Evaluating Variation of Nitrate Concentrations in Indian Rivers

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This study first explains the dangers of nitrate toxicity in drinking water and the possible sources. It then uses data collected from India's Central Pollution Control Board to perform two statistical tests, chi-squared and linear correlation. These two tests are used to conclude that variation of nitrate concentrations in Indian rivers is not correlated with population density, and that risk level varies by each river, suggesting that the source of nitrate concentration issues may lie in land management or pollution control. The last section discusses further research possibilities and uses for the data.

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Introduction

I would first like to speak briefly about myself, my interests, and my purpose in this report. I am seventeen years old and I attend Mission San Jose High School in Fremont, California. I am in the twelfth grade as of August, 2013. My interests include chemistry and chemical engineering, environmental science and engineering, and nanotechnology. I undertook this research after interning at a water pollution control facility in Hayward, California. It gave me a background in environmental science and chemistry and inspired me to undertake this research.

The purpose of this research is to analyze nitrate concentrations in Indian rivers and identify factors that may affect those concentrations. Nitrate is a covalent ion, NO_3^-, with a negative charge. Most nitrates in water come from fertilizer and industrial runoff. Fertilizers use nitrates for nitrogen fixation, stimulating growth of crops, and industries have various uses for nitrogen products, one being the production of explosives. Though nitrate as an ion is less dangerous than ammonia, it can still be highly toxic to humans, especially younger children and infants. The major danger from high nitrate concentrations is methemoglobinemia, which occurs when nitrates oxidize the ferrous (Fe^{2+}) ions in hemoglobin to ferric ions (Fe^{3+}). Since oxygen's ionic state (O^{2-}) has a double negative charge, ferric ions cannot bond with and carry oxygen through the bloodstream. Methemoglobinemia can be fatal if left untreated.

I believe this research will be helpful because research in India is mostly focused on coliforms and heavy metals. Though nitrates appear to be less obviously dangerous substances compared to coliforms and metals, they are still serious contaminants that require more research. I read two reports before choosing nitrates as the course of my study; they are both excellent sources of information on contamination of the environment. The first is *Nitrates: Health Effects in Drinking Water* by Margaret McCasland, Nancy M. Trautmann, and Keith S. Porter and Robert J. Wagenet. The second is *Water Quality* published by the Center for Earth and Environmental Science at Purdue University. I will cite these and a few other resources in the List of Works Cited at the end.

Data Collection and Analysis/Methodology

For this project, I used data from the Central Pollution Control Board in India, using water statistics from major Indian rivers. I performed two tests using different sets of data.

The first set of data utilized 264 data points from the rivers Beas, Sutlej, Ganga, Yamuna, Brahmaputra, Mahi, Narmada, Tapti, Mahanadi, Brahmani, Baitarani, Subarnarekha, Godavari, Krishna, Pennar, and Cauvery. Tributaries were not included. Each data point is the mean nitrate concentration in mg/L taken at a point on the river. The data is in Table 1.

TABLE 1- Mean Nitrate Concentration at Points Along the River (mg/L)

BEAS	SUTLEJ	GANGA	YAMUNA	BRAHMAPUTRA	MAHI	NARMADA	TAPTI
0.20	0.10	0.15	0.20	0.13	0.85	0.85	2.42
0.40	0.10	0.08	0.20	0.14	0.36	1.06	2.50
0.30	0.00	0.08	0.06	0.12	0.34	1.30	3.14
0.40	0.30	0.08	0.07	0.16	0.22	0.98	0.10
0.50	0.20	0.09	0.19	0.15	0.38	0.90	0.22
0.50	0.30	0.06	0.34	0.13	0.14	1.03	0.30
0.70	0.60	0.08	1.39	0.12	0.05	0.48	0.30
0.50	0.70	0.50	1.33	0.12	0.05	0.75	0.27
0.40	0.30	0.21		0.16		0.18	0.23
1.10	1.90	0.23		0.10			0.20
0.40	1.90	0.23					
0.80	5.30	0.28					
1.60	2.00	2.25					
2.00	3.30	2.25					
0.60	2.00	1.70					
1.00	4.00	2.03					
1.80	12.00	2.77					
2.00	6.00	0.85					
1.80	5.00	0.84					
1.50	3.00	1.71					
0.40	3.00	1.65					
0.30	2.70	1.61					
0.50		1.96					
		2.29					
		0.39					
		0.34					
		0.26					
		0.43					
		0.26					
		0.30					
		0.27					
		0.29					
		0.38					
		0.34					

MAHANADI	BRAHMANI	BAITARANI	SUBARNAREKHA	GODAVARI	KRISHNA	PENNAR	CAUVERY
0.80	1.19	0.94	0.25	1.10	0.21	0.65	0.14
1.40	4.15	0.40	5.67	1.51	1.25	0.69	0.13
1.40	2.35	0.85	4.80	1.71	0.43	0.26	0.31
1.60	1.53	0.75	6.55	2.63	1.10	1.30	0.33
2.07	1.54	1.37	6.63	1.91	0.98		0.38
2.51	0.86		5.18	2.84	1.46		0.46
1.48	0.59			2.81	0.61		0.39
1.26	0.54			1.88	0.64		0.35
0.92	0.63			1.89	0.44		0.20
0.18	0.57			1.27	7.28		0.25
0.51	0.60			1.35	7.45		0.20
0.22	0.68			1.23	0.21		0.25
0.39	0.66			1.87	0.30		0.17
0.34	0.92			2.10	0.38		0.22
0.19	0.97			1.40	0.24		0.16
0.66	0.31			1.52	0.41		0.17
0.49				1.81	0.43		0.18
0.59				1.05	1.11		0.23
0.48				1.78	1.07		0.20
0.35				0.31	0.27		0.16
0.69				0.30	0.24		0.20
0.78				0.80	0.18		0.21
1.40				0.28			0.22
				0.27			0.25
				0.23			0.19
				0.30			0.21
				0.26			0.22
				0.26			
				0.27			0.20
				0.32			0.16
				1.74			
				1.20			
				1.49			
				1.96			
				1.90			

From this data, I calculated risk counts. A data point was considered a risk to humans and the environment if it was above 1.00 mg/L. Literature is unclear as to specific levels of nitrates that constitutes a risk, but the Center for Earth and Environmental Science defines concentrations of under 0.9 mg/L as good or excellent, 0.9 to 2.0 mg/L as fair, and above 2.0 mg/L as poor. However, this is consideration for stream water, not for drinking water, so I used the more conservative metric of 1.00 mg/L. The risk counts were as follows:

TABLE 2- Nitrate Toxicity Risk Counts by River

BEAS	SUTLEJ	GANGA	YAMUNA	BRAHMAPUTRA	MAHI	NARMADA	TAPTI
7	13	10	2	0	0	3	3
MAHANADI	**BRAHMANI**	**BAITARNI**	**SUBARNAREKHA**	**GODAVARI**	**KRISHNA**	**PENNAR**	**CAUVERY**
8	5	1	5	24	7	1	0

This added up to a total of 89 risk counts. I then conducted a χ^2Goodness of Fit Test to test whether rivers in India vary substantially in number of health risks due to nitrate concentrations.

The second test I conducted used 363 data points from the rivers Beas, Sutlej, Ganga, Yamuna, Brahmaputra, Mahi, Narmada, Tapti (also referred to as Tapi), Mahanadi, Brahmani, Baitarani (also referred to as Baitarni), Godavari, and Subarnarekha. Tributaries were included. The other rivers were not included due to lack of sufficient data. Each data point was matched with a corresponding population density, collected from the India Census, and a linear correlation test was performed. The data is in Table 3. This test was conducted to reveal any correlation between population density and nitrate concentration, with population density as the independent variable and nitrate concentration as the dependent variable.

TABLE 3- Mean Nitrate Concentration vs. Population Density

STATION # AND LOCATION		MEAN N CONC. (mg/L)	POPULATION DENSITY (inh/sq km)
1001	BEAS AT U/S MANALI	0.20	123
1002	BEAS AT D/S KULU	0.40	69
1003	BEAS AT D/S AUT	0.30	69
1004	BEAS AT U/S PANDON DAM	0.40	230
1005	BEAS AT EXIT OF TUNNEL DEHAL POWER HOUSE	0.50	230
1550	U/S MANDI	0.50	230
1006	BEAS AT D/S MANDI	0.70	5446
2604	BEAS AT D/S JAISINGHPUR	0.50	205
1007	BEAS AT D/S ALAMPUR	0.40	772
1008	BEAS AT D/S DEHRAGOPIPUR	1.10	263
1009	BEAS AT D/S PONG DAM	0.40	2300
1693	BEAS AT TALWARA H/W	0.80	2300
1694	U/S PATHANKOT	1.60	649
1695	U/S PATHANKOT	2.00	649
1010	BEAS AT MIRTHAL BRIDGE, GURDASPUR	0.60	649
1294	BEAS AT 1KM.D/S OF EFFL. DISH. POINT AT MUKERIAN	1.00	8193
1011	BEAS AT G.T.ROAD UNDER BDG. NEAR KAPURTHALA	1.80	501
1696	U/S GOINDWAL	2.00	464
1012	BEAS AT 100M D/S INDUST. DISCH. GOINDWAL	1.80	464
1697	BEAS AT HARIKE	1.50	464
2601	BEAS AT D/S MANALI	0.40	123
2602	BEAS AT U/S KULLU	0.30	69
2603	BEAS AT D/S PANDOH DAM	0.50	230
1867	SUTLEJ B/C WITH RIVER SPITI AT KHAB, DISTT.KINNAUR	0.10	13
2611	SUTLEJ AT KHAB	0.10	13
1389	SUTLEJ AT NEPTHA ZAKHAI	0.00	13
1086	SUTLEJ AT U/S RAMPUR	0.30	3900
1087	SUTLEJ AT D/S RAMPUR	0.20	3900
1013	SUTLEJ AT U/S TATAPANI	0.30	352
1014	SUTLEJ AT U/S SLAPPER	0.60	987
1015	SUTLEJ AT D/S SLAPPER	0.70	987
1016	SUTLEJ AT D/S BHAKHRA	0.30	123
1017	SUTLEJ AT 100M U/S OF HEADWORKS, NANGAL	1.90	987
1018	SUTLEJ AT 100M D/S ,NANGAL	1.90	987
1293	SUTLEJ AT 1 KM. D/S OF ZENITH	5.30	987
1814	SUTLEJ AT D/S KIRATPUR SAHIB	2.00	610
1019	SUTLEJ AT U/S HEAD WORKS ROPAR	3.30	610
1380	SUTLEJ AT D/S NFL	2.00	610

1690	U/S BUDHA NALLAH (UPPER)	4.00	975
1020	SUTLEJ AT 100M D/S BUDHA NALA CONFL.,LUDHIANA	12.00	975
1021	SUTLEJ AT BOAT BDG. DHARMKOTNAKODAR ROAD, JALANDHAR	6.00	598
1381	SUTLEJ AT D/S EAST BASIN	5.00	747
1691	U/S HUSSANIWALA - H/W FEROZEPUR	3.00	380
1692	D/S HUSSANIWALA-H/W FEROZEPUR	3.00	380
1022	SUTLEJ AT BRIDGE HARIKE, AMRITSAR	2.70	932
1088	RAVI AT U/S MADHOPUR	0.50	248
1089	RAVI AT U/S CHAMBA	0.40	1645
2614	RAVI AT AT CHAMERA RESERVOIR	0.40	977
2615	RAVI AT AT D/S CHAMERA III HEP	0.30	977
2613	RAVI AT D/S OF CHAMBA TOWN	0.60	1645
1097	RAVI AT U/S OF MADHOPUR HEADWORKS,GURDASPUR	0.70	248
1290	PARVATI BEFORE CONF. TO RIVER BEAS	0.30	69
2605	PARVATI AT U/S MANIKARAN	0.30	69
2606	PARVATI AT D/S MANIKARAN	0.30	69
1090	LARGI AT D/S	0.40	69
1551	SIRSA , U/S SITOMAJRI NALLAHGARH	1.30	4970
1552	SIRSA , D/S NALAGARH BRIDGE	0.80	4970
1868	SIRSA AT D/S NALAGARH DISTT. SOLAN	1.20	4970
1869	SWAN AT D/S NANGAL DISTT. UNA	1.00	488
2616	SIUEL AT D/S SURGANI	0.50	464
2607	SUKETI KHAD AT D/S MANDI	0.90	253
2608	BINWA AT D/S PAPROLA/BAIJNATH	0.50	263
2609	NEUGAL AT D/S THURAL	0.60	263
2610	SPITI AT KHAB	0.10	13
2612	BASPA AT U/S RESERVOIR BASPA PROJECT	0.10	13
1491	BHAGIRATHI AT GANGOTRI	0.15	30
1484	ALKANANDA B/C MANDAKINI AT RUDRA PRAYAG	0.08	119
1485	MANDAKINI B/C ALKALNADA AT RUDRAPRAYAG	0.08	119
1486	ALKANANDA A/C MANDAKINI AT RUDRAPRAYAG	0.08	119
1487	ALKANANDA B/C TO BHAGIRATHI AT DEVPRAYAG	0.09	41
1488	BHAGIRATHI B/C WITH ALAKNANDA AT DEVPRAYAG	0.06	41
1489	ALKANANDA A/C WITH BHAGIRATHI AT DEVPRAYAG	0.08	41
1062	GANGA AT GARHMUKTESHWAR	0.50	100
2488	GANGA U/S, ANOOPSHAHAR	0.21	1600
2489	GANGA D/S, ANOOPSHAHAR	0.23	1600

1145	GANGA AT NARORA (BULANDSAHAR)	0.23	788
2490	AT KACHHLA GHAT, ALIGARH	0.28	991
1063	GANGA AT KANNAUJ U/S (RAJGHAT)	2.25	700
1066	GANGA AT KANNAUJ D/S	2.25	700
1146	GANGA AT BITHOOR (KANPUR)	1.70	1366
1067	GANGA AT KANPUR U/S (RANIGHAT)	2.03	1366
1068	AT KANPUR D/S (JAJMAU PUMPING STATION)	2.77	1366
1147	GANGA AT DALMAU (RAI BAREILLY)	0.85	739
2498	GANGA AT KALA KANKAR, RAEBARELI	0.84	739
1046	AT ALLAHABAD (RASOOLABAD)	1.71	1087
2487	GANGA AT KADAGHAT, ALLAHABAD	1.65	1087
1049	AT ALLAHABAD D/S (SANGAM)	1.61	1087
2485	GANGA U/S, VINDHYACHAL, MIRZAPUR	1.96	552
2486	GANGA D/S, MIRZAPUR	2.29	552
1080	GANGA AT BAHARAMPORE	0.39	9891.5
2511	NABADIP ON GANGA,GHOSHPARA NEAR MONIPURGHAT	0.34	3300
2506	TRIBENI ON GANGA, NR BURNING GHAT	0.26	1800
1054	GANGA AT PALTA	0.43	2500
1472	GANGA AT SERAMPORE	0.26	1800
1053	GANGA AT DAKSHINESHWAR	0.30	2500
1471	GANGA AT HOWRAH-SHIVPUR	0.27	3300
1470	GANGA AT GARDEN REACH	0.29	820
1052	GANGA AT ULUBERIA	0.38	3300
1469	GANGA AT DIAMOND HARBOUR	0.34	820
1492	YAMUNA AT YAMUNOTRI	0.20	41
1493	YAMUNA AT HANUMANCHATTI	0.20	280
1494	YAMUNA AT U/S OF LAKHWAR DAM	0.06	550
1490	YAMUNA AT U/S DAK PATTHAR	0.07	550
1553	YAMUNA , U/S PAONTA SAHIB	0.19	188
1554	YAMUNA , D/S PAONTA SAHIB	0.34	188
1129	YAMUNA AT ALLAHABAD	1.39	1087
1069	YAMUNA AT ALLAHABAD D/S (BALUA GHAT)	1.33	1087
2724	SUSWA RIVER AT MOTHRAWALA, DEHRADUN	0.70	550
1064	RAMGANGA AT KANNAUJ (BEFORE CONF.)	3.79	792
2497	KALINADI (EAST) AT KHARKHODA-PARIKSHIT GARH RD, VILL. KOL, MEERUT	5.52	697

1480	KALINADI (EAST) AT U/S OF GULAOTHI TOWN IN BULANDSAHAR	0.70	788
1065	KALINADI (EAST) AT KANNAUJ (BEFORE CONF.)	3.72	792
1361	SAI AT UNNAO AFTER DRAIN OUTFALL	1.70	682
1350	GOMTI AT SITAPUR U/S AT WATER INTAKE	1.47	779
1351	GOMTI AT LUCKNOW U/S AT WATER INTAKE POINT	1.71	1815
1352	GOMTI AT LUCKNOW D/S	3.74	1815
2491	RAPTI AT RAJGHAT, GORAKHPUR	0.55	1336
1363	RAPTI A/C R. HONIN NR. DOMINGARH RLY BDG, GORAKHPUR	0.39	1336
1354	SARYU AT AYODHYA AT MAIN BATHING GHAT	0.62	4800
1355	GHAGHARA AT DEORIA D/S	0.44	1220
2492	GHAGHRA AT BARHALGANJ, GORAKHPUR	0.50	1336
1359	RIHAND AT RENUKUT U/S	0.82	274
1360	RIHAND AT RENUKUT D/S	0.89	274
1510	TONS RIVER	0.13	550
2620	ASHWANI AT U/S YASHWANT NAGAR	0.79	1157
2626	BATTA AT U/S PAONTA	0.31	188
2621	GIRI AT D/S YASHWANT NAGAR	0.49	1157
2623	GIRI D/S SATAUN	0.38	188
2618	PABBAR AT U/S ROHRU	0.19	159
2619	PABBAR AT D/S SWARAKUDDU	0.12	159
1477	KALINADI AT U/S MUZAFFAR NAGAR	2.44	1033
1478	KALINADI AT D/S MUZAFFAR NAGAR	2.24	1033
1483	HINDON A/C WITH R. KRISHNA & KALI NEAR BINAULI TOWN, MEERUT	1.74	1342
2496	HINDON AT SARDHANA BUDHANA ROAD, VILLAGE BAPARSI, MEERUT	4.53	1342
1358	HINDON AT GHAZIABAD D/S	0.65	3967
2119	BETWA AT NAYAPUR D/S MANDIDEEP INDL. AREA NO.1, .RAISEN	4.26	157
2121	BETWA NEAR ROAD BDG, BHOJPUR	1.28	1136
2122	BETWA NEAR W/S INTAKE WELL POINT RAISEN	0.93	157
1614	BETWA NEAR INTAKE POINT, VIDISHA	1.35	198
2124	BETWA AT CHARANTIRGHAT, VIDISHA	4.37	198
2125	BETWA D/S AFTER MIXING BAIS AT VIDISHA	1.89	198
1735	GOVIND SAGAR	0.00	322
1356	BETWA B/C YAMUNA AT HAMIRPUR	0.06	406
1613	KOLAR DAM WATER SUPPLY INTAKE WELL, DISTT. SEHORE	0.46	199

1365	CHAMBAL AT NAGDA U/S (WATER INTAKE POINT)	1.23	356
1366	CHAMBAL AT NAGDA D/S	2.89	356
2955	CHAMBAL ENTERING IN RAJASTHAN AT GANDHI SAGAR DAM, KOTA	0.23	374
1418	CHAMBAL AT GANDHI SAGAR DAM, RAMPURA	0.60	194
1288	CHAMBAL AT KOTA U/S (INTAKE PT. NEAR BARRAGE)	0.38	374
1289	CHAMBAL AT KOTA D/S	0.43	374
1413	CHAMBAL AT RAMESHWARGHAT NR. SAWAIMADHOPUR	0.62	257
1609	CHAMBAL AT DHOLPUR	0.48	398
2126	PARVATI A/C OF VINDHYACHAL NALLA, PILUKHEDI	1.92	251
2954	PARVATI BEFORE MEETING RIVER CHAMBAL AT KHATOLI, KOTA	0.52	374
1607	GOHAD DAM, GOHAD	0.40	382
1367	KHAN AT KABIT KHEDI (NR INDORE)	0.03	839
1369	KSHIPRA AT RAMGHAT AT UJJAIN	1.60	356
1370	KSHIPRA AT TRIVENISANGAM	3.01	1087
1468	KSHIPRA AT SIDDHAWAT (D/S)	1.95	356
2953	KALI SINDH AT ANICUT OF M/S CFCL GADEPAN, KOTA	0.67	374
2956	KALI SINDH AT BAROD RD BDG, KOTA	0.57	374
1608	SINDH AT DABRA	0.40	445
2117	BICHIA, BRIDGE GOVINDGARH ROAD	2.80	788
1433	SANKH AT TIGRA RESERVOIR	0.30	445
2950	BANAS, DHANARI DAM, NEAR SWAROOPGANJ, SIROHI	0.33	202
2952	BANAS NEAR NEWTA DAM, JAIPUR	0.52	598
2951	BANAS, BISULPUR DAM, TONK	0.19	198
2945	CHHAPI, U/S CHHAPI DAM	0.51	290
2946	UJAD U/S BHIM SAGAR DAM	0.37	227
1331	DAMODAR AT DISHERGARH VILL.(NR.BIHAR-WB BORDER)	0.29	1100
1332	DAMODAR AT D/S OF IISCO AFTER 3RD OUTFALL AT DHENNA VILLAGE	0.25	1072
1334	DAMODAR NEAR MUJHER MANA VILLAGE A/C TAMLA NALLAH	1.97	1100
1335	DAMODAR AT HALDIA D/S (2 KM AWAY FROM HALDIA TOWN)	0.32	923
2527	WATER INTAKE PT BURDWAN TOWN	0.63	6200
1336	BARAKAR AT ASANSOL (WATER INTAKE PT)	0.50	4434
2509	D/S OF RUPNARAYAN AT KOLAGHAT, NEAR KOLAGHAT RAIL BRIDGE NO.3	0.31	923

1337	RUPNARAYAN B/C R. GANGA NR GEONKHALI	0.38	923
2541	WATER INTAKE POINT - BANKURA TOWN ON R. DWARAKESHWAR	0.29	523
2531	U/S OF TARAPITH ON RIVER DWARKA AT SADHAK BAMDEB GHAT	1.35	1721
2532	D/S OF TARAPITH ON DWARKA, SATIGHAT	0.97	1721
2508	D/S OF SILABATI AT GHATAL,	0.30	1076
2514	JALANGI, D/S OF KRISHNA NAGAR	0.45	1316
1764	CHURNI D/S OF SANTIPUR TOWN	0.41	1316
2518	CHURNI, MAJHADIA	0.41	1316
2517	MATHA BHANGA, GOBINDAPUR	0.48	24,252
2534	WATER INTAKE POINT FOR SURI TOWN ON R. MAYURAKSHI	0.18	771
2507	D/S OF KANSI AT MIDNAPORE, NEAR NEW HANUMAN MANDIR	0.17	1076
1946	MAHANANDA AT SILIGURI	0.33	585
2525	MAHANANDA D/S, RAMGHAT	0.27	356
2549	U/S OF VINDYADHARI AT HAROA BDG	0.17	2463
2550	D/S OF VINDYADHARI AT MALANCHA BURNING GHAT	0.64	819
1260	BRAHMAPUTRA AT KHERGHAT (A/ C DIBANG & DIHANG)	0.13	5
1030	BRAHMAPUTRA AT DIBRUGARH	0.14	393
1262	BRAHMAPUTRA AT NIMATIGHAT	0.12	383
1031	BRAHMAPUTRA AT PANDU	0.15	436
2069	BRAHMPUTRA NEAR WATER INTAKE PT AT KACHARIGHAT, PANBAZAR	0.12	436
2064	BRAHMAPUTRA AT CHANDRAPUR	0.12	192
2067	BRAHMPUTRA AT SUALKUCHI	0.16	436
2066	BRAHMAPUTRA AT DHUBRI	0.10	1171
1261	SUBANSIRI AT GEREKAMUKH,ASSAM,(B/C BRAH.)	0.11	213
2061	KHARSANG B/C BURIDIHING NEAR KHARSANG	0.13	32
1422	BURHIDIHING AT MARGHERITA	0.12	347
2062	BURIDIHING NR DULIAJAN AT D/S,	0.13	393
2230	BURHIDIHING AT DULIAJAN (INTAKE POINT OF OIL INDIA LTD.)	0.16	393
2065	PAGLDIA NALBARI TOWN, NALBARI	0.12	763
1530	DIGBOI AT LAKHIPATHE,RES. FOREST	0.11	393
2063	JAI BHARALI NEAR BISWANATH CHARALI, SONITPUR	0.10	365

2237	KALONG AT U/S OF ANANDARAM DEKIAL PHUKAN BRIDGE, NAGAON	0.11	711
2059	KOLONG AT MARIGAON	0.11	618
2060	MANAS AT NH-31 CROSSING, BARPETA, DISTRICT	0.13	632
2058	DISANG AT DILLIGHAT, DIBRUGARH	0.16	393
1298	DISANG AT GUNDAMGHAT	0.13	393
1258	JHANJI AT N.H. CROSSING JORHAT	0.15	383
1527	BHOGDOI AT JORHAT	0.12	383
1531	*MORA BHARALI AT TEZPUR	0.12	365
1423	BORAK AT PANCHAGRAM	0.11	753
1528	BHARALU AT GUWAHATI	0.27	2010
1529	DEEPAR BILL	0.20	436
2068	U/S OF KATHAKAL ,MATIJURI	0.11	192
1801	TEESTA A/C RIVERS LACHENCHU AND LACHUNGCHU AT CHUNGTHAANG	2.31	10
1807	TEESTA A/C RANICHU AT SINGTAM	2.70	295
1809	TEESTA AT MELLI DOWNSTREAM	2.80	196
1947	TEESTA AT SILIGURI	0.25	585
1802	DIKCHU B/C RIVER TEESTA NEAR NHPC HYDROELECTRIC POWER PROJECT, SIKKIM	2.30	196
1803	MANEY KHOLA AT BURTUK NEAR ARMY BASE CAMP, 4 KM U/S OF GANGTOK, SIKKIM	2.32	295
1804	MANEY KHOLA A/C RAY KHOLA AT ADAMPOOL AFTER MEETING WASTE OF STP, GANGTOK	2.37	295
1805	AFTER CONFLUENCE OF RANICHU AND RORACHU AT RANIPOOL, SIKKIM	2.54	295
1806	RANICHU BEFORE CONFLUENCE WITH RIVER TEESTA AT SINGTAM	2.53	295
2229	KUNDLI AT KUNDLI/ SAPAKHOWA, SADIA.	0.14	347
2231	DIKHOW AT DIKHOW BDG SIVASAGAR	0.15	431
2232	KOHORA AT N.H. CROSSING, KOHORA	0.12	302
2233	BOGINADI NR BDG NH-52, LAKHIMPUR	0.10	457
2236	KAPILI AT DHARMTUL BRIDGE, NH-31, NAGAON	0.10	711
2239	SANKOSH, DHUBRI	0.14	1171
2240	BARAK AT D/S OF SILCHAR	0.14	459
2241	SONAI AT SONAI	0.11	365
2242	KUSHIARA AT KARIMGANJ	0.13	673
2523	KAROLA, D/S OF JALPAIGURI, NEAR MIN BHAWAN	0.19	621

2524	KALJANI D/S OF ALIPURDWAR, MUNICIPALITY DISCHARGE POINT	0.19	621
2235	PANCHNAI AT NH-52 CROSSING, ORANG	0.11	365
1863	MAHI AT UMETA BRIDGE	0.36	711
1864	MAHI AT MUJPUR	0.34	234
4	MAHI AT SEVALIA	0.22	541
5	MAHI AT VASAD	0.38	711
1229	MAHI NEAR RAJASTHAN BORDER AT KADANA DAM	0.14	458
1231	MAHI AT VIRPUR	0.05	282
2102	SHIVNA AT RAMGHAT, MANDSAUR	0.93	242
2103	JAMMER AT DHOLOWAD, RATLAM	0.72	299
2104	MALEI AT JAORA	1.48	299
2105	CHILLAR AT SHAJAPUR	0.99	244
1228	ANAS AT DAHOD,(KUSHALGARH), PANCHMAHAL	0.17	458
1227	PANAM AT LUNAWADA	0.03	458
1482	SABARMATI AT MAHUDI JAIN TEMPLE, 150 KM. FROM ORIGIN	0.47	660
1222	SHEDHI AT KHEDA	0.27	541
1241	NARMADA AT MANDLA NR RD BDG	0.85	182
44	NARMADA AT SETHANIGHAT	1.06	185
1240	NARMADA AT NARSINGHPUR	1.30	213
1234	NARMADA AT HOSHANGABAD U/S	0.98	185
2123	NARMADA AT KORIGHAT	0.90	185
1235	NARMADA AT HOSHANGABAD D/S	1.03	185
2106	RIVER NARMADA AT NEMAWAR	0.48	223
2099	NARMADA AT LALPUR, JABALPUR	0.75	472
1245	NARMADA AT CHANDOD	0.18	561
2100	GOUR AT BHOGA DOOR, JABALPUR	0.73	472
2101	KATNI RIVER NEAR NAGAR NIGAM	0.97	310
1251	TAPI AT BHUSAWAL US	2.50	359
1247	TAPI AT MANDAVI	0.22	46
47	TAPI AT KATHORE, (NH-8 BRIDGE)	0.30	653
1248	TAPI AT SURAT U/S KATHORE	0.30	653
1982	TAPI AT RANDER BRIDGE, SURAT	0.27	653
1983	TAPI NR BARDOLI (KAPP BRIDGE)	0.23	653
2071	TAPI AT ONGC BRIDGE AT SURAT	0.20	653
1253	GIRNA AT MALEGAON (MANMAD)	1.74	393
1252	GIRNA AT JALGAON	2.51	359

2070	KIM AT SAHOL BRIDGE, OLPAD HANSOT ROAD, DIST. SURAT	0.30	653
1907	RANGAVALI D/S OF NAVAPUR	2.75	276
2127	DENWA NEAR SARNI, ROAD BRIDGE	3.40	157
2155	PURNA A/C MORNA, NANDURA VILL.	3.25	268
2652	AMRAVATI D/S DONDAICHA, DHULE	3.03	285
2658	BORI D/S OF AMALNER, JALGAON	2.47	359
2666	GOMAI D/S OF SHAHADA, DHULE	2.84	285
2667	HIWARA D/S OF PACHORA, JALGAON	2.28	359
2674	MOR NEAR PADALSHE, JALGAON	2.54	359
2675	MORNA AT D/S OF RAILWAY BRIDGE AT AKOLA.	2.04	321
2684	PANZARA NEAR PANZARAKAN SSK LTD, PANZARA,DHULE	2.15	285
2695	PEDHI NEAR ROAD BRIDGE AT DADHI-PEDHI VILLAGE, BHATKULI, AMRAVATI	2.41	237
2710	TITUR D/S OF CHALISGAON, JALGAON	1.96	359
2718	WAGHUR AT SAKEGAON B/C TAPI RIVER, JALGAON	2.12	359
1851	MAHANADI AT SIHAWA	0.80	236
1264	MAHANADI AT RUDRI U/S AT DHAMTORI RESERVOIR	1.40	236
1099	MAHANADI AT U/S OF RAJIM	1.40	310
1852	MAHANADI AT ARRANG, RAIPUR	1.60	310
1281	MAHANADI AT HIRAKUD RESERVOIR	0.92	158
1270	MAHANADI AT SAMBALPUR U/S	0.18	158
1271	MAHANADI AT SAMBALPUR D/S	0.51	158
1272	MAHANADI D/S (AFTER CONFL. WITH R. ONG SONEPUR U/S)	0.39	279
1274	MAHANADI A/C R.TEL (SONEPUR D/S)	0.34	279
1275	MAHANADI AT TIKARPADA	0.19	199
1276	MAHANADI AT NARSINGHPUR	0.66	213
1277	MAHANADI AT CUTTACK U/S	0.49	666
1278	MAHANADI AT CUTTACK D/S	0.59	666
2409	CUTTACK FDS (SERUA) AT SANKHATRASA	0.48	666
2406	MUNDALI(WATER INTAKE POINT OF BHUBANESWAR CITY	0.35	799
2404	POWER CHANNEL D/S NEAR BURLA	0.69	158
2407	PARADEEP U/S (BEFORE INDUSTRIAL ACTIVITY AT PARADEEP)	0.78	681
1639	MAHANADI AT PARADEEPD/S	1.40	681

1107	SEONATH AT U/S RAJNANDGAON	0.49	191
1845	SEONATH RIVER WATER SUPPLY WELL, DURG.	0.40	191
1265	KHAROON AT RAIPUR U/S	1.40	310
1847	KHAROON RIVER B/C KHAPRI DRAIN, DURG, RAIPUR ROAD BRIDGE	0.50	310
1846	KHAROON RIVER A/C KHAPRI DRAIN	0.60	192
1853	KHAROON RIVER BUNDRI, RAIPUR	1.50	310
1105	HASDEO AT U/S KORBA	1.31	183
1849	KELO RIVER U/S OF RAIGARH	1.22	211
1850	KELO RIVER D/S OF RAIGARH	1.26	211
1267	IB AT SUNDARGARH, ORISSA	0.39	214
1268	IB AT JHARSUGUDA (INTAKE)	0.34	274
1269	IB AT BRAJRAJNAGAR (INTAKE) D/S	0.42	274
2403	BHEDEN B/C WITH IB RIVER	0.43	253
1279	KUAKHAI AT BHUBANESWAR U/S	1.29	799
1280	KUAKHAI AT BHUBANESWAR D/S	3.19	799
2410	KUAKHAI AT BHUBANESWAR FU/S	0.29	799
2411	DAYA AT BHUBANESWAR FD/S (2 KM AFTER CONFL. OF GANGUA NALLAH W.RIVER DAYA)	2.39	799
1301	KATHAJODI AT CUTTACK D/S	0.54	666
2412	SANKHA U/S (D/S OF MANDIRA DAM)	1.51	214
2408	TEL RIVER	0.51	251
1640	BIRUPA AT CHOUDWAR	0.63	666
1037	BRAHMANI AT U/S PANPOSH	1.19	214
1038	BRAHMANI AT D/S PANPOSH	4.15	214
1302	BRAHMANI AT ROURKELA D/S	2.35	6696
2414	ROURKELA FD/S AT BIRITOLA	1.53	992
1039	BRAHMANI AT BONAIGARH	1.54	214
1040	BRAHMANI AT RENGALI	0.86	199
1303	BRAHMANI AT TALCHER U/S	0.54	199
2415	BRAHMANI AT TALCHER FU/S (INTAKE WELL OF MCL, TALCHER)	0.63	199
2416	BRAHMANI AT TALCHER FD/S	0.57	199
1042	BRAHMANI AT KAMALANGA	0.60	268
2417	DHENKANAL D/S, DHENKANAL TOWN	0.68	268
1043	BRAHMANI AT BHUBAN	0.66	268
2418	KABATABANDHA (BEFORE IMPACT OF INDL ACTIY KALINGANAGAR AREA)	0.92	630
1044	BRAHMANI AT DHARMASHALA	0.97	630

1045	BRAHMANI AT PATTAMUNDAI	0.31	545
2419	KHANDITARA (D/S OF INDUSTRIAL ACTIVITIES AT KALINGA NAGAR)	0.50	630
1081	BAITARNI AT JODA	0.94	217
1082	BAITARNI AT ANANDPUR	0.40	217
1083	BAITARNI AT JAJPUR	0.85	630
1084	BAITARNI AT CHANDBALI	0.75	601
1085	BAITARNI AT DHAMRA	1.37	601
2421	KUSEI BEFORE JOINING BAITARANI AT ANANDPUR	0.28	217
2399	SUBARNAREKHA AT CHANDIL DAM	5.67	390
48	SUBARNAREKHA AT CHANDIL BDG	4.80	390
24	SUBARNAREKHA AT JAMSHEDPUR	6.55	648
49	SUBARNAREKHA AT D/S JAMSHEDPUR,(TATA NAGAR)	6.63	648
2387	SUBARNAREKHA AT GHATISLA ROAD BRIDGE	5.18	650
1312	GODAVARI AT JAYAKWADI DAM, AURNAGABAD	1.10	760
2177	GODAVARI RIVER NEAR SOMESHWAR TEMPLE.	1.51	393
2182	GODAVARI RIVER AT SAIKHEDA.	1.71	204
2179	GODAVARI AT HANUMAN GHAT, NASHIK CITY.	2.63	393
2183	GODAVARI AT NANDUR-MADMESHWAR DAM.	1.91	393
2181	GODAVARI AT KAPILA- GODAVARI CONFLUENCE POINT, TAPOVAN.	2.84	393
2180	GODAVARI RIVER NEAR TAPOVAN	2.81	393
1096	GODAVARI AT PANCHAVATI AT RAMKUND	1.88	393
1211	GODAVARI AT NASIK D/S	1.89	393

Nitrates χ^2Goodness of Fit Test

1. We will conduct a χ^2 test for goodness of fit to test whether rivers in India vary substantially in the number of health risks due to mean nitrate concentrations using 16 samples and risk counts, $\pi_1 - \pi_{16}$
2. $H_o: \pi_1 = \pi_2 = \pi_3 = \pi_4 = \pi_5 = \pi_6 = \pi_7 = \pi_8 = \pi_9 = \pi_{10} = \pi_{11} = \pi_{12} = \pi_{13} = \pi_{14} = \pi_{15} = \pi_{16}$
3. $H_a: H_o\ is\ false$
4. Significance level: $\alpha = 0.05$
5. Test statistic: $\chi^2 = \sum_{all\ cells} \frac{(observed - expected)^2}{expected}$ where $expected = \frac{total\ observed}{nuber\ of\ cells}$
6. Requirements
    a. Samples are assumed to be random and independent
    b. Samples are assumed to contain less than 10% of the population, the population being all sites on the river
    c. Data is categorical

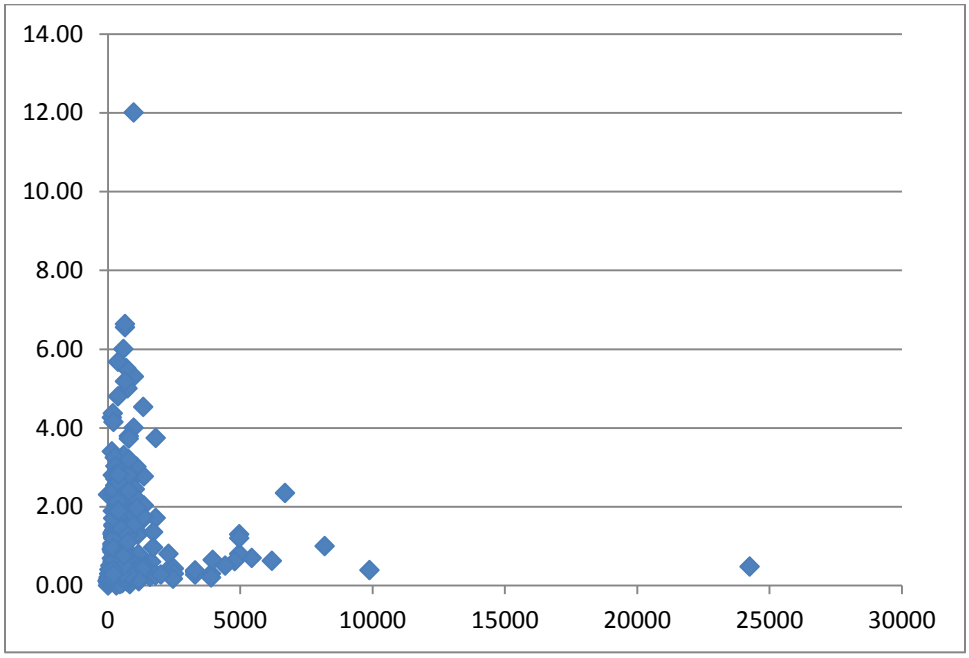
Observed	Expected
7	5.5625
13	5.5625
10	5.5625
2	5.5625
0	5.5625
0	5.5625
3	5.5625
3	5.5625
8	5.5625
5	5.5625
1	5.5625
5	5.5625
24	5.5625
7	5.5625
1	5.5625
0	5.5625

Since all expected cell counts are greater than or equal to 5, requirements for the test appear to be met and we proceed.

7. $\chi^2 = \frac{(7-5.5625)^2}{5.5625} + \frac{(13-5.5625)^2}{5.5625} \ldots + \frac{(0-5.5625)^2}{5.5625} = 105.3371$
8. Using a graphing utility and χ^2 distribution, we calculate a p-value of 1.2596×10^{-15} using 15 degrees of freedom.
9. Based on these samples (and significance level $\alpha = 0.05$), we reject H_o. Because $p = 1.2596 \times 10^{-15} < \alpha = 0.05$, there is sufficient evidence to conclude that different rivers in India have differing levels of risk due to nitrate concentration.

Nitrates Linear Regression Test

1. We will conduct a linear regression t-test to determine whether there is a useful positive correlation between population density and mean nitrate concentration in Indian rivers.
2. $H_o: \beta = 0$
3. $H_a: \beta > 0$
4. Significance level: $\alpha = 0.05$
5. Test statistic: $t = \frac{b-0}{s_b}$
6. Requirements



Based on this scatterplot there does not appear to be a linear correlation nor does there appear to be independent variation between population density and mean nitrate concentration. Therefore, we proceed with reservations.

7. $t = -0.4874$
8. $p = 0.6869$
9. Based on this sample (and significance level $\propto = 0.05$), we fail to reject H_o. Because $p = 0.6869 > \propto = 0.05$, there is insufficient evidence to conclude that there is a useful positive correlation between population density and mean nitrate concentration in Indian rivers.

Results and Discussion

The χ^2 test indicated that different rivers were inclined to have different risk levels for nitrate toxicity, whereas the linear correlation test indicated that there was likely no significant positive linear correlation between population density and mean nitrate concentration, meaning that higher population densities probably do not coincide with higher nitrate concentrations. However, two caveats must be pointed out in the linear correlation test. The first is that the population density data collected is not very accurate. The Indian census only calculates land area for districts and large cities; thus there is no population density statistic for many of the small villages where the samples were collected. When this was the case, I deferred to using the district population density, but this clearly skews the accuracy of the test. The second caveat is that the scatterplot did not indicate a very strong correlation, nor did it indicate independent variation between population density and mean nitrate concentration.

However, if we proceed with the assumption that the tests were reasonably accurate, we have ample room for discussion. If nitrate concentration/risk is more related to the river instead of the population density, it appears to be an issue of land and water management instead of the general activities of people. The river with the highest risk count, Godavari, should be examined carefully for sources of nitrates. Possibilities, as mentioned before, are cropland that uses fertilizer is probably the biggest sourc of nitrates in India. Though sewage and fecal waste can also contribute to nitrates in water, it does not appear to be the significant factor here, as population density does not have a correlation with mean nitrate concentration.

Further research should be done in two areas: land management and pollution control facilities. How do facilities in India maintain health and environmental standards effectively? Do they neglect the danger of nitrates, or do they focus mostly on coliform and heavy metal hazards? How is land managed in river basins? Are farmers subsidized to limit fertilizer use? Are there systems to reduce runoff? Are there enough trees to use up excess nitrates during fixation? I found a helpful paper on the Godavari river basin that analyzes land usage and could be useful for future studies, titled *Assessment of Land Use Land Cover Changes in Middle Godavari (G-5) Sub Basin of River Godavari Using RS and GIS*. It indicates that most worked land in the basin is cropland or fallow. This is useful for any continuing studies into water pollution.

As a concluding statement, I would like to say that these results are actually uplifting because it suggests that the problem lies not in overpopulation, which is difficult, if not impossible, to control, but that it lies within land use and water management, which is something that can be improved and fixed given the right amount of work in Indian pollution and water policy. I look forward to seeing advances in risk assessment and resource management in the future.

Works Cited

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