tidore Kepulauan	114,000	83%	237	0.196	48%	0.095
Kota Jambi	606,000	84%	649	0.408	21%	0.085
Kota Depok	2,056,000	8%	698	0.190	44%	0.084
Kota Cimahi	568,000	20%	652	0.316	26%	0.084
Kota Bogor	1,043,000	41%	929	0.291	28%	0.082

Kota Name	Population (2020)	% groundwater sources that are wells	Rainfall in Oct to Nov 2020	Mean probability of *E coli* > 100 CFU/100mL	% HH using groundwater for drinking	Risk Score
Kota Padang	909,000	64%	777	0.348	23%	0.081
Kota Pekalongan	307,000	46%	364	0.194	41%	0.080
Kota Tangerang Selatan	1,354,000	1%	588	0.158	49%	0.078
Kota Banjar Baru	253,000	95%	415	0.246	29%	0.070
Kota Tual	88,000	89%	261	0.258	27%	0.070
Kota Jakarta Selatan	2,265,000	4%	515	0.175	39%	0.069
Kota Kupang	443,000	42%	111	0.165	39%	0.065
Kota Kediri	287,000	5%	195	0.105	61%	0.064
Kota Tanjung Pinang	228,000	85%	553	0.192	32%	0.062
Kota Tebing Tinggi	173,000	3%	536	0.122	50%	0.062
Kota Palopo	185,000	91%	507	0.411	15%	0.061
Kota Blitar	149,000	32%	300	0.090	65%	0.059
Kota Bandung	2,444,000	20%	642	0.428	13%	0.056
Kota Binjai	292,000	19%	584	0.184	30%	0.055
Kota Lhokseumawe	189,000	84%	525	0.275	20%	0.054
Kota Palangka Raya	293,000	3%	507	0.275	20%	0.054
Kota Kotamobagu	124,000	43%	218	0.148	36%	0.054
Kota Bima	155,000	8%	123	0.122	43%	0.052
Kota Pangkal Pinang	219,000	21%	693	0.185	28%	0.051
Kota Baru	#N/A	50%	433	0.176	28%	0.050
Kota Singkawang	235,000	52%	598	0.348	14%	0.049
Kota Baubau	159,000	44%	217	0.260	18%	0.047
Kota Tomohon	101,000	24%	255	0.094	50%	0.047
Kota Sawah Lunto	65,000	62%	589	0.175	27%	0.047
Kota Jayapura	398,000	31%	560	0.325	14%	0.046
Kota Surakarta	522,000	13%	427	0.144	29%	0.042
Kota Malang	844,000	46%	329	0.172	23%	0.040
Kota Pekanbaru	983,000	14%	686	0.207	19%	0.039

Kota Name	Population (2020)	% groundwater sources that are wells	Rainfall in Oct to Nov 2020	Mean probability of *E coli* > 100 CFU/100mL	% HH using groundwater for drinking	Risk Score
Kota Semarang	1,654,000	17%	476	0.154	26%	0.039
Kota Serang	692,000	6%	423	0.110	35%	0.038
Kota Mataram	430,000	44%	272	0.193	19%	0.037
Kota Bandar Lampung	1,166,000	27%	394	0.140	26%	0.036
Kota Sibolga	90,000	43%	717	0.294	12%	0.036
Kota Langsa	186,000	16%	583	0.178	20%	0.036
Kota Salatiga	192,000	55%	540	0.164	22%	0.036
Kota Jakarta Timur	2,938,000	6%	485	0.179	20%	0.036
Kota Probolinggo	240,000	1%	99	0.110	30%	0.033
Kota Bekasi	2,544,000	3%	493	0.149	22%	0.033
Kota Sungai Penuh	97,000	61%	558	0.218	15%	0.032
Kota Tangerang	1,895,000	4%	449	0.179	18%	0.032
Kota Palu	373,000	11%	316	0.125	25%	0.031
Kota Parepare	151,000	26%	393	0.185	17%	0.031
Kota Padang Panjang	56,000	65%	552	0.185	16%	0.030
Kota Sorong	284,000	33%	537	0.215	14%	0.030
Kota Kendari	345,000	33%	221	0.134	21%	0.028
Kota Magelang	122,000	14%	612	0.178	15%	0.027
Kota Dumai	317,000	14%	630	0.199	12%	0.024
Kota Bukittinggi	121,000	8%	527	0.147	15%	0.023
Kota Manado	452,000	34%	298	0.116	19%	0.022
Kota Pasuruan	208,000	3%	88	0.096	21%	0.020
Kota Mojokerto	132,000	1%	147	0.121	15%	0.018
Kota Bitung	225,000	31%	279	0.117	15%	0.018
Kota Ternate	205,000	8%	257	0.135	13%	0.017
Kota Pematang Siantar	268,000	0%	552	0.118	14%	0.017
Kota Sabang	41,000	67%	845	0.217	7%	0.015
Kota Palembang	1,669,000	70%	620	0.357	4%	0.014

Kota Name	Population (2020)	% groundwater sources that are wells	Rainfall in Oct to Nov 2020	Mean probability of *E coli* > 100 CFU/100mL	% HH using groundwater for drinking	Risk Score
Kota Payakumbuh	140,000	66%	525	0.166	8%	0.014
Kota Cilegon	435,000	23%	411	0.114	11%	0.013
Kota Cirebon	333,000	28%	346	0.229	5%	0.013
Kota Makassar	1,424,000	7%	329	0.165	7%	0.012
Kota Medan	2,435,000	25%	558	0.229	5%	0.012
Kota Tarakan	243,000	14%	796	0.225	5%	0.010
Kota Gorontalo	199,000	18%	173	0.153	7%	0.010
Kota Jakarta Pusat	928,000	7%	402	0.177	6%	0.010
Kota Madiun	195,000	12%	324	0.135	7%	0.010
Kota Balikpapan	688,000	50%	530	0.225	4%	0.008
Kota Jakarta Barat	2,590,000	0.01%	395	0.236	3%	0.008
Kota Batam	1,196,000	71%	523	0.243	3%	0.007
Kota Jakarta Utara	1,828,000	12%	342	0.162	4%	0.007
Kota Solok	73,000	67%	582	0.225	3%	0.006
Kota Denpasar	725,000	18%	257	0.110	6%	0.006
Kota Banda Aceh	253,000	100%	779	0.361	2%	0.006
Kota Tegal	274,000	58%	339	0.230	2%	0.005
Kota Tanjung Balai	176,000	0%	458	0.227	2%	0.005
Kota Surabaya	2,874,000	29%	143	0.162	2%	0.002
Kota Bontang	179,000	67%	451	0.268	1%	0.001
Kota Samarinda	828,000	25%	498	0.194	1%	0.001
Kota Pontianak	659,000	0%	686	0.194	0%	0.000
Kota Banjarmasin	658,000	0%	427	0.195	0%	0.000

5 REFERENCES

Atherholt, T., Feerst, E., Hovendon, B., Kwak, J., & Rosen, J. D. (2003). Evaluation of indicators of fecal contamination in groundwater. *JOURNAL AMERICAN WATER WORKS ASSOCIATION*, *95*(10), 119-131.

Bain, R., Johnston, R., Khan, S., Hancioglu, A., & Slaymaker, T. (2021). Monitoring Drinking Water

Quality in Nationally Representative Household Surveys in Low- and Middle-Income Countries: Cross-Sectional Analysis of 27 Multiple Indicator Cluster Surveys 2014–2020. *Environmental Health Perspectives*, *129*(9), 097010. https://doi.org/10.1289/EHP8459

BPS-Statisitics Indonesia. (2020). *National Socio-Economic Survey (SUSENAS)*. https://www.bps.go.id/

Fan, Y., Li, H., & Miguez-Macho, G. (2013). Global Patterns of Groundwater Table Depth. *Science*, *339*(6122), 940-943. https://doi.org/10.1126/science.1229881

Genter, F., Putri, G. L., Maysarah, S., Rolia, E., Pratama, M. A., Priadi, C., Willetts, J., & Foster, T. (2023). Associations between seasonality and faecal contamination of self-supply sources in urban Indonesia. *Journal of Water, Sanitation and Hygiene for Development*, *13*(10), 793-800. https://doi.org/10.2166/washdev.2023.060

Hartmann, J., & Moosdorf, N. (2012). *Global Lithological Map Database v1.0 (gridded to 0.5° spatial resolution)* PANGAEA. https://doi.org/10.1594/PANGAEA.788537

HOSMER, D. W. J., LEMESHOW, S., & STURDIVANT, R. X. (2013). *Applied Logistic Regression* (3rd ed.). Wiley.

IBM. (2021). *IBM SPSS Statistics for Windows*. In (Version 28.0.0.0 (190)) IBM Corp.

Irianto, J. (2020). *Research Results Report Study of Household Drinking Water Quality in Indonesia*.

Joint Research Centre, J. R. C. E. C., & Center for International Earth Science Information Network, C. C. U. (2021). *Global Human Settlement Layer: Population and Built-Up Estimates, and Degree of Urbanization Settlement Model Grid* NASA Socioeconomic Data and Applications Center (SEDAC). https://doi.org/10.7927/h4154f0w

Kelly, E. R., Cronk, R., Kumpel, E., Howard, G., & Bartram, J. (2020). How we assess water safety: A critical review of sanitary inspection and water quality analysis. *The Science of the total environment*, *718*, 137237-137237. https://doi.org/10.1016/j.scitotenv.2020.137237

Kostyla, C., Bain, R., Cronk, R., & Bartram, J. (2015). Seasonal variation of fecal contamination in drinking water sources in developing countries: A systematic review. *Science of The Total Environment*, *514*, 333-343. https://doi.org/https://doi.org/10.1016/j.scitotenv.2015.01.018

Mbae, M., Hansen, P., Way, C., Mills, F., Willetts, J., Foster, T., & Evans, B. (2024). Onsite sanitation systems and contamination of groundwater: A systematic review of the evidence for risk using the source-pathway-receptor model. *PLOS Water*, *3*(7), e0000167. https://doi.org/10.1371/journal.pwat.0000167

Tillett., H. E. (1993). Potential inaccuracy of microbiological counts from routine water samples. *Water Science and Technology*, *27*(3-4), 15-18.

WHO. (2024, 15 February 2024). *Sanitary inspection for drinking-water supplies*. World Health Organisation. Retrieved 2 August 2024 from https://www.who.int/teams/environment-climate-change-and-health/water-sanitation-and-health/water-safety-and-quality/water-safety-planning/sanitary-inspection-packages

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