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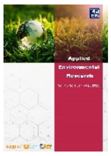

Research Article

Path Analysis of The Relationship between Diarrhea, Climate and Environmental Variables in Province of West Nusa Tenggara-Indonesia

Khadijah Azhar[1,*], Ika Dharmayanti[2], Dwi Hapsari Tjandrarini[2], Bambang Wispriyono[1]

[1] Faculty of Public Health, Universitas Indonesia, Kampus UI, Depok 16424, Indonesia
[2] Research Center for Public Health and Nutrition, Research Organization for Health, National Research and Innovation Agency, West Java 16915, Indonesia

*Correspondence Email: khadijah.azhar@gmail.com

Abstract

Diarrhea is a major cause of morbidity and mortality, particularly in West Nusa Tenggara Province, Indonesia, due to certain factors. Therefore, this study aims to examine the influence of climate, economic status, demographic, water, sanitation, and hygiene factors on diarrhea. The study procedures were carried out using an ecological design that focused on the characteristics of the sample population. The unit of analysis was districts/cities, where data on diarrhea cases from 2017–2020 were used, along with other variables in the same period. The dependent variable was the number of diarrhea cases per month, while the independent variables included average temperature, economic status, population density, access to water, sanitation, and hygiene. A total of 480 records were analyzed descriptively using path analysis to determine the relationships between the variables. The results showed that average temperature had a significant direct relationship with diarrhea ($b = 0.127$, 95% CI $= 0.027 – 0.227$, $p = 0.013$;) and indirectly through unsafe drinking water-limited sanitation ($b = 0.088$, 95% CI $= 0.001 – 0.175$, $p = 0.047$). Economic status and population density were also reported to have a significant indirect effect, while unsafe drinking water-limited sanitation and limited hygiene had a direct influence ($b = 0.166$, 95% CI $= 0.07 – 0.263$, $p = 0.001$ and $b = 0.124$, 95% CI $= 0.019 – 0.229$, $p = 0.021$). In addition, the model also showed that water sanitation had a positive and significant correlation with hygiene. In summary, diarrhea was directly influenced by the average local temperature, access to water, sanitation, and hygiene. Indirectly, the average temperature played a significant role along with population density and economic status.

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Introduction

Diarrhea is widely known as the leading cause of death and severe disease in children worldwide. In 2017, it caused approximately 1.6 million deaths, with one-third occurring among children and elderly groups [1]. Diarrhea patients typically experience dehydration due to excessive loss of fluids and electrolytes, which can be fatal when not treated immediately. Persistent or repeated diarrhea can also cause damage to intestinal tissue, reduce nutrient absorption, and inhibit growth and development. Despite the availability of a simple treatment solution, deaths caused by disease among children under 5 are highest in South Asia and sub-Saharan Africa. According to the 2020 International Vaccine Access Center (IVAC) report, Indonesia ranks 7th among 15 countries with the highest number of deaths of children under 5 due to pneumonia and diarrhea, after India, Nigeria, Pakistan, DRC, Ethiopia, and Chad [2].

Several studies have shown that diarrhea is an endemic disease, specifically in developing countries, and has the potential to become an outbreak accompanied by severe mortality [3]. The majority of cases are often caused by contaminated food and water sources. According to the 2014 report of the World Health Organization, the transmission of the disease is affected by several factors, including temperature and rainfall at various timescales. Water scarcity (a measure of per capita water availability) has also been reported to be associated with a range of health problems, including diarrhea, in certain populations [4].

Climate change can increase the risk of diarrhea through several pathways. For example, changes in rainfall patterns often affect the availability and quality of water, potentially leading to unsafe drinking water sources and increased risk of waterborne disease. In addition, extreme weather events, such as floods and storms can disrupt sanitation infrastructure, expose communities to pathogens, and improve the potential of diarrhea outbreaks. Secondary impacts of climate change, including crop losses or population displacement, may lead to malnutrition, exacerbating the prevalence of disease [5]. Based on these results, climate change alters the environmental conditions necessary for the transmission of diarrhea, thereby increasing the overall risk.

Patz proposed a theory outlining 5 primary health categories vulnerable to climate change, including 1) temperature-related morbidity and mortality, 2) impacts from extreme weather events, 3) air pollution, 4) water and foodborne diseases, and 5) vector-borne diseases [6]. Moreover, Hellden expanded on Patz's theory, emphasizing intermediary factors that influence health issues associated with climate change [7]. Several studies on the relationship between diarrhea and climate have also shown mixed associations [8-9]. For example, as temperature and rainfall increase, the risk of developing diarrhea also becomes higher for households without access to sanitation or safe, clean water [10].

Building on the theoretical frameworks and results from previous studies, it is essential to explore the relationship between access to drinking water, sanitation, hygiene (WASH), socio-economic factors, and climate on the incidence of diarrhea. In this study, the path analysis was used to examine more complex models beyond the scope of multiple linear regression. This approach is also helpful in identifying both direct and indirect relationship, including those comprising intervening variables. Path analysis showed the causal relationship between variables in a diagrammatic form, enhancing comprehensibility. The diagrams showed the association between dependent and independent variables as well as the relationship with moderating variables compared to regression analysis, which only accounted for direct effects.

The current study was carried out in West Nusa Tenggara (NTB) Province, due to its high prevalence of diarrhea, which was above the national figure (8.6% versus 6.8%) [11]. Based on the Basic Health Research (Riskesdas) report in Indonesia, the prevalence of the condition was 7% in 2013, which later increased to 8% in 2018. Therefore, this study aims to investigate the correlation between climate and the incidence of diarrhea, as well as to identify contributing factors in NTB Province. The results are expected to provide valuable insights for formulating targeted policies and strategies to manage diarrhea in NTB Province.

Material and methods

1) Study design and data sources

This was an analytic observational study with an ecological design focused on the characteristics of population groups in place of their members. The study was conducted using monthly aggregated disease count data from 10 districts or cities in NTB Province in 2017–2020 sourced from the Ministry of Health. In addition, data related to climate fluctuations between 2017 and 2020 included average temperature, relative humidity, and rainfall obtained from the Meteorological, Climatological, and Geophysical Agency (BMKG). Subsequently, WASH and economic status data was obtained from the national socio-economic survey, conducted by the Central Statistics Agency (BPS), and population density data ensured that the total records (N) analyzed were 480.

The conceptual framework of this study outlined the primary connections between elements of climate, WASH, economic status, and population density related to diarrhea (Figure 1). The primary relationships of interest revolved around the potential indirect associations between climate conditions and diarrhea through WASH. Based on the following model, the path coefficient value was not significant for the humidity, rainfall, and hygiene variables.

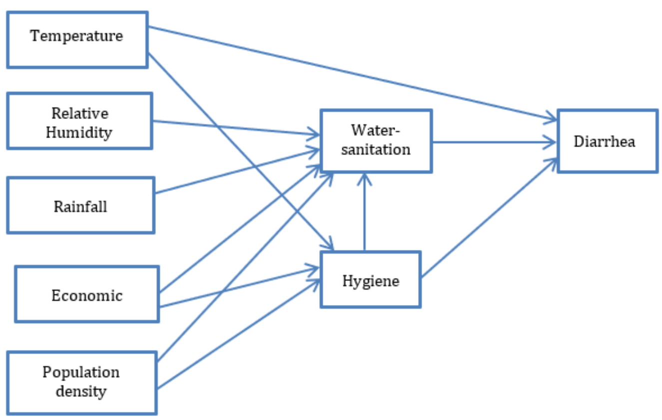

Figure 1 The conceptual model of study.

2) Data processing

The endogenous variables in this study were the number of diarrhea cases per month, while the exogenous variables, included (1) climate variables, (2) unsafe drinking water and limited sanitation (hereinafter abbreviated to water-sanitation), (3) limited hygiene referring to standards from the Joint Monitoring Program (JMP-WHO/Unicef) [12], (4) population density, and (5) economic status. The endogenous variables in this study were the number of diarrhea cases per month.

Assessment of access to drinking water, sanitation, and hygiene was conducted by establishing service levels using statistical software. Drinking water categorization was based on the availability of drinking water sources, which was represented by the presence of these facilities in the length of time required to collect water, which was not more than 30 minutes [12]. Furthermore, it must meet the physical quality requirements of drinking water, such as turbidity, color, taste, foam, and odor.

In sanitation aspect, the variables analyzed included ownership of latrine facilities and their use, type of toilet, and final place of disposal of feces. The aspect of hygiene was measured by the availability of hand washing facilities, water for washing hands, and soap or antiseptic liquid in the house. The level of access to drinking water, sanitation, and hygiene services was analyzed as a percentage of the worst access coverage in each district or city. The portion of service access coverage included unsafe drinking water, limited sanitation, and limited hygiene.

Unsafe drinking water was from unprotected wells or dug springs. Limited hygiene referred to using shared latrines or public facilities, while sanitation was considered inadequate when soap and water were not available in hand washing facilities. In this study, the drinking water and sanitation variables were combined into 1 variable, which was the unsafe drinking water and limited sanitation. The poor status used was the first quintile for the economy, representing the lowest fifth of data (1%-20%) for household expenditure levels according to BPS.

3) Data analysis

Descriptive analysis was used to elucidate the monthly average of air temperature, humidity, and rainfall and examine the percentage of access to WASH, population density, and economic status. The unit analysis was districts or cities in the Province of NTB. Subsequently, a path analysis was conducted using STATA software version 15 [13]. The path analysis model analyzed the relationship pattern between variables to determine the direct or indirect impact of a set of exogenous variables on the endogenous variable. This analysis was an extension of the regression analysis model that aimed to estimate the magnitude and significance of the hypothesized causal relationship between variables through a path diagram [13].

Given that certain variables in this study, significant diarrhea cases, did not exhibit a normal distribution, the robust maximum likelihood (RML) estimation method was used. Consequently, this approach corrected bias caused by non-normality in standard errors [14].

Results and discussions

This analysis showed that each year, there was a month with no rainfall, showed by a minimum monthly rainfall of 0 mm in certain areas. The average monthly relative humidity ranged from 74% to 78% with a minimum of 62%. The average monthly temperature was from 27°C to 28°C with the highest recorded temperature being 30.23°C and the lowest 24.89 °C (Table 1).

District or city characteristics were showed through economic status and population density indicators. On average, from 30% to 34% of districts or cities fell into the lowest economic status (poor). Moreover, the average population density typically increased yearly (2017–2020). The highest percentage of limited access to safe drinking water and sanitation was recorded in 2017, which showed a tendency to decrease despite fluctuations. This could be interpreted as an increased availability of drinking water and sanitation facilities that the community could access. However, the average limited hygiene coverage remained relatively stable over the past 4 years as shown in Table 1.

The monthly number of diarrhea cases fluctuated annually, showing a general downward trend, with the peak occurring in 2020. Significantly, this decline began with the onset of the COVID-19 pandemic in Indonesia, which could have influenced the reporting of confirmed diarrhea cases as presented in Figure 2.

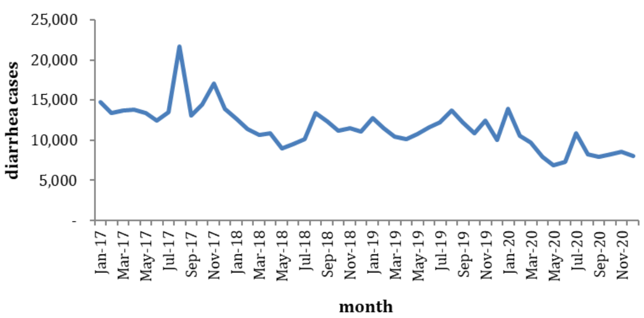

Figure 2 Trends in monthly diarrhea cases in West Nusa Tenggara Province from 2017 to 2020.

Table 1 Description of climate, WASH, population density, and economic status in West Nusa Tenggara Province from 2017 to 2020

Variables	2017	2018	2019	2020
Temperature (°C)				
Mean	27.76	28.02	27.95	28.25
Standard deviation	0.89	1.03	1.22	0.88
Minimum-maximum	25.41 – 29.14	25.32 – 29.79	24.89 – 30.23	25.72 – 29.63
Relative humidity (%)				
Mean	78.03	75.6	74.41	77.13
Standard deviation	5.13	5.9	6.70	4.84
Minimum-maximum	67.0 – 87.0	67.0 – 89.0	62.0 – 92.0	67.0 – 87.0
Rainfall (mm)				
Mean	153.07	113.21	118.06	133.93
Standard deviation	132.12	126.05	140.83	102.43
Minimum-maximum	0 – 567.80	0 – 448.30	0 – 447.50	0 – 327.70
Population density (km^{-2})				
Mean	1,121.88	1,141.09	1,160.65	1,188.39
Standard deviation	2,202.89	2,245.55	2,289.57	2,329.98
Minimum-maximum	67.68 - 7,642.89	68.30 - 7,789.17	68.89 - 7,939.89	76.72 – 8,086.15
Economic status *(poor* (%))				
Mean	33.77	33.77	34.14	30.79
Standard deviation	3.65	3.65	3.28	13.80
Minimum-maximum	28.0 - 41.0	28.0- 41.0	30.9 - 40.6	5.7 - 54.0
Unsafe drinking water and limited sanitation (%)				
Mean	10.06	5.85	8.22	7.29
Standard deviation	3.92	2.58	3.10	2.01
Minimum-maximum	4.3 - 17.2	0.1 - 9.3	1.9 - 13.3	3.8 - 10.3
Limited hygiene (%)				
Mean	31.86	30.88	31.53	30.38
Standard deviation	10.0	12.62	13.61	12.48
Minimum-maximum	16.6 - 49.6	15.3 - 52.7	17.9 - 65.5	15.7 - 50.5

A model path analysis was constructed as the most suitable final model as showed in Figure 3. The factors affected diarrhea in different ways such as (1) direct path from temperature, (2) direct path from unsafe drinking water and limited sanitation, (3) direct path from limited hygiene, (4) indirect path from temperature, economic status, population density, and limited hygiene were mediated by unsafe drinking water as well as limited sanitation.

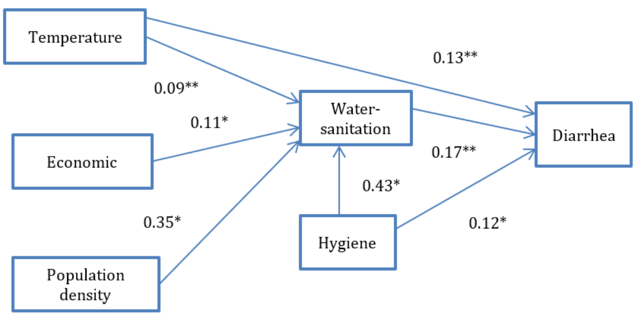

Figure 3 The estimated weights for the path model.
Note: standardized coefficient; *denotes $p < 0.01$; **$p < 0.05$

Path analysis was conducted to obtain the most fitting model and to quantify variables of the direct and indirect effects on each other. The goodness of fit indices commonly used for the path model were appropriate in this analysis namely the root mean square error of approximations (RMSEA), and standardized root mean square residual (SRMR). Meanwhile, comparative fit indices namely comparative fit index (CFI) explained the degree of similarity between the proposed and ideal baseline model [15].

Several path analysis models were attempted to understand the relationship between exogenous and endogenous variables. The 3 fit indices results obtained were included as presented in Table 2.

In the final model, the analysis results showed that RMSEA was low at 0.093 and was classified as a mediocre fit. In addition, a high CFI of 0.947 was obtained, where values > 0.90 showed a good model fit. These indices suggested an acceptable model fit. In terms of conventions for evaluating fit, Whittaker and Schumacker in Crowson [16] offered RMSEA values of 0 to less than 0.05 showing close fit, while 0.05 to 0.08 showed an acceptable fit. Typically values ranging between 0.08 and 0.10 were regarded as evidence of mediocre fit. SRMS values were 0 showing perfect fit, 0.05 showed good fit, and 0.05 to 0.10 which showed acceptable fit. According to the conventions mentioned earlier, an SRMR of 0.047 showed a good-fitting model.

According to the coefficient of determination (R^2), values associated with each endogenous variable's temperature, economy status, population density, and hygiene accounted for 38.1% of the variation in water sanitation access. Furthermore, temperature, water sanitation, and hygiene variables accounted for 11.3% of the variation in diarrhea incidence.

The estimates of standardized coefficients of this path model were provided in Table 3. This calculation showed that the prevalence of diarrhea was influenced by exogenous factors, directly and indirectly. According to the analysis, the most suitable model involved the temperature variable representing climate factors besides the WASH, economic, and population density variables. However, humidity and rainfall variables were not in the model fit criteria.

Concerning the model shown in Figure 3, the following table provided an overview of the variables with the most significant direct influence on diarrhea. Direct effect occurred when something was affected without any intervening variables, while indirect influence involved an intermediary variable that impacted the endogenous variable. In addition, the magnitude of a path was showed by a coefficient ranging from -1 to +1, similar in concept to a standard partial regression coefficient. A higher coefficient signified a stronger influence of a variable on others, the magnitude of the standardized coefficient obtained showed the extent of influence that each exogenous variable had on the endogenous variable. This path showed that the influence of temperature average, economic status, hygiene, and population density towards diarrhea was mediated by water-sanitation limited access.

The variables in this study, such as temperature, economic status, hygiene, and population density, also had significant indirect impacts on diarrhea at the district or city level in West Nusa Tenggara Province. Increased temperature averages, low economic status, limited hygiene, and population density were associated with the prevalence of this disease.

Temperature significantly influenced access to WASH which affected diarrhea. When observed from the direct effect of this disease, unsafe drinking water and limited sanitation produced the largest and the most significant contribution (b = 0.166). Higher average air temperatures characterized the dry season and it was usually more difficult for individuals to get clean water, specifically those who lived in areas that had no access to piped water.

Table 2 Variation of fit indices based on analysis models

Program	Model fit indices	Estimation result	Conclusion
Initial	RMSEA	0.177; 95%CI (0.156-0.20) *	Non fit
	CFI	0.654	Fit
	SRMS	0.073	Non fit
First Revision	RMSEA	0.249; 95%CI (0.219-0.281) *	Non fit
	CFI	0.615	Fit
	SRMS	0.118	Non fit
Final	RMSEA	0.093; 95%CI (0.062-0.126) *	Fit
	CFI	0.947	Fit
	SRMS	0.047	Fit

Note: *upper and lower end of confidence interval

Table 3 Results of path analysis on climate and environmental variables affecting diarrhea in West Nusa Tenggara Province

From	To	Standardized path coefficient	CI 95%		*p*
			Lower limit	Upper limit	
Temperature	Water-sanitation	0.088	0.001	0.175	0.047
Temperature	Diarrhea	0.127	0.027	0.227	0.013
Economic status	Water-sanitation	0.113	0.042	0.183	0.002
Population density	Water-sanitation	0.350	0.281	0.418	0.000
Water-sanitation	Diarrhea	0.166	0.070	0.263	0.001
Hygiene	Diarrhea	0.124	0.019	0.229	0.021
Hygiene	Water-sanitation	0.422	0.348	0.496	0.000

Note: $^{*}p < 0.05$

Table 4 Direct, indirect, and total effects on the incidence of diarrhea in West Nusa Tenggara Province from 2017 to 2020

Variable	Direct effect	Indirect effect	Total effect
Temperature	0.127	0.015	0.142
Economic status	-	0.019	0.019
Population density	-	0.06	0.06
Water-sanitation	0.166	-	0.166
Hygiene	0.124	0.073	0.197

According to Wang [17], effective WASH practices were associated with a lower risk of diarrhea diseases. Climate change, specifically increased drought, leading to shortages of clean water could result in reduced water availability for personal hygiene and sanitation as sufficient water for drinking needed to be prioritized, leading to increased exposure to enteric pathogens. Consequently, WASH practices could assume a dual role by interacting with and mediating the relationship between drought and diarrhea incidence.

These results were consistent with studies conducted in sub-Saharan Africa, where an increase in the average temperature of approximately 1°C increased the IRR of this disease by 6.7% at the household level (IRR = 1.067; p<0.001). Moreover, it was concluded that the environment mediated the effect of climate variations on diarrhea cases. Furthermore, households with low and middle economic status had disease IRR 1.21 times higher than households with high financial levels (IRR = 1.21 and IRR = 1.12; $p < 0.001$) [10].

Different results from a study related to climate variability and diarrhea in Singapore discovered an extremely weak relationship between air temperature and this disease. Meanwhile, the positive relationship between relative humidity and the risk of this disease was plausible [8]. Relatively different conclusions were obtained from a study in Egypt. It was concluded that the meteorological data that could be used as predictors for the morbidity rate of this disease depended on the geographical location and infrastructures of the target location [9].

Insufficient rainfall could result in heightened water demand, potentially depleting water sources such as boreholes and springs. Furthermore, climate change-induced water scarcity could increase water expenses, exacerbating unequal access to this essential resource. This inequality could hinder households from obtaining enough clean water for proper hand-washing and hygiene, limiting children's potential for healthy growth and strength. Meanwhile, excessive rain and flooding had the potential to harm water sources and sanitation infrastructure, transport runoff and pollutants into rivers and lakes, and contaminate the water supply. Between 2000 and 2022, worldwide, 25% of the global population lacked access to safely managed drinking water, while 40% had no safely managed sanitation, and 25% lacked basic hygiene services [18].

The results of a study conducted in Ngawi, East Java, showed that the level of availability of hand-washing facilities in schools had a positive impact on the level of compliance with diarrhea prevention practices [19]. The easier it was for individuals to wash their hands, the more compliance with hand washing could increase, which ultimately had the potential to reduce diseases in the community.

According to the path model in this study, economic status had an indirect effect on diarrhea through mediation by WASH. Districts or cities that had a high percentage of people with low economic levels were at risk of more cases of disease occurring in their area. It was easier for middle-rich economic groups to provide hygienic sanitation facilities for family members, such as soap, clean water, and latrines that met health requirements. Meanwhile, families from weak economic backgrounds had more difficulty providing these facilities, leading to their vulnerability to diarrhea.

This result was consistent with a study on diarrhea in children under 5 in Papua showing an indirect relationship between family income and the incidence of disease through environmental, sanitation, and nutrition status [20]. Moreover, another study observed that low income and inequality at the country level, not accompanied by sufficient health spending, were associated with disease, showing that family income was an important determinant of health [21].

In terms of population density, the outcomes derived from this study showed a significant and positive indirect impact on diarrhea incidence. This discovery aligned with results from a study conducted in Afghanistan, revealing the connection between rising temperatures and population density in an area, which could exacerbate the transmission of diarrhea [22]. The results of that study showed that increasing temperatures in densely populated districts or cities could heighten the spread of diarrhea, specifically in areas with highly vulnerable groups such as toddlers. Urban areas with high population densities and insufficient waste disposal systems were at higher risk of disease transmission during severe weather events such as heavy rains and floods. Moreover, addressing the impacts of climate change required a comprehensive approach that included improving sanitation facilities, ensuring access to clean drinking water, improving hand-washing infrastructure, and integrating climate-resilient infrastructure into district or city planning.

This study had limitations due to the absence of microbiological quality data, leading to the exclusion of information regarding the microbiological quality of drinking water consumed when creating the WASH variable. This weakness impacted the analysis results and the suitability of the model obtained. However, the period needed to be longer to explain the relationship between climate, environmental variables, and diarrhea in more detail. It was recommended that further studies must be conducted with a more extended observation period of at least 10 years, covering a more varied area and assessing the microbiological quality of drinking water to ensure that it could accommodate these needs.

Conclusions

In conclusion, diarrhea was directly influenced by the average local temperature and access to WASH. The average temperature indirectly played a role together with population density and economic status. Considering the critical role of WASH accessibility in the risk of diarrhea, it was imperative to enhance community access to drinking water as well as sanitation facilities and educational initiatives that promoted the significance of hand hygiene. Moreover, it was crucial to consider community resilience to climate change, including measures to mitigate the effects of extreme heat and anticipate potential disease outbreaks.

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Author contribution

Khadijah Azhar: conceptualization, writing original draft, formal analysis, resources and editing. Ika Dharmayanti and Dwi Hapsari: formal analysis, resources, supervision, and editing. Bambang Wispriyono: supervision and editing. All authors approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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