**Prevalence of childhood diarrheal disease in Bangladesh and the association between *Escherichia coli (E. coli)* contaminated household drinking water, evidence from two waves of multiple indicator cluster surveys**

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**Abstract:**

Background: Fecal contamination of household drinking water by *Escherichia coli [E. coli]* can have negative impacts on children's health, especially increasing the occurrences of childhood diarrhea. We aimed to find out the association between diarrheal episodes in Bangladeshi children under the age of five and the concentration of *E. coli* in household drinking water.

Methods: Two waves of Multiple Indicator Cluster Survey (MICS), MICS-2012 and MICS-2019 were used in this analysis. *E. coli* colonies were quantified as colony-forming units (CFUs) per 100 ml of water and were then categorized into three risk groups. Greater than ten (>10) CFU/100 ml is regarded as high risk, one to ten (1-10) CFU/100 ml is regarded as moderate risk, and less than one (<1) CFU/100 ml of *E. coli* concentration is regarded as low risk of contamination. Unadjusted and adjusted logistic regression models were used to analyze the data considering the complex survey design.

Results: According to MICS data from 2019 and 2012, respectively, we found that children from households with a moderate risk of *E. coli* contamination in drinking water were 1.46 times (adjusted odds ratio, AOR = 1.46, 95% confidence interval, 95% CI: 0.71 - 3.01; P-value = 0.301) and 1.01 times (AOR = 1.01, 95% CI: 0.45 – 2.28; P-value = 0.981) more likely to experience diarrhea than children from the household with a low risk of *E. coli* contamination. Also, for MICS 2019 and 2012, children from households with a high risk of *E. coli* contamination in drinking water were 1.96 (AOR = 1.96, 95% CI: 1.06 - 3.63; P-value = 0.032) and 1.07 (AOR = 1.07, 95% CI: 0.53 - 2.16; P-value = 0.847) times more likely to experience diarrhea than children from households with a low risk of *E. coli* contamination, respectively. However, using MICS-2019 data, we found a strong correlation between *E. coli* contamination (high-risk group) of household drinking water and child diarrheal episodes, but not in MICS-2012 data.

Conclusions: Health outcomes can be improved by lowering fecal contamination of drinking water sources and successfully maintaining good water quality. *E. coli* contamination in drinking water should be kept to a minimum, and good hygiene habits should be developed to stop childhood diarrhea.

**Key Words:** *Escherichia coli*, Drinking water, Childhood disease, Diarrhea, Under-5 children, Bangladesh

1. **Background**

Diarrhea is caused by a variety of bacterial, viral, and parasite organisms, the majority of which are spread by contaminated water. The passing of three or more liquid or loose stools per day is considered to be diarrhea (or more frequent passage than is normal for the individual). Regularly passing formed feces is not diarrhea, and neither is a breastfed baby passing loose, "pasty" stools 1. Diarrhea may be acute, persistent, or chronic. It is one of the leading causes of pediatric sickness and mortality 2. Every year, there are around 1.7 billion cases of childhood diarrhea worldwide 3. In children under the age of five, diarrhea is one of the main causes of malnutrition. Approximately 8% of all fatalities among children under the age of five globally in 2017 were due to diarrhea. Around 525,000 children every year or over 1400 young children per day are dying 4. Diarrhea is the second most common cause of death in children under five 3. It is, however, both treatable and preventable by using clean water, maintaining proper sanitation, and practicing good hygiene 5.

Reducing preventable enteric infections and sometimes chronic illnesses that cripple and kill children is obstructed by poor water quality. In low-income countries like Bangladesh, diarrheal diseases—which are a major cause of child mortality—have mostly been related to exposure to fecal contaminations in drinking water. Point-of-use water treatment is one of the most efficient water, sanitation, and hygiene (WASH) interventions for lowering diarrheal disease, according to systematic reviews and meta-analyses on the efficiency of WASH programs 6,7. Globally, it is likely that massive expansions in access to oral rehydration therapy, water, and sanitation have reduced the number of children dying from diarrheal illnesses 8. Poor WASH practices could raise the risk of diarrheal illnesses, parasitic enteric infections, illnesses spread by mosquitoes, and environmental enteric dysfunction (EED), all of which can have an impact on children's health outcomes 9.

*E. coli* is widely used as a fecal indicator organism. A common fecal indicator bacterium is *E. coli*. Temperature, solar insolation, hydrologic conditions, water chemistry, nutritional conditions, suspended and settled particles, and land-use patterns are only a few of the variables that affect their ability to spread and survive in the environment 10. It can be found in the intestines of mammals, including humans 11. The concentration of *E. coli* is significant in terms of human health. Diarrheal illness is linked to *E. coli* indicators in household drinking water, an appropriate indicator of fecal contamination7. Further, a meta-analysis of 14 studies on various WASH interventions (improved microbiological quality of drinking water, water quantity and supply, sanitation coverage, handwashing, and disposal of child feces) discovered that interventions with solar water disinfection, provision of soap, and improvement of water quality had some benefit on the linear growth of children under 5 years old 12. The effect would be in line with the biological plausibility that enteric infection in young infants can disrupt crucial growth phases if they are exposed to fecal contaminations. Additionally, the impact can be linked to quantifiable concentrations of *E. coli* bacteria that young children may undoubtedly regularly be exposed to through drinking water. Drinking water that has an *E. coli* concentration of more than 100 CFU/100 ml presents a serious health risk to the consumer. It is conceivable that drinking water tainted with *E. coli* could have an impact on children's health status through a variety of biological mechanisms, such as frequent episodes of diarrhea, environmental enteropathy, parasites, or other barriers to nutrient uptake and absorption 9. Salmanzadeh-Ahrabi et al. investigated *E. coli* in youngsters from Tehran who had serious diarrhea 13. It was shown that diarrhea caused by *E. coli* occurs often in children under the age of five in Eastern Ethiopia 14. In a different study, Yu et al. (2015) evaluated 2524 patients and found that 10.7% of cases had diarrhea and 4.6% were caused by *E. coli* (4.6 percent) 15. The Bathing Water Directive emphasizes that bathers' health is seriously at risk if *E. coli* concentrations in bathing water reach 500 CFU/100 ml. According to Nag et al. (2021), there is a 10% probability that a digestive ailment will develop after one exposure to a substance with more than 500 CFU/100 ml 16.

Around 7% of Bangladesh's children under five get affected by diarrhea 17. Around half of those surveyed claimed that diarrheal illness had cost them more than 10% of their income, with the cost of treating diarrhea in Bangladesh estimated to be $79 million in 2018 18. Higher episodes of diarrhea also pose a significant burden to the health system and exert an adverse economic consequence on the children’s families, often requiring an out-of-pocket payment for treatment. According to MICS 2012 and MICS 2019, respectively, around 62% and 82% of people used contaminated drinking water with bacteria like *E. coli* 17,19. The spatial risk distribution and underlying causes of *E. coli* contamination in household drinking water have been identified by a recent study conducted in Bangladesh 20. After examining data from fifty villages in rural Bangladesh, Luby et al. discovered an association between the severity of childhood diarrhea and *E. coli*-polluted drinking water 21.

The benefit of better household water microbiological quality on reducing childhood diarrhea has received fewer experimental studies, however, there is some encouraging evidence for a potential influence. Also, there aren't any empirical studies comparing different survey data on the association between *E. coli* risk groups and diarrhea in young infants. In two successive Multiple Indicator Cluster Surveys (MICS) in Bangladesh, we wanted to examine the association between *E. coli* concentration in household drinking water and diarrheal episodes among children under the age of five. The findings of this study will provide information that will assist decision-makers in managing *E. coli* in drinking water and how frequently childhood diarrhea is observed in Bangladesh.

1. **Methods**

To improve the reporting of observational cross-sectional studies in epidemiology, we adhered to the STROBE guideline (see Supplementary Materials for more details).

* 1. Data source and sampling design

The MICS-2012 and MICS-2019 surveys of Bangladesh, conducted consecutively (https://www.unicef.org/), were used in this study. For this nationwide survey, a two-stage stratified cluster sampling technique was utilized to collect data at the household level. A specified number of census enumeration zones were systematically chosen within each stratum with a probability proportional to size. A systematic sample of 20 households was drawn in each sample PSU following the completion of a household listing within the chosen enumeration regions. For the purpose of reporting survey findings, sample weights are utilized since the sample is not self-weighting. Information on the thorough survey methodology can be found in the final report of the Bangladesh MICS surveys from 2012 and 2019. In MICS-2019, 64,400 households participated and 51,895 households participated in MICS-2012. In the survey, a total of 2760 and 6440 households, one from each cluster in MICS-2012 and two from MICS-2019, were randomly selected for water quality testing 17,19.

* 1. Outcome variables

Childhood diarrhea was the outcome variable; specifically, diarrhea in children under 5 years old was the outcome variable of interest. The mothers (or caretakers) report that the children had any type of diarrheal episode (according to the WHO definition 1) with their children within two weeks before the survey was processed to collect the case of diarrhea in the MICS survey. When respondents said "yes," the diarrhea variable was coded as 1; otherwise, it was set to "0", prior to the analysis 17,19.

* 1. Exposure

The concentration of *E. coli* found in drinking water was the exposure variable. The responders were asked to bring a glass of water for the water test that they frequently drank. A 100 ml sample of drinking water was examined in this investigation by incubating for *E. coli*. The test was performed within 30 minutes after the sample was collected, and the incubation period was between 24 and 48 hours. To classify the risk of contamination, *E. coli* colonies were quantified as colony-forming units (CFUs) per 100 ml of water. A more thorough explanation of the water quality test may be found in the MICS report 17,19. Fecal coliforms are frequently utilized as a fundamental indicator or marker of bacteriological water pollution in sanitary surveys 22. The *E. coli* CFU data from household drinking water were categorized into different risk groups according to the WHO guidelines 23. Less than one (<1) CFU/100 ml of *E. coli* contamination is considered low risk, one to ten (1-10) CFU/100 ml are considered moderate risk, and more than ten (>10) CFU/100 ml are considered as a high-risk category of contamination. A more detailed description of the water quality test can be found in the Bangladesh MICS reports 17,19. A region's water is deemed highly contaminated if it contains more than 100 CFU/100 ml 24. It has been demonstrated that the frequency of *E. coli* detection is linked to a higher chance of contamination with pathogenic Shigella, *E. coli*, and Vibrio 25. When *E. coli* is found in water, it is likely that there are pathogens present that can cause cholera, typhoid, diarrhea, and dysentery. Bangladesh has a criterion that states that a 100 ml sample of drinking water cannot contain any *E. coli* 26.

* 1. Confounding variables

Based on the available data, the variables child age in months, sex of the child, and mother's educational status were included in the study. Household size (<5 or 5/5+), livestock ownership, household wealth status (Poor, middle, or rich), and other factors were considered. An all-encompassing measure of wealth is the wealth index. Principal components analysis is used to create weights (factor scores) for each of the elements used in the wealth index by using data on the ownership of consumer goods, housing characteristics, water and sanitation, and other qualities that are associated with the household's wealth. The survey household population is then divided into three equal quintiles based on the wealth score of the home they reside in, with the lowest quintile (poor) to the highest quintile being the wealthiest (rich) 17,19. Place of residence (rural vs. urban) and administrative division were two variables at the community level (Barisal, Chattogram, Dhaka, Khulna, Mymensingh, Rajshahi, Rangpur, and Sylhet).

Additionally, source water type (the population using improved sources of drinking water is defined as those using any of the following types of supply: piped water (into a dwelling, compound, yard, or plot, to a neighbor, public tap/standpipe), tube well/borehole, protected dug well, protected spring, rainwater collection, and packaged or delivered water) (packaged water (bottled water and sachet water) and delivered water (tanker truck and cart with a small drum/tank are treated as improved based in new SDG definition27), types of toilet facilities (a facility that hygienically separates human interaction from human excreta is referred to as an improved sanitation facility). Shared toilet facilities, source water quality (low, moderate, and high), and improved sanitation facilities like a flush or pour-flush to piped sewer systems, septic tanks or pit latrines, ventilated improved pit latrines, pit latrines with slabs, and composting toilets should all be taken into account. Similar to an exposure sample test, a source water *E. coli* test was used to assess the risk of *E. coli* contamination in the source water 17,19.

* 1. Statistical analysis

In this study, the unadjusted and adjusted logistic regression models were fitted separately. Unadjusted logistic regression analysis was utilized to assess the distribution of the diarrhea variable with other variables. To find out the association, we also fitted the logistic regression model with a complex survey design. As the sampling of the MICS survey considers two-stage cluster sampling, this analysis was considered a complex survey design by taking into account, the sampling cluster/strata, PSU, and also sampling weight. All confounding variables are included in the adjusted logistic regression model. The 95% confidence interval (CI), the crude odds ratio (COR), and the adjusted odds ratio (AOR) were presented. All investigations were performed utilizing R software 4.2.1.

The propensity score (PS) approach was used to evaluate the reliability of the conclusions from our primary studies. By balancing observed baseline factors across treatment groups, PS approaches, widely used in observational studies with dichotomous variables, imitate the intended benefits of randomization 28. All PS techniques seek to generate study populations that are comparable for the treated and untreated categories of target variable when changes in outcome risk may be attributable to the influence of treatment alone and risk factors for the desired result are balanced at baseline. To emulate a PS weighted population, we employed the PS weighting to reweight both exposed (moderate and high) and unexposed (low) groups. A good covariate balancing (0.1) was determined between exposed and non-exposed by the standardized mean difference 29. Using the same covariates as the primary study, we computed the PS using multivariable logistic regression. To eliminate the residual covariate imbalance between the exposed and non-exposed groups, we changed the model by adding related confounders 30.

1. **Results**

In the 2019 MICS, among 2332 children, 10.88% of the 12- to 23-month-olds and had diarrhea. In comparison to all other age groups, the 12- to 23-month-old age group likewise had the greatest prevalence of diarrhea (5.49%) according to the 2012 MICS. Children of mothers with no education or primary incomplete education had diarrhea in 10.17% of MICS 2019 children and 3.30% of MICS 2012 children. In the MICS for 2019 and 2012, 3.81% and 9.12%, respectively, of children from low-wealth status families reported having diarrhea. In 2019 MICS, 7.47% of children drinking from improved sources suffered diarrhea, compared to 3.61% in 2012 MICS. Moreover, the proportion of children from the household with high water *E. coli* concentrations was comparatively higher among those who had diarrhea. The 2019 MICS found that 8.48% of children came from households with high *E. coli* contamination in the drinking water, compared to 3.59% in the 2012 MICS. Also, 7.85% and 2.67%, of the household used water treatment in the 2019 MICS and 2012 MICS, respectively (Table 1).

Table 1. Frequency distribution of diarrhea among children younger than 5 years of MICS 2019 and MICS 2012 data in Bangladesh

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Characteristics | MICS 2019 | | | MICS 2012 | | |
| Diarrhea | | | Diarrhea | | |
|  | Yes  N (%) | No  N (%) | Total  N (%) | Yes  N (%) | No  N (%) | Total  N (%) |
| Total | 173 (7.42) | 2159 (92.58) | 2332 (100.00) | 74 (3.7) | 2000 (96.3) | 2074 (100.00) |
| Child Characteristics | | | | | | |
| Age (in months) |  |  |  |  |  |  |
| 0-11 | 38 (7.96) | 438 (92.04) | 476 (20.40) | 21 (5.04) | 387 (94.96) | 408 (19.64) |
| 12-23 | 49 (10.88) | 398 (89.12) | 446 (19.14) | 25 (5.49) | 439 (94.51) | 464 (22.40) |
| 24-35 | 37 (7.79) | 440 (92.21) | 478 (20.48) | 13 (3.15) | 394 (96.85) | 407 (19.62) |
| 36-47 | 29 (6.17) | 443 (93.83) | 472 (20.23) | 9 (2.23) | 382 (97.77) | 391 (18.84) |
| 48-59 | 20 (4.35) | 440 (95.65) | 460 (19.74) | 6 (1.57) | 398 (98.43) | 404 (19.50) |
| Sex |  |  |  |  |  |  |
| Male | 91 (7.35) | 1152 (92.65) | 1244 (53.33) | 34 (3.17) | 1028 (96.83) | 1062 (51.21) |
| Female | 81 (7.48) | 1007 (92.52) | 1088 (46.67) | 40 (3.98) | 971 (96.02) | 1011 (48.79) |
| Maternal Characteristics | | | | | |  |
| Education Status |  |  |  |  |  |  |
| None/Primary incomplete | 28 (10.17) | 248 (89.83) | 276 (11.86) | 24 (3.30) | 690 (96.70) | 714 (34.42) |
| Primary Complete | 30 (5.59) | 513 (94.41) | 543 (23.31) | 12 (3.53) | 317 (96.47) | 329 (15.85) |
| Secondary | 91 (7.88) | 1059 (92.12) | 1150 (49.31) | 32 (4.40) | 704 (95.60) | 736 (35.50) |
| Secondary Complete/ Higher | 24 (6.52) | 338 (93.48) | 362 (15.53) | 6 (2.16) | 288 (97.84) | 295 (14.22) |
| Household Characteristics | | | | | | |
| Household size |  |  |  |  |  |  |
| <5 | 76 (7.89) | 884 (92.11) | 960 (41.18) | 47 (3.91) | 1165 (96.09) | 1213 (58.51) |
| 5/5+ | 97 (7.07) | 1275 (92.93) | 1372 (58.82) | 26 (3.07) | 834 (96.92) | 860 (41.49) |
| Livestock ownership |  |  |  |  |  |  |
| Yes | 102 (7.39) | 1276 (92.61) | 1378 (59.14) | 47 (3.98) | 1139 (96.02) | 1186 (57.31) |
| No | 71 (7.45) | 881 (92.55) | 952 (40.86) | 27 (3.02) | 857 (96.98) | 883 (42.69) |
| Wealth status |  |  |  |  |  |  |
| Poor | 90 (9.12) | 894 (90.88) | 984 (42.19) | 36 (3.81) | 903 (96.19) | 939 (45.28) |
| Middle | 23 (5.10) | 425 (94.90) | 448 (19.21) | 15 (3.56) | 398 (96.44) | 412 (19.90) |
| Rich | 60 (6.70) | 840 (93.30) | 900 (38.59) | 23 (3.25) | 698 (96.75) | 722 (34.82) |
| Source water type |  |  |  |  |  |  |
| Improved | 171 (7.47) | 2120 (92.53) | 2291 (98.27) | 73 (3.61) | 1944 (96.39) | 2017 (97.28) |
| Unimproved | 2 (3.77) | 39 (96.23) | 40 (1.73) | 1 (1.79) | 55 (98.21) | 56 (2.72) |
| Toilet facility type |  |  |  |  |  |  |
| Improved | 168 (7.44) | 2083 (92.56) | 2251 (96.54) | 69 (3.45) | 1915 (96.54) | 1984 (95.69) |
| Non-improved | 5 (6.43) | 76 (93.57) | 81 (3.46) | 5 (5.98) | 84 (94.02) | 89 (4.31) |
| Toilet facility shared |  |  |  |  |  |  |
| Yes | 58 (7.85) | 675 (92.15) | 733 (31.81) | 14 (2.67) | 514 (97.33) | 528 (25.77) |
| No | 115 (7.32) | 1456 (92.68) | 1571 (68.19) | 59 (3.86) | 1462 (96.14) | 1520 (74.23) |
| Household water *E. coli* concentration |  |  |  |  |  |  |
| Low | 16 (4.25) | 369 (95.75) | 386 (16.54) | 13 (3.19) | 383 (96.81) | 396 (19.08) |
| Moderate | 31 (6.63) | 438 (93.37) | 469 (20.10) | 14 (3.88) | 359 (96.12) | 373 (18.00) |
| High | 125 (8.48) | 1352 (91.52) | 1477 (63.36) | 47 (3.59) | 1258 (96.41) | 1305 (62.92) |
| Source of water |  |  |  |  |  |  |
| Direct from source | 11 (7.37) | 134 (92.63) | 145 (6.21) | 3 (2.51) | 106 (97.49) | 108 (5.26) |
| Covered container | 117 (7.99) | 1346 (92.01) | 1463 (62.86) | 48 (3.70) | 1259 (96.30) | 1307 (63.35) |
| Uncovered container | 45 (6.28) | 675 (93.73) | 720 (30.93) | 23 (3.52) | 625 (96.48) | 648 (31.39) |
| Source water *E. coli* concentration |  |  |  |  |  |  |
| Low | 96 (7.25) | 1227 (92.75) | 1323 (57.37) | 49 (4.00) | 1186 (96.00) | 1235 (60.50) |
| Moderate | 39 (7.44) | 488 (92.56) | 527 (22.86) | 13 (2.67) | 476 (97.33) | 489 (23.98) |
| High | 38 (8.23) | 418 (91.76) | 456 (19.77) | 10 (3.24) | 307 (96.76) | 317 (15.52) |
| Water treatment |  |  |  |  |  |  |
| Yes | 58 (7.85) | 675 (92.15) | 733 (31.81) | 14 (2.67) | 514 (97.33) | 528 (25.77) |
| No | 115 (7.32) | 1456 (92.68) | 1571 (68.19) | 59 (3.86) | 1462 (97.14) | 1520 (74.23) |
| Community characteristics | | | | | | |
| Place of residence |  |  |  |  |  |  |
| Rural | 36 (7.49) | 438 (92.51) | 474 (20.33) | 18 (4.17) | 423 (95.82) | 441 (21.29) |
| Urban | 137 (7.39) | 1720 (92.61) | 1858 (79.67) | 55 (3.40) | 1576 (96.60) | 1632 (78.71) |
| Division |  |  |  |  |  |  |
| Barisal | 23 (17.34) | 108 (82.66) | 131 (5.62) | 2 (2.09) | 117 (97.91) | 119 (5.74) |
| Chattogram | 38 (7.18) | 496 (92.82) | 534 (22.92) | 20 (3.95) | 488 (96.05) | 508 (24.53) |
| Dhaka | 38 (7.00) | 500 (93.00) | 537 (23.04) | 19 (3.16) | 580 (96.84) | 598 (28.87) |
| Khulna | 15 (6.67) | 212 (93.33) | 228 (9.76) | 10 (4.43) | 211 (95.57) | 221 (10.64) |
| Mymensingh | 23 (12.56) | 158 (87.44) | 181 (7.77) | - | - | - |
| Rajshahi | 15 (5.26) | 278 (94.74) | 293 (12.58) | 6 (2.62) | 226 (97.38) | 232 (11.21) |
| Rangpur | 14 (5.68) | 235 (94.32 | 249 (10.67) | 11 (4.30) | 242 (95.70) | 253 (12.18) |
| Sylhet | 7 (3.69) | 172 (96.31) | 178 (7.64) | 6 (4.01) | 136 (95.99) | 142 (6.83) |

Table 2 shows the logistic regression model between *E. coli* concentration in drinking water and childhood diarrhea in Bangladesh by both crude and adjusted odds ratio. According to the crude odds ratio, high-risk *E. coli* contamination in drinking water was associated with 2.09 (COR= 2.09; 95 percent CI: 1.17-3.72; P-value = 0.012) and 1.13 (COR= 1.13; 95% CI: 0.57–2.24; P-value = 0.727) times more often of diarrhea than low-risk group according to the 2019 MICS and 2012 MICS report, respectively. After adjusting for confounding variables in the model with 2019 MICS data, we found that children from high-risk groups of *E. coli* contamination were associated with 1.93 (AOR: 1.93; 95% CI: 1.02-3.63; P-value = 0.042) and children from moderate risk groups of *E. coli* contamination in household drinking water was associated with 1.37 (AOR: 1.37; 95% CI: 0.66–2.84; P-value = 0.398) times higher odds of diarrhea in comparison from low-risk *E. coli* contamination groups.

Table 2. Association with the level of *E. coli* contamination in household drinking water and diarrhea among children younger than 5 years of MICS 2019 and MICS 2012 data in Bangladesh

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | MICS 2019 | | | | MICS 2012 | | | |
|  | Crude odds ratio | p-value | Adjusted odds ratio | p-value | Crude odds ratio | p-value | Adjusted odds ratio | p-value |
| Age (in months) |  |  |  |  |  |  |  |  |
| 0-11 | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| 12-23 | 1.41 (0.83 – 2.39) | 0.200 | 1.29 (0.75 - 2.23) | 0.351 | 1.09 (0.60 - 2.00) | 0.770 | 1.02 (0.56 - 1.86) | 0.957 |
| 24-35 | 0.98 (0.57 – 1.66) | 0.931 | 0.89 (0.51 - 1.55) | 0.688 | 0.61 (0.29 - 1.28) | 0.193 | 0.52 (0.24 - 1.11) | 0.092 |
| 36-47 | 0.76 (0.41 – 1.39) | 0.373 | 0.73 (0.39 - 1.37) | 0.331 | 0.43 (0.16 - 1.17) | 0.098 | 0.39 (0.14 - 1.06) | 0.065 |
| 48-59 | 0.53 (0.27 – 1.01) | 0.054 | 0.48 (0.25 - 0.94) | 0.031\* | 0.30 (0.13 - 0.70) | 0.006\*\* | 0.23 (0.09 - 0.57) | 0.001\*\* |
| Sex |  |  |  |  |  |  |  |  |
| Male | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Female | 1.02 (0.71 – 1.45) | 0.916 | 1.00 (0.69 - 1.45) | 0.991 | 1.27 (0.76 - 2.12) | 0.367 | 1.33 (0.78 - 2.27) | 0.301 |
| Education Status |  |  |  |  |  |  |  |  |
| None/Primary incomplete | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Primary Complete | 0.52 (0.28 – 0.97) | 0.041 | 0.48 (0.25 - 0.94) | 0.032\* | 1.07 (0.55 - 2.09) | 0.837 | 1.28 (0.62 - 2.65) | 0.508 |
| Secondary | 0.76 (0.44 – 1.31) | 0.317 | 0.77 (0.42 - 1.41) | 0.394 | 1.35 (0.76 - 2.39) | 0.309 | 1.60 (0.88 - 2.93) | 0.123 |
| Secondary Complete/ Higher | 0.62 (0.31 – 1.23) | 0.170 | 0.65 (0.30 - 1.40) | 0.274 | 0.65 (0.26 - 1.59) | 0.341 | 0.67 (0.21 - 2.16) | 0.504 |
| Household size |  |  |  |  |  |  |  |  |
| Small (<5) | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Large (5/5+) | 0.89 (0.61 – 1.28) | 0.528 | 0.86 (0.56 - 1.32) | 0.477 | 0.78 (0.46 - 1.31) | 0.349 | 0.71 (0.40 - 1.26) | 0.245 |
| Livestock ownership |  |  |  |  |  |  |  |  |
| Yes | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| No | 1.01 (0.70 – 1.46) | 0.967 | 1.09 (0.72 - 1.65) | 0.675 | 0.75 (0.46 - 1.23) | 0.254 | 0.61 (0.35 - 1.06) | 0.078 |
| Wealth status |  |  |  |  |  |  |  |  |
| Poor | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Middle | 0.54 (0.30 – 0.95) | 0.031 | 0.55 (0.31 - 0.97) | 0.039\* | 0.93 (0.51 - 1.70) | 0.816 | 0.81 (0.43 - 1.54) | 0.522 |
| Rich | 0.72 (0.48 – 1.07) | 0.099 | 0.72 (0.43 - 1.20) | 0.204 | 0.85 (0.48 - 1.51) | 0.576 | 0.65 (0.30 -1.41) | 0.275 |
| Source water type |  |  |  |  |  |  |  |  |
| Improved | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Unimproved | 0.48 (0.17 – 1.40) | 0.180 | 0.32 (0.09 - 1.16) | 0.084 | 0.49 (0.07 - 3.62) | 0.482 | 0.66 (0.09 -5.06) | 0.687 |
| Toilet facility type |  |  |  |  |  |  |  |  |
| Improved | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Non-improved | 0.85 (0.35 – 2.08) | 0.728 | 1.12 (0.39 - 3.23) | 0.841 | 1.78 (0.65 - 4.84) | 0.261 | 2.04 (0.61 - 6.80) | 0.245 |
| Toilet facility shared |  |  |  |  |  |  |  |  |
| Yes | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| No | 0.93 (0.63 – 1.37) | 0.700 | 0.91 (0.59 - 1.41) | 0.674 | 1.47 (0.83 - 2.58) | 0.184 | 1.46 (0.76 - 2.81) | 0.254 |
| Household water *E. coli* concentration |  |  |  |  |  |  |  |  |
| Low | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Moderate | 1.60 (0.79 – 3.25) | 0.193 | 1.37 (0.66 - 2.84) | 0.398 | 1.23 (0.54 - 2.78) | 0.628 | 1.25 (0.53 -2.97) | 0.613 |
| High | 2.09 (1.17 – 3.72) | 0.012 | 1.93 (1.02 - 3.63) | 0.042\* | 1.13 (0.57 - 2.25) | 0.727 | 1.25 (0.60 - 2.60) | 0.556 |
| Source of water |  |  |  |  |  |  |  |  |
| Direct from source | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Covered container | 1.09 (0.52 – 2.28) | 0.816 | 1.09 (0.52 - 2.33) | 0.814 | 1.49 (0.42 - 5.36) | 0.537 | 1.38 (0.41 - 4.64) | 0.599 |
| Uncovered container | 0.84 (0.38 – 1.88) | 0.673 | 0.92 (0.40 - 2.10) | 0.837 | 1.42 (0.39 - 5.22) | 0.597 | 1.38 (0.36 - 5.30) | 0.643 |
| Source water *E. coli* concentration |  |  |  |  |  |  |  |  |
| Low | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Moderate | 1.03 (0.64 – 1.65) | 0.911 | 0.93 (0.56 - 1.54) | 0.774 | 0.66 (0.34 - 1.28) | 0.216 | 0.61 (0.29 - 1.28) | 0.190 |
| High | 1.15 (0.73 – 1.82) | 0.556 | 1.00 (0.60 - 1.69) | 0.990 | 0.80 (0.39 - 1.65) | 0.552 | 0.78 (0.34 - 1.76) | 0.551 |
| Water treatment |  |  |  |  |  |  |  |  |
| Yes | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| No | 0.95 (0.51 – 1.77) | 0.875 | 0.79 (0.40 - 1.56) | 0.498 | 1.05 (0.46 - 2.40) | 0.913 | 0.84 (0.33 -2.13) | 0.720 |
| Place of residence |  |  |  |  |  |  |  |  |
| Rural | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Urban | 0.99 (0.62 -1.56) | 0.948 | 0.92 (0.56 - 1.53) | 0.757 | 0.81 (0.40 - 1.62) | 0.548 | 0.68 (0.32 -1.44) | 0.310 |
| Division |  |  |  |  |  |  |  |  |
| Sylhet | Ref. |  | Ref. |  | Ref. |  | Ref. |  |
| Barisal | 5.48 (2.08 – 14.42) | <0.001 | 5.12 (1.83 - 14.26) | 0.002\*\* | 0.51 (0.14 - 1.80) | 0.297 | 0.41 (0.11 - 1.58) | 0.194 |
| Chattogram | 2.02 (0.78 – 5.20) | 0.145 | 2.22 (0.86 - 5.77) | 0.101 | 0.98 (0.39 - 2.48) | 0.971 | 1.01 (0.38 - 2.72) | 0.985 |
| Dhaka | 1.97 (0.75 – 5.15) | 0.169 | 1.97 (0.73 - 5.32) | 0.182 | 0.78 (0.31 - 1.99) | 0.602 | 0.67 (0.24 - 1.83) | 0.435 |
| Khulna | 1.87 (0.69 – 5.04) | 0.218 | 2.19 (0.76 - 6.31) | 0.147 | 1.11 (0.43 - 2.88) | 0.832 | 0.94 (0.36 - 2.50) | 0.908 |
| Mymensingh | 3.75 (1.36 – 10.31) | 0.010 | 3.82 (1.35 - 10.85) | 0.012 | - | - | - | - |
| Rajshahi | 1.45 (0.51 – 4.14) | 0.486 | 1.53 (0.49 - 4.79) | 0.464 | 0.64 (0.21 - 2.01) | 0.448 | 0.59 (0.19 - 1.87) | 0.370 |
| Rangpur | 1.57 (0.56 – 4.40) | 0.388 | 1.82 (0.60 - 5.54) | 0.291 | 1.08 (0.41 - 2.80) | 0.882 | 0.84 (0.32 - 2.23) | 0.729 |

*Ref. = Reference*

Briefly, according to crude and adjusted models, 12-23 months’ children were 1.41 (95% CI: 0.83-2.39; P-value = 0.200) and 1.29 (95% CI: 0.75-2.23; P-value = 0.351) times more likely to suffer diarrhea in 2019 than they were in 2012 [1.09 (95% CI: 0.60-2.00; P-value = 0.770) and 1.02 (95% CI: 0.56-1.86; P-value = 0.957)]. The crude MICS 2019 model indicates that diarrhea in female children is 1.02 (95% CI: 0.71 - 1.45; P-value = 0.916), which is higher than the crude MICS 2012 model's estimate of 1.27 (95% CI: 0.76 - 2.12; P-value = 0.367). In the 2019 MICS adjusted model, children from livestock-owning families had a 1.09 (95% CI: 0.72-1.65; P-value = 0.675) times greater likelihood of developing diarrhea than children from non-livestock-owning families, a difference that was less in the 2012 MICS adjusted model [0.61 (95% CI: 0.35-1.06; P-value = 0.078). In the 2019 MICS adjusted model, children who have access to unimproved toilet facilities had a 1.12 (95 percent CI: 0.39 – 3.23; P-value = 0.841) times higher risk of developing diarrhea than in the 2012 MICS adjusted model. When compared to families who used better toilet facilities, children who had unimproved toilet facility access had a 2.04 (95% CI: 0.61-6.80; P-value = 0.245) times higher risk of developing diarrhea in 2012 MICS adjusted model. According to the 2019 MICS adjusted model, families with children who use water from covered containers have a 1.09 (95% CI: 0.52–2.33; P-value = 0.814) times higher risk of developing diarrhea than families who use water directly from the source, which is down from 1.38 (95% CI: 0.41–4.64; P-value = 0.599) in the 2012 MICS.

In PS-weighted samples, supplementary Figure S1 shows the standardized mean difference between *E. coli* concentrations in household drinking water with all other covariates. The covariates were unbalanced prior to weighing, but after weighting, we saw a reasonable balance as a standardized mean difference of less than 0.1. Table 3 shows the findings of a sensitivity analysis using the PS weighting method in relation to the association between *E. coli* contamination in household drinking water and diarrhea.

Table 3. Exploring the relationship between the categories of *E. coli* contamination and diarrhea among children younger than 5 years of MICS 2019 and MICS 2012 data in household drinking water in Bangladesh using sensitivity analysis and the propensity score weighting method

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | MICS 2019 | | MICS 2012 | |
|  | Adjusted odds ratio | p-value | Adjusted odds ratio | p-value |
| Exposure group |  |  |  |  |
| Low | Ref. |  | Ref. |  |
| Moderate | 1.46 (0.71 – 3.01) | 0.301 | 1.01 (0.45 – 2.28) | 0.981 |
| High | 1.96 (1.06 – 3.63) | 0.032 | 1.07 (0.53 – 2.16) | 0.847 |

*Ref. = Reference*

Like the primary analysis, we observed approximately similar strength of association between household drinking water *E. coli* contamination and diarrhea. High-risk group *E. coli* contamination in drinking water was associated with 1.96 (95% CI: 1.06-3.63; P-value = 0.032) and 1.07 (95% CI: 0.53-2.16; P-value = 0.847) times higher odds of diarrhea than low-risk group *E. coli* contamination water in 2019 MICS and 2012 MICS data, respectively, according to sensitivity analysis using the PS weighting instead of sample weight in the multivariable logistic regression model. In 2019 MICS and 2012 MICS data, *E. coli* contamination in the moderate risk group with 1.46 (95% CI: 0.71-3.01; P-value = 0.301) and 1.01 (95% CI: 0.45-2.28; P-value = 0.981) times higher odds of diarrhea than in the low-risk group, respectively. However, the association was not statistically significant in both surveys (P>0.05).

1. **Discussion**

The study investigated the relationship between *E. coli* concentration in household drinking water and diarrheal episodes using data collected across the country. This study discloses the *E. coli* contamination in drinking water in Bangladesh which could also result from the educational and wealth status of the household, source water type, storage status (unsafe and safe), and inadequate treatment.

The current study found strong correlations between E. coli contamination in drinking water and childhood diarrheal episodes in the 2019 MICS survey, as well as a high degree of *E. coli* contamination in drinking water. Khan et al. 2022 conducted a similar analysis with this data among under-5 children from Bangladesh and found that the prevalence of childhood diarrhea was associated with the use of *E. coli*-contaminated water 31. This finding is corroborated by their findings.

Even after applying sensitivity analysis using the PS weighting approach, we were unable to detect any relation between E. coli contamination in drinking water and childhood diarrheal episodes in the 2012 MICS survey. But according to two newly published randomized controlled trials conducted in rural Bangladesh and Kenya, neither the incidence of diarrheal illness nor anthropometric measurements were impacted by the water quality 32,33. The findings of this research do not necessarily mean that there is no relation between contaminated water and episodes of diarrhea; rather, it is more likely that the interventions failed to successfully and sustainably reduce exposure to feces. Understanding the relations between fecal exposure pathways and amounts and pediatric diarrheal episodes requires more study. The bacteria *E. coli* is typically found in the digestive tracts of warm-blooded animals and humans. *E. coli* strains in general are not harmful. However, some strains, such as Shiga toxin-producing *E. coli* (STEC), can result in serious foodborne illness. It is primarily spread to people by eating infected foods such as raw or undercooked ground beef, raw milk, contaminated raw vegetables, and sprouts 34. Not all *E. coli* strains were taken into account in this survey’s water quality tests. *E. coli* may not be enough as a measure of water contamination to account for variations in diarrheal risk. Probably because, in this study, bacterial CFU markers cannot be used to evaluate water contamination with other pathogens, such as viral pathogens. The prevalence of diarrhea is substantially higher in MICS 2019 data than in MICS 2012 data, which may be another explanation for the lack of a meaningful relationship. This could be the cause of the increasing occurrence of diarrhea infected with *E. coli*. Even Nevertheless, the probabilities of developing diarrhea were higher in the 2019 MICS data, despite the fact that we did not identify any relationship in the MICS-2012 data.

According to the findings, children between the ages of 12 and 23 months and children older than 2 years have the highest chance of contracting the diarrheal disease. The first two years of a child’s life are more common for diarrheal disease. Numerous pieces of evidence point to the first two years of a child's life as the time when diarrheal infections are most common, making infants less than 23 months more susceptible to them 35,36. This could be explained by the fact that young children are typically very reliant on their mothers and hence require nutrition that is appropriate for their age 37. The ingestion of food contaminated with germs that cause diarrhea during this time may expose children to unclean feeding methods, dirty water, filthy utensils, and unhealthy settings. Children over the age of six months are starting to be introduced to meals other than breast milk, which could compromise their immunizations against infectious agents that cause diarrhea 38,39. Additionally, toddlers at this age will begin to crawl, making it possible for them to pick up dirt or other contaminated objects and put them in their mouths 40. In Japan and the United States, outbreaks of diarrhea in adults have been linked to tainted food or water sources 41. Low levels of immunity and an increased risk of infection are contributory variables, yet this phenomenon is difficult to explain.

In this study, households that drank water from covered containers had a higher incidence of childhood diarrhea. According to a nationally representative water quality assessment, *E. coli* was present in 41% of all improved water sources studied across Bangladesh 42. The distribution system may become contaminated due to frequent pipe breaks and unauthorized connections, low or negative water pressure from intermittent service, insufficient household water storage facilities, all of the above, or any combination of the above 43. This study is congruent with research from the Pawi Special District in Benishangul-Gumuz Region and the Derashe district in Southern Ethiopia 44. Unprotected sources, which are those without a barrier or other structure to shield the water from contamination, are more likely to get contaminated and to give rise to diarrhea when consumed. Unprotected water sources are a significant source of intestinal parasites like giardiasis 45, which cause diarrhea. Microbial contamination and a rise in the prevalence of diarrhea are both related to factors including improper storage, interrupted piped water delivery, an untreated source used for the supply, and irregular usage of the improved sources 46,47.

Water source pollution may be caused by a variety of environmental factors, such as tube wells near ponds and latrines. And results from different study evince that, the establishment of tube wells near the latrines can be the major cause of contamination of drinking water at the source. In this case, water treatment can meager the risk of water contamination from difference sources. Water storage containers (such as a kolshi, bucket, or jug) may get polluted when water from storage pots is touched with unclean hands. This is true even for very pristine water sources, such as tube wells, where contamination levels are sufficiently low 17. The same conclusion—that better water and sanitation facilities were linked to a lower risk of diarrheal disease—was also made in earlier studies—is repeated here 48.

This study looked into the possibility that children from poor households were more likely to have diarrhea. Similar studies revealed that middle or poor households had a 90% risk of having high levels of contamination in their household drinking water if there was high *E. coli* contamination at source 49. This supports other research from Bangladesh that were related to this and found that children from poor households had a higher risk of developing diarrhea 50. As a result, point-of-use pollution of water storage and middle-class or lower-class families' inability to maintain safe water storage are the main causes of the reduction in water quality. This could be supported by the fact that it can be difficult for poorer households to obtain clean water, which may increase their risk of developing the diarrheal disease. The high level of pollution in drinking water caused by dangerous bacteria like *E. coli* and other organisms that cause diarrhea may also have an effect on children 51.

This study discovered a stronger link between diarrhea and place of residence, despite the fact that flooding during the summer is supposed to increase diarrhea transmission because contaminated matter can be moved from source sites to nearby locations more easily in a rural area rather than an urban area 52. Additionally, we discovered a statistically significant association between geographic location and the likelihood of developing diarrhea. The Barisal region was shown to have the highest risk of diarrheal illness in children, followed by Mymensingh, Chattogram, Dhaka, and so on. This is in line with earlier research from Bangladesh that discovered comparable results in respect to regional variations in the prevalence of diarrheal illness 37. Regions like Barisal, according to Sarker et al. 37, are defined by being more densely populated and having more rivers and water reservoirs, both of which promote an environment that is conducive to the spread of diarrheal disease among the inhabitants. The regions have more rivers, water reservoirs, and high populated areas than other places, especially those in the Barisal, Dhaka, and Chittagong divisions. The majority of the slums, however, are located in the Dhaka and Chittagong areas, which have already been shown to have a significant risk of diarrhea-related diseases due to the inadequate sanitation system and lack of drinkable water 37. High prevalence of diarrheal infections in these areas may have this as the more plausible cause.

As was already mentioned, there is a direct correlation between the likelihood of contracting *E. coli* diarrhea and factors such as maternal education, wealth status, personal hygiene, and general sanitation. Begum and her colleagues discovered that providing mothers with information on water, sanitation, and hygiene was an effective way to lessen the burden of diarrhea in children under the age of five, who had a greater prevalence of diarrhea 53. Higher parental education levels are crucial for the prevention and control of morbidity because informed parents can lower their children's risk of contracting infectious diseases through education and other preventative measures 54,55. However, it was found that in Bangladesh, higher levels of education are also linked to better toilet facilities in both rural and urban settings, which means better access to sanitation and hygiene in the families 56. In line with other research conducted in Bangladesh, we discovered that the availability of better sanitary facilities decreased the prevalence of childhood diarrhea among children under the age of five 57,58. The most straightforward explanation would be that having access to latrines minimizes fecal contamination of the environment and the likelihood that mechanical vectors will come into contact with organisms that cause diarrhea, hence reducing diarrheal disease. This is because the majority of prevalent causes of diarrheal diseases in children under five are hygiene-related in terms of food serving and predation. In order to reduce the spread of bacterial infections between children and the environment, sanitation infrastructure such as upgraded latrines and hand hygiene are also important 59.

1. **Strengths and limitations**

This study basically based on recent MICS data in the context on developmental status of Bangladeshi children. We used a sufficiently large nationally representative dataset, which represents the respective children and women of Bangladesh. We considered a great variety of influential factors that affect the dependent variable.

This study however is not devoid of some drawbacks. The selection variables, data quality, and indicator measurement were out of control because the data was secondary data. Furthermore, it is challenging to determine the relationship between the exposure and the outcome variable due to the cross-sectional data. To distinguish between pathogenic and non-pathogenic *E. coli*, our *E. coli* definition falls short. However, we don’t get any potential contaminants other than *E. coli* bacteria that result in childhood diarrhea. Yet, in low-income countries, the two most common etiological agents of diarrhea are rotavirus and *E. coli* 60. But, aside from *E. coli*, which can cause diarrhea in children, lack of information on other possible pollutants. The absence of these concentrations can result in severe miscalculations in the model results because they can vary by an order of magnitude during very brief times. The scenario is further complicated by the fact that there are numerous sources of biological contamination coming in, even though most strains of *E. coli* are not harmful.

1. **Recommendations**

The findings of our study have some potential implications for our policymakers. Different government and non-government organizations, international agencies, and public health professionals who work for the betterment of children’s health can initiate awareness-raising activities to make them aware of *E. coli* contamination in drinking water. For this, the awareness-raising campaign should also emphasize educating people on how to use water that has been tested or inspected by the appropriate authorities. The relevant authorities must carry out awareness-raising initiatives. In Bangladesh, it is found that the high education level of parents has a sense of the sanitation and hygiene of their children. Household access to electronic media can seek concern from the public for childhood diarrhea. Particularly, the young mother is more likely to be exposed than the older mother due to the older mother's superior health-seeking behaviors. Future research should concentrate on both the amount and quality of water in Bangladesh’s rural villages. Water storage capabilities play a role in how much water is available for washing and cleaning in the home.

1. **Conclusion**

In Bangladesh, children under the age of five still frequently experience diarrhea as a serious public health issue. Current investigation revealed a substantial relationship between *E. coli* concentration in household drinking water and diarrheal episodes among children aged under-5 years in Bangladesh. The mothers of low-income countries like Bangladesh should be the main target because the prevalence of diarrhea and the behavior of mothers in that nation are influenced by factors like age, wealth, and educational attainment. Public health professionals, community-based organizations, and policymakers should concentrate on educating the public about the use of safe drinking water. Additionally, appropriate authorities should improve drinking water management (such as handling practices, treatment, and storage) and make sure that water supplies are safe, help modify personal hygiene behavior, improve health literacy and engaging community health workers in the prevention of diarrhea prevention, control, and treatment.

**Abbreviations**

AOR: Adjusted Odds Ratio

CI: Confidence Interval

COR: Crude Odds Ratio

*E. coli: Escherichia coli*

MICS: Multiple Indicator Cluster Surveys

PS: Propensity Score

**Declarations**

**Ethics approval and consent to participate**

No ethics approval was required as this study used secondary analysis of the cross-sectional data obtained from the 2019 and 2012 Bangladesh Multiple Indicator Cluster Surveys (MICS), which is available freely and publicly with all identifier information removed. Bangladesh Government's technical committee, led by the Bangladesh Bureau of Statistics (BBS), approved the survey protocol. In addition, informed consent was obtained from a parent and/or legal guardian for study participation in the survey by the MICS team during fieldwork. The interviewers explained that taking part in the survey was entirely voluntary and that the information would be kept confidential and private. Participants may also refuse to answer any or all questions, and the interview may be terminated at any moment. All methods were carried out in accordance with the relevant guidelines and regulations.

**Consent for publication**

Not applicable.

**Availability of data and materials**

The datasets generated and analyzed during this study are available from the corresponding author on reasonable request.

**Competing interests**

The authors declare that they have no competing interests.

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**Authors' contributions**

Mohammad Nayeem Hasan: Methodology, Formal Analysis, Writing-original draft. Maya Biswas: Methodology, Data curation, Moumita Paul: Methodology, Data curation, Tanvir Ahammed: Methodology, Data curation, Writing-Reviewing and Editing. Muhammad Abdul Baker Chowdhury: Supervision, Methodology, Writing-Reviewing and Editing. Md Jamal Uddin: Conceptualization, Supervision, Writing-Reviewing and Editing.

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