



The effect of meteorological variables on salmonellosis incidence in Kermanshah, West of Iran: a generalized linear model with negative binomial approach

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Abstract

Purpose Salmonella is one of the main causes of gastroenteritis, and its incidence may be affected by meteorological variables. This is the first study about the effect of climatic factors on salmonella incidence in Kermanshah, Iran.

Methods Data about salmonellosis cases in Kermanshah were inquired from Center for Communicable Disease Control, at the Ministry of Health and Medical Education of Iran, for the 2008 to 2018 time-frame. Meteorological variables including maximum, minimum and mean of temperature and humidity, sunshine hours and rainfall were inquired for the same time frame. Negative binomial generalized linear models (GLM) were used to assess the effect of meteorological variables on the weekly incidence of salmonellosis.

Results During the years under study, 569 confirmed cases were registered in Kermanshah province. Study results showed a 3 % increase in salmonellosis incidence, after 1 % increase in minimum humidity in the week before (incidence rate ratio (IRR): 1.03; 95 % confidence interval (CI):1.02–1.05) and also a 4 % increase in incidence for 1 °C increase in mean temperature in the same week (IRR: 1.04; 95 % CI:1.02–1.06).

Conclusions Increase in minimum humidity and mean temperature may have a role in increasing the incidence of salmonellosis in Iran.

Keywords Forecasting · Generalized linear model · Negative binomial regression · Salmonellosis · Environment · Iran · Kermanshah

Introduction

Salmonella bacteria are one of the leading causes of diarrheal disease in the world [1]. The natural bacterial reservoirs of salmonella are animals and the environment [2]; and food is the main source for human infection [3]. A meta-analysis about the incubation period of this disease showed that the average incubation period is from 7 to 21 days. The minimum reported incubation period was 2 and the maximum was 41 days [4]. A study done in Iran, showed the most prevalent serotypes of *Salmonella spp.* isolated were *Enteritidis* (37 %), *Typhimurium* (35.3 %), and *Infantis* (21.1 %); and chicken and cattle were identified as the most likely sources of transmitting the infection to humans [5]. Around the world, about 11–20 million people get typhoid every year, and about 128,000 to 161,000 people die from the disease. Poor and unsanitary communities are more likely to acquire the disease [6].

Numerous studies have shown an association between climate and food born disease such as salmonellosis [7–11].

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48 Previous studies have shown associations between high tem- 74
 49 peratures [11–14], rainfall and humidity [8, 14–16] with the 75
 50 incidence of Salmonellosis, but with different magnitudes and 76
 51 lag lengths. A study conducted in Yazd, Iran reported a IRR of
 52 1.14 (95 % CI:1.10–1.19) for the monthly incidence of
 53 foodborne illnesses, per each percent increase in relative hu-
 54 midity and 1.05 (95 % CI:1.02–1.08), per each millimeter
 55 increase in rainfall in the same month [17].

56 Due to the complex and multi-factorial nature of salmonel-
 57 la infections, which might also be related to human behavior
 58 and environmental factors, the impact of meteorological factors
 59 on disease progress is relatively difficult to predict [18]. In
 60 recent years, several studies have used statistical models to
 61 evaluate the effect of environmental factors on salmonellosis
 62 [10, 11, 14, 19–22].

63 Figure 1 illustrates the incidence of salmonellosis in differ-
 64 ent provinces of Iran during 2008–2018. Two provinces
 65 which were Lorestan and Kermanshah had the highest inci-
 66 dence; however, the number of registered cases was more in
 67 Kermanshah province, and therefore, in this study the data of
 68 Kermanshah was inquired.

69 The climate of Kermanshah is moderate and mountainous.
 70 It rains mainly in winter and is moderately warm in summer
 71 [23]. It is one of the relatively wet parts of Iran. According to
 72 the De Martonne climate index, this region has a
 73 Mediterranean climate [24]. Understanding the quantitative

74 impact of meteorological variables on disease incidence can
 75 help policy makers predict disease outbreaks and allocate
 76 medical facilities and financial resources more appropriately.

77 **Materials and methods**

78 **Study design**

79 This ecological study was performed on salmonella surveil-
 80 lance data from Kermanshah Province, Iran.

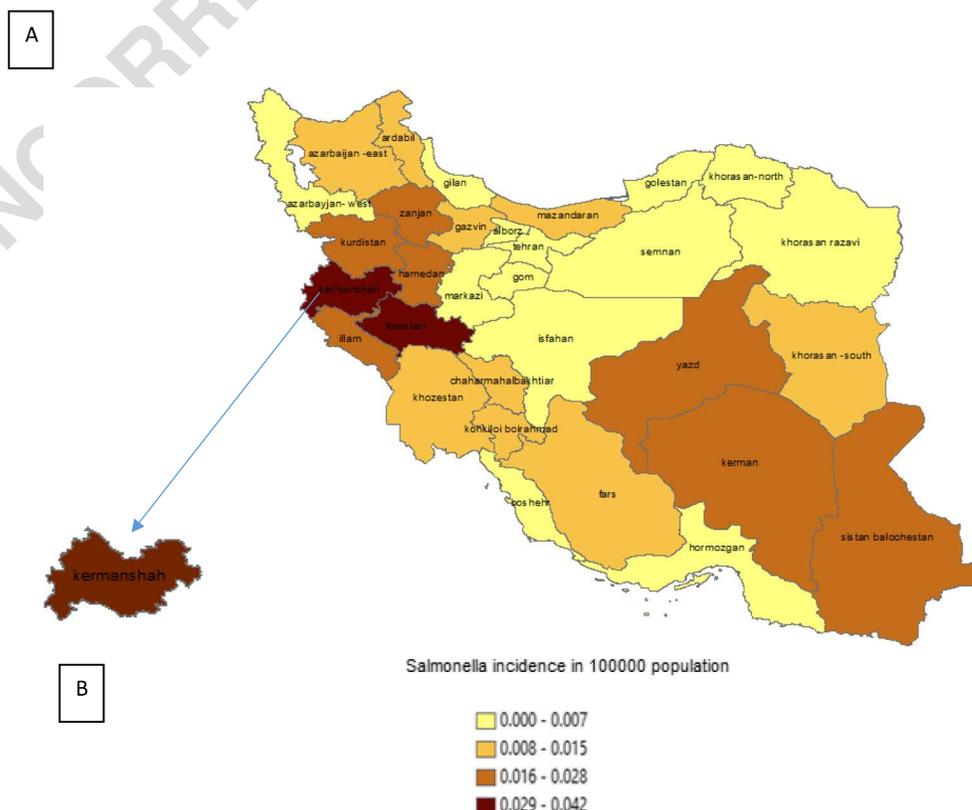
81 **Study setting**

82 The population of Kermanshah province was 1,952,435 ac-
 83 cording to the 2016 national census, and about 2.5 % of Iran’s
 84 population lives in this province. The area of this province was
 85 24,998 km² (or 9652 square miles). Kermanshah is one of the
 86 31 Iranian provinces and is located in the west of Iran. The
 87 geographical coordinates of Kermanshah province are from
 88 45°20’39” E to 48°1’58” E and from 33°37’8” N to 35°17’8”N.

89 **Meteorological data**

90 The meteorological data used in this study were inquired from
 91 the Kermanshah city synoptic meteorological station. These

Fig. 1 The incidence of salmonella cases in different provinces of Iran during 2008–2018 (A), Kermanshah province (B)



92 variables included mean, maximum and minimum of daily
 93 ambient air temperature, daily rainfall, daily sunshine, daily
 94 mean, daily minimum and maximum relative humidity, from
 95 2008 to 2018. Meteorological data were all inquired on a daily
 96 basis, and weekly data were calculated. The maximum and
 97 minimum humidity recorded in the week, and the maximum
 98 and minimum temperature recorded in the week, were used.
 99 Rainfall and sunshine hours were the sum of daily values.

100 Outcome measure

101 Salmonellosis incidence data for the 2008 to 2018 period were
 102 inquired from the Center for Communicable Disease Control,
 103 at the Ministry of Health and Medical Education of Iran.
 104 Salmonellosis incidence data is recorded as suspicious, prob-
 105 able and definite cases in this database.

106 Suspected cases are patients which have symptoms includ-
 107 ing fever for more than a week, headache, nausea and
 108 vomiting, abdominal pain, weakness, dizziness, rose spots
 109 on the trunk, constipation, diarrhea, and enlarged liver or
 110 spleen.

111 Probable cases are suspected cases that in addition to the
 112 symptoms mentioned above, have one or two of the following
 113 signs as well. (1) A Widal test showing 4 times increase in the
 114 somatic O antigen titer within 2 weeks. (2) Existence of cases
 115 of disease among the people surrounding the patient or in the
 116 area.

117 Confirmed cases are probable cases with one or both of the
 118 following signs. (1) A positive salmonella culture in samples
 119 taken from blood, bone marrow, urine, feces, Rose spots, or
 120 duodenal secretions. (2) Finding the specific antigen in urine
 121 or serum[25].

122 The time of disease onset used in this study, was the time
 123 that the first symptoms appeared, not the time the diagnosis
 124 was made. The total number of cases (which means the sum of
 125 suspicious, probable and definite cases) in the province was
 126 used as the outcome variable.

127 Statistical analysis

128 Spearman's rank correlation coefficient was calculated to de-
 129 termine the correlation between salmonellosis case counts and
 130 each meteorological variable. Collinearity was checked by
 131 calculating the variance inflation factor (VIF) for each predic-
 132 tor variable in the regression models. VIF is an index that
 133 shows how much the variance (the square of the estimated
 134 standard deviation) of an estimated regression coefficient in-
 135 creases because of collinearity [26]. Meteorological variables
 136 and the number of cases on consequent days, may be well
 137 related to each other. Therefore, Generalized Linear Models
 138 that take into account the correlation between observations
 139 was used. A negative binomial approach was chosen, because
 140 the count of salmonella cases was over-dispersed, and the

141 variance was greater than the mean [27]. The Vuong test
 142 was employed to determine whether the negative binomial
 143 (NB) regression model fits the data better than the zero inflat-
 144 ed negative binomial (ZINB) regression model or not [28].
 145 This test did not suggest that the ZINB model was a better
 146 fit (p -value = 0.41). Therefore, NB generalized linear models
 147 with lags were used. In the negative binomial regression, that
 148 belongs to the GLM family, the mean (μ) of the response
 149 variable Y is defined as an exponential of the independent
 150 variables called X , and $\mu = e^{x\beta}$. In this equation, β is the re-
 151 gression coefficient. When there are several independent var-
 152 iables, such as x_1, x_2, \dots, x_n the regression equation is written
 153 as follows:

$$154 \ln(y_i) = \alpha + \sum_{j=1}^r x_{ij}\beta_{ij} + \epsilon_i \quad 156$$

157 In this equation, α is the intercept, ϵ is the error, which is
 158 independent of all random variables and has a distribution of
 159 $(1, 1/\varphi)$. It is assumed that the predictors only affect the re-
 160 sponse variable. Because of the overdispersion, the NB uses a
 161 parameter called φ , which makes the variance of the depen-
 162 dent variable Y equal to $\mu + \varphi\mu^2$. The best fit model is deter-
 163 mined by selecting the predictors that are significantly corre-
 164 lated with the response variable, i.e., have significant coeffi-
 165 cients with a P value less than the significance level, [29],
 166 which in this study was 5 %.

167 The model used in this study, included meteorological vari-
 168 ables and their first k lagged values, as the predictor variables.
 169 As the incubation period of salmonella is 2–41 days [4]; there-
 170 fore, k was assumed to be 1 to 6 weeks.

171 The best model was determined based on the lowest
 172 Akaike information criteria (AIC). All statistical analysis
 173 was performed using the STATA statistical software version
 174 16.

175 Results

176 A total of 4957 cases of salmonellosis had been registered
 177 during 2008–2018, in the whole country (Iran) and the inci-
 178 dence rate in the country was 6.8 in 100,000 population.
 179 During this time 569 cases (11.5 % of total country cases)
 180 had been recorded in Kermanshah province.

181 The mean age of the cases was 27.49 (± 17.53) and the
 182 median of age was 25 years. 58 % of the cases were female
 183 and 57 % were from rural areas. Table 1 illustrates the demo-
 184 graphic characteristic of salmonellosis cases in Kermanshah
 185 province.

186 The annual incidence rate of salmonellosis for Kermanshah
 187 province ranged from 14.04 to 100,000 population in 2010 to
 188 0.5 per 100,000 population in 2016 (Fig. 2). The monthly
 189 number of salmonellosis cases are presented in Fig. 3.
 190

t1.1 **Table 1** Demographic characteristics of salmonella cases in Kermanshah province from 2008 to 2018

t1.2	Variables		No. of cases (%)
t1.3	Gender	Male	236 (41)
t1.4		Female	333 (59)
t1.5	Age	Under one years old	8 (1.4)
t1.6		1–5	70 (12.3)
t1.7		6–20	122 (21.5)
t1.8		21–60	345 (60.6)
t1.9		>60	24 (4.2)
t1.10	Residence	Urban	244 (43)
t1.11		Rural	325 (57)
t1.12	Toilet situation	Sanitary toilets	501 (88)
t1.13		Non- Sanitary toilet	68 (12)
t1.14	Water situation	Sanitary water	523 (92)
t1.15		Non- Sanitary water	46 (8)

191 Table 2 shows the descriptive statistics of meteorological variables of Kermanshah.

192
193
194 Significant correlations were detected between the weekly
195 count of salmonella cases and weekly mean temperature ($r =$
196 0.12 , P -value < 0.01) and minimum humidity ($r = 0.1$, P -val-
197 ue < 0.01). Therefore, the GLM was fitted using these two
198 independent variables. VIF was checked and there was no
199 significant collinearity between these two variables.
200 According to the calculated cross-correlation functions, mini-
201 mum humidity with 1-week lag and mean temperature with-
202 out lag had a significant relation with salmonellosis incidences
203 and were added to the GLM. We observed a 3 % increase in
204 the incidence of salmonellosis associated with 1 % increase in
205 minimum weekly humidity (incidence rate ratio (IRR):1.03;
206 95 % confidence interval (CI):1.02–1.05), in the week before;
207 and also a 4 % increase in the incidence associated with 1 °C
208 increase in mean weekly temperature

(IRR:1.04;95 %CI:1.02–1.06) in the same week. Table 3
shows the estimates of GLM for weekly salmonellosis inci-
dence in Kermanshah Province.

Discussion

In this study, negative binomial generalized linear models were performed to quantify the relation between meteorological variables and salmonellosis cases in Kermanshah province. The present study showed that salmonellosis incidence was related to the mean temperature of the same week. Similarly, in Maryland, by using negative binomial generalized estimating equations (GEE), the risk of salmonellosis increased 4.1 % per each unit increase in extreme temperature events [20]. The rate of hospitalization due to salmonellosis in Hong Kong was also shown to be directly correlated with increase in daily temperature, and the relative risk of hospitalization comparing 30.5 to 13 °C was 6.13 (CI 95 %: 3.53–10.67) [13]. Another study from Bangladesh examined the relation between the weekly number of typhoid cases and meteorological variables by generalized linear Poisson regression models allowing for overdispersion, and showed that for every 1 °C increase in temperature, the incidence of typhoid cases increased 14.2 % [30]. A study from Singapore using negative binomial time series regression models on a weekly scale, showed a 4.3 and 6.3 % increase in reported salmonellosis cases in the same week, and 3 weeks later respectively, per 1° C increase in mean ambient air temperature [11]. A study from Australia which was also done on a weekly basis, used four regression methods and found an association between the incidence of salmonellosis and 2-week lagged maximum temperature in the standard Poisson regression model ($\beta=0.015$, CI: 0.003,0.027), in multiple linear regression ($\beta=0.02$, CI: 0.01,0.03), in seasonal autoregressive integrated moving average and ($\beta=0.025$, $P < 0.0001$) in autoregressive

Fig. 2 Annual incidence of salmonellosis in Kermanshah province during 2008–2018

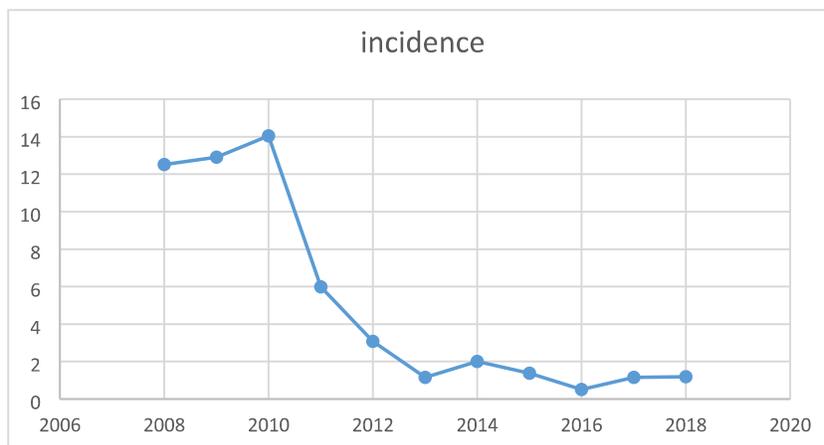
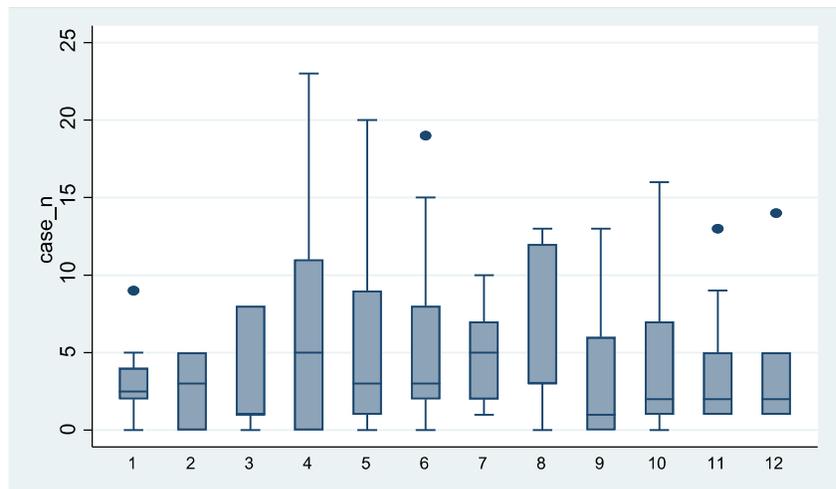


Fig. 3 Box plot of monthly salmonellosis incidence in Kermanshah province, 2008–2018



243 adjusted Poisson regression ($\beta=0.017$, CI: 0.011,0.024) [8]. In
 244 a study conducted in Kazakhstan, by using time series analysis,
 245 for every 1 °C increase in temperature, the incidence of
 246 Salmonellosis increased 5.3 % (2.1–8.6 %) in the same month
 247 [10].

248 There are numerous studies that have shown an increase in
 249 Salmonellosis incidence due to increased temperature [20, 31,
 250 32]. Bacterial proliferation and survival on foods such as poultry,
 251 eggs, vegetables and fruits in warm weather can partly explain
 252 the relation between increased ambient temperature and salmonellosis
 253 [33, 34]. Temperature has a profound effect on the growth of
 254 *Salmonella spp.*, and in vitro the growth of this bacterium is
 255 observed at temperatures between 7.5 and 48 °C, and the highest
 256 growth rate is observed at 37 °C [35]. In the absence of appropriate
 257 interventions, ambient temperature rises, can increase bacteria
 258 reproduction in various edible products [22, 36]. Increase in
 259 ambient air temperature may also affect people’s behavior, and
 260 for example increase their tendency to eat raw food such as fruits
 261 or vegetables, which may contain bacteria [37]. Storage and
 262 preparation of food may take several weeks and during this time,
 263 bacterial contamination may occur unintentionally because of
 264 temperature increase [11].
 265

The results of this study showed that the minimum humidity
 in the week before, was positively associated with the number
 of cases of salmonellosis. A study in Singapore showed, 1.3 %
 decrease in salmonellosis cases with 1 % increase in mean
 relative humidity, after 6 weeks (IRR: 0.987, 95 % CI: 0.981,
 0.994) [11]. In Yazd, Iran the IRR of foodborne illness was
 1.14 per each percent increase in relative humidity [17]. In
 Hong Kong, higher hospitalization rates of salmonella were
 associated with elevated relative humidity above 60 %, for a
 period of 17 days [38]. Other laboratory studies have reported
 that *Salmonella* bacteria proliferation on food, increases at
 high relative humidity (96 %) at 10 °C [39], and up to 10
 days at 22 °C and 97 % relative humidity [40]. However,
 relative humidity was not significantly associated with
Salmonella cases in some other studies [8, 16, 41].
 Increase in relative humidity may increase the pathogen load
 and survivability of pathogens on surfaces and foods, and
 increase the risk of salmonellosis.

It seems like, the impact of rainfall on the incidence of
 salmonellosis varies depending on the region, since the results
 of studies in different tropical, subtropical and Mediterranean
 regions have shown contradictory results [8, 14, 15].

t2.1 **Table 2** Descriptive statistics of
 t2.2 meteorological variables on a
 t2.3 weekly basis in Kermanshah
 t2.4 province from 2008 through 2018

	Mean (SD)	Min	P(1st)	P(25th)	Median	P(75th)	P(99th)	Max
t2.6 Mean temperature	16.7 (10)	-15.6	-0.8	8.2	15.8	25.6	34.4	67
t2.7 Minimum temperature	7.7 (7.3)	-8.2	-6.2	1.7	8.3	14	20	22.4
t2.5 Maximum temperature	24.4 (10.6)	2.5	5.1	14.8	23.4	34.7	41.1	42
t2.6 Mean humidity	40.6 (21.6)	9	9.7	19	40	59.3	81	91
t2.7 Minimum humidity	12.6 (10.5)	0	1	4	9	19	43	62
t2.8 Maximum humidity	71.7 (26.3)	21	23	46	86	96	100	100
t2.9 Rainfall	6.7 (14.1)	0	0	0	0.1	7.1	75	109
t2.10 Sunshine	54.6 (19.3)	5.8	13	40	53.6	71.6	87.6	134

Variables	IRR	Std.Err	z	P > z	[95% CI]
Minimum humidity lagged 1 week	1.03	0.008	4.63	0.000	1.02–1.05
Mean temperature	1.04	0.008	5.00	0.000	1.02–1.06
Intercept	0.31	0.07	-5.06	0.000	0.19–0.48
Number of obs	569				
Deviance	522.15				
Pearson	504.4				
family	Neg. binomial				
AIC	2.75				
Link function	Log				

288 However, in the present study, the incidence of cases did not
 289 show any association with rainfall.

290 The incidence of salmonella is affected by several factors,
 291 including socio-economic factors, urbanization, food hygiene
 292 and safe water, and climate factors. The annual incidence of
 293 salmonellosis in Kermanshah province has declined over the
 294 11 years under study. This may be due to increase in safe
 295 water and sanitary toilets, and human interventions. Rural
 296 improvement programs can play an important role in
 297 preventing gastrointestinal infections, including salmonellosis
 298 [42].

299 One of the limitations of the present study is that only
 300 climatic factors were assessed, and other factors that might
 301 have been related were not investigated. Also, there might
 302 have been under-reporting of the disease, from public centers
 303 and private offices.

304 Although in this study humidity and temperature had an
 305 effect on the incidence of salmonellosis, but because this dis-
 306 ease is multifactorial and several factors such as water and
 307 wastewater status and general hygiene affect its incidence,
 308 therefore, the results of this study have limited
 309 generalizability.

310 Conclusions

311 Increase in mean ambient temperature and minimum humidity
 312 may be directly related to the incidence of salmonellosis in
 313 Kermanshah, Iran. This information can help predict the out-
 314 breaks of this disease in the future, and help allocate resources
 315 efficiently.

316 **Authors contribution** NK suggested the topic, was the main supervisor,
 317 and helped in writing and editing the final manuscript. SN acquired the
 318 data, cleaned the data, analyzed the data and prepared the initial draft. BB
 319 provided scientific advice and edited the final article. YJ supervised data
 320 analysis, provided statistical consultation and edited the final manuscript.
 321 HD helped in inquiring meteorological data, cleaning the data, and writ-
 322 ing the manuscript.
 323

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Code availability STATA software version 16. 326

Declarations 327

Conflict of interest The authors declare that they have no competing
 interests. 328 329

Ethics approval The study proposal was approved by the Ethics
 Committee of Kerman University of Medical Science. Ethics Code:
 IR.KMU.REC.1397.231. 330 331 332

Consent to participate Not applicable. 333

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