

IMPACT OF AMBIENT TEMPERATURE AND HUMIDITY ON THE FREQUENCY OF ECLAMPSIA: A SEASONAL ANALYSIS

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Abstract

Background: Eclampsia remains a major contributor to maternal mortality globally, particularly in resource-limited settings. While environmental factors have been implicated in pregnancy complications, evidence linking ambient temperature and humidity to eclampsia incidence in South Asian populations remains limited. This study investigates seasonal patterns of eclampsia and their association with meteorological variables in northwestern Pakistan.

Methods: We conducted a prospective observational study at Women & Children Hospital, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan, from January 2022 to December 2024. All eclampsia cases (n=102) were systematically documented using standardized protocols. Concurrent meteorological data (temperature, humidity) were obtained from regional weather stations. Statistical analyses included chi-square tests for seasonal distribution, Pearson correlation for temperature-humidity associations, and comparative analyses between seasonal groups.

Results: Among 102 eclampsia cases, 67 (65.7%) occurred during winter months (November-February), representing a 3.3-fold higher incidence compared to summer months (8 cases, 7.8%; $p < 0.001$). Winter months were characterized by significantly lower temperatures ($14.7 \pm 2.1^\circ\text{C}$ vs. $32.5 \pm 1.2^\circ\text{C}$ in summer; $p < 0.001$) and higher humidity ($68.8 \pm 4.3\%$ vs. $43.7 \pm 5.8\%$; $p < 0.001$). Strong inverse correlation existed between monthly temperature and eclampsia incidence ($r = -0.782$, $p < 0.001$), with positive correlation between humidity and incidence ($r = +0.694$, $p < 0.001$). Primigravid women comprised 74.5% of cases. The case fatality rate was 6.9%, with acute kidney injury (14.7%) and HELLP syndrome (11.8%) being the most common complications. Clinical severity and outcomes showed no significant differences between winter and summer cases.

Conclusion: This study highlights distinct seasonal patterns in eclampsia in northwestern Pakistan, with peak incidence during cooler, humid winter months. These findings suggest environmental influences on the timing of eclampsia and support the implementation of season-specific surveillance and preventive strategies in similar climatic regions.

INTRODUCTION

Eclampsia, defined as new-onset generalized seizures in women with preeclampsia in the absence of other causative neurological conditions that remains one of the most severe and life-threatening complications of pregnancy [1]. Despite significant progress in prenatal care and obstetric management, hypertensive disorders of pregnancy still account for approximately 10-15% of maternal deaths worldwide, with the greater impact seen in low and middle income countries (LMICs) [2]. In South Asia, eclampsia remains a leading cause of maternal mortality, with Pakistan reporting a maternal mortality ratio of 186 deaths per 100,000 live births [3]. The pathophysiology of eclampsia involves complex interplay of abnormal placentation, endothelial dysfunction, systemic inflammation, and vasospasm [4]. The traditional risk factors include primigravida status, extremes of maternal age, multiple gestation, chronic hypertension, diabetes mellitus, renal disease, and history of preeclampsia in previous pregnancies [5]. However, these established risk factors do not fully account for the geographic and temporal differences in eclampsia incidence across different populations and time periods. Emerging evidence suggests that environmental factors, particularly ambient temperature and humidity, may significantly influence the onset and timing of eclampsia [6,7]. Several studies from diverse geographic regions have documented seasonal patterns in eclampsia incidence, though findings remain inconsistent. Research from India has consistently reported higher eclampsia rates during winter and monsoon seasons. Many studies from Pakistan have shown similar patterns, with peak incidence during cooler months [8]. International research from China, Hong Kong, and South Africa has demonstrated associations between temperature extremes and hypertensive disorders of pregnancy [9,10].

The biological mechanisms underlying these environmental associations remain incompletely understood but may involve thermoregulatory stress, cardiovascular adaptations to temperature extremes, humidity-related alterations in blood volume homeostasis, seasonal variations in vitamin D synthesis, and changes in infectious

disease patterns [11]. The understanding these relationships is particularly important in the context of climate change, which is projected to increase both temperature extremes and weather variability [12]. Despite increasing recognition of environmental influences on maternal health, significant knowledge gaps remain. Most existing studies are retrospective with small sample sizes, lack concurrent weather monitoring, and provide limited data from semi-arid climates characteristic of many South Asian regions. Furthermore, few studies have examined whether environmental factors affect both the incidence and severity of these cases. This prospective study addresses these gaps by systematically examining the relationship between ambient temperature, humidity, and eclampsia frequency over a two-year period at a tertiary care hospital in Khyber Pakhtunkhwa, Pakistan. We hypothesized that eclampsia incidence would demonstrate significant seasonal variation, with higher rates during periods of lower temperature and higher humidity.

2.0 Materials and Methods

2.1 Study Design and Setting

This prospective observational study was conducted at Women & Children Hospital, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan, from January 2022 to December 2024 (24 months). The hospital serves as a tertiary referral center for the southern districts of the province. The district, Dera Ismail Khan is located in northwestern Pakistan (31.8°N, 70.9°E) and experiences a semi-arid climate with distinct seasonal variations. The region has four seasons: hot summers (June-August) with temperatures ranging from 28-40°C and low humidity (35-50%), cool winters (November-February) with temperatures of 8-20°C and higher humidity (60-75%), and transitional spring (March-May) and autumn (September-October) periods with moderate temperatures and humidity.

2.2 Study Population

All pregnant and postpartum women presenting with eclampsia during the study period were considered eligible for inclusion. Patients were

excluded if seizures were attributable to other causes such as epilepsy, cerebral malaria, meningitis, encephalitis, cerebral venous thrombosis, brain tumors, or metabolic disorders. Additionally, patients with incomplete medical records lacking essential clinical data and those referred from other healthcare facilities after initial management without complete documentation of presentation were excluded to ensure data reliability and consistency.

2.3 Data Collection

Prospective data collection was conducted using standardized case report forms specifically designed for this study. Data collection commenced immediately upon patient presentation and continued throughout the duration of hospital stay. Trained medical officers, under the supervision of senior obstetricians, systematically recorded demographic characteristics, including maternal age, gravidity, parity, gestational age at presentation, residence (rural or urban), socioeconomic indicators, and educational status. Detailed obstetric history was obtained, including antenatal care attendance, prior pregnancy complications, pre-existing medical conditions, and complications during the current pregnancy. The clinical presentation data included the timing of eclampsia (antepartum, intrapartum, or postpartum within 48 hours of delivery), number and duration of seizure episodes, blood pressure measurements, degree of proteinuria, associated symptoms such as headache, visual disturbances, epigastric pain, oliguria, and the level of consciousness following seizures. Management-related information included administration of magnesium sulfate (loading and maintenance doses), use of antihypertensive medications, mode of delivery, and timing of delivery relative to seizure onset. Maternal outcomes were documented in detail, including recovery status, complications such as HELLP syndrome, acute kidney injury, pulmonary edema, disseminated intravascular coagulation, cerebral hemorrhage, aspiration pneumonia, and posterior reversible encephalopathy syndrome, along with ICU admission, duration of hospital stay, and maternal mortality. To ensure data

accuracy and quality, regular audits were performed, cross-verification with hospital electronic medical records was carried out, and discrepancies were reviewed by senior investigators.

2.3 Meteorological Data

Daily meteorological data were obtained from the Pakistan Meteorological Department weather station located in Dera Ismail Khan, approximately 3 km from the study hospital. Recorded parameters included daily mean, maximum, and minimum ambient temperature, relative humidity, precipitation, and atmospheric pressure. Monthly averages of these variables were calculated to assess their correlation with eclampsia incidence. The meteorological station utilizes calibrated instruments maintained according to standards set by the World Meteorological Organization, ensuring high-quality and reliable environmental data.

2.4 Data Analysis

All data were entered and analyzed using IBM SPSS Statistics version 25.0. Descriptive statistics were applied to summarize the data. Continuous variables were expressed as mean \pm standard deviation or median with interquartile range depending on normality, which was assessed using the Shapiro-Wilk test. Categorical variables were presented as frequencies and percentages.

For inferential analysis, chi-square tests were used to evaluate seasonal distribution and differences between categorical variables. Pearson's correlation coefficient was applied to determine the relationship between meteorological factors and eclampsia incidence. Independent-samples *t*-tests were used to compare continuous variables between seasonal groups. Relative risk was calculated using the annual monthly average as a reference. A *p*-value of less than 0.05 was considered statistically significant.

2.5 Ethical Considerations

Ethical approval for the study was obtained from the Institutional Review Board of Gomal Medical College, affiliated with Women & Children Teaching Hospital. As the study was observational

in nature and utilized routinely collected clinical data without any experimental interventions, the requirement for individual informed consent was waived by the ethics committee. Patient confidentiality was strictly maintained through the use of coded identifiers and secure data storage systems.

3.0 Results

3.1 Overall Incidence and Seasonal Distribution

During the two-year study period from January 2022 to December 2024, a total of 102 eclampsia cases were prospectively documented at Women & Children Hospital, Dera Ismail Khan. The hospital recorded 8,640 deliveries during this

period, yielding an eclampsia incidence of 11.8 per 1,000 deliveries (1.18%). Winter accounted for 67 cases (65.7%), representing the highest seasonal burden. The winter monthly average of 16.8 cases was 3.3-fold higher than the summer monthly average of 2.7 cases and 6.2-fold higher than the baseline monthly average of 2.7 cases. This seasonal variation was highly statistically significant ($\chi^2 = 89.45$, $p < 0.001$), indicating that the distribution was not due to chance. The seasonal distribution of eclampsia cases revealed a striking and statistically significant pattern, with marked clustering during the winter months is presented in Table 1.

Table 1: Seasonal Distribution of Eclampsia Cases and Meteorological Parameters (N=102)

Season	Months	Number of Cases (n)	Percentage (%)	Average Temperature (°C)	Average Humidity (%)	Cases per Month
Winter	Nov-Feb	67	65.7	12-18 (mean: 14.7)	60-75 (mean: 68.8)	16.8
Spring	Mar-May	18	17.6	22-28 (mean: 25.5)	45-55 (mean: 49.3)	6
Summer	Jun-Aug	8	7.8	28-35 (mean: 32.5)	35-50 (mean: 43.7)	2.7
Autumn	Sep-Oct	9	8.8	20-26 (mean: 26.0)	50-60 (mean: 55.0)	4.5
Total		102	100			8.5

3.2 Demographic and Obstetrics Characteristics

Table 2 presents the demographic and obstetric profile of the 102 eclampsia cases, highlighting key risk factors and population characteristics. Primigravidity was predominant, with 74.5% of eclampsia cases occurring in first pregnancies, reaffirming it as a major risk factor. Most patients were young, with 41.2% aged 20–25 years and a mean maternal age of 24.8 ± 5.1 years. A large proportion (76.5%) belonged to rural areas, reflecting the hospital's catchment population and

suggesting possible barriers to accessing prenatal care. More than half of the women (51.0%) had no formal education, and antenatal care was inadequate, with only 30.4% receiving the recommended four or more visits, while 25.5% had none. All cases presented in the third trimester (mean gestational age 35.6 ± 2.8 weeks), two-thirds before term, and most patients (62.7%) were unbooked, presenting as emergency admissions [Table 2].

Table 2: Demographic and Obstetric Characteristics of Eclampsia Cases (N=102)

Characteristic	Category	Number (n)	Percentage (%)
Gravidity	Primigravida	76	74.5
	Multigravida (2-3)	19	18.6
	Grand multigravida (≥4)	7	6.9
Maternal Age (years)	<20	15	14.7
	20-25	42	41.2
	26-30	28	27.5
	31-35	12	11.8
	>35	5	4.9
	Mean ± SD	24.8 ± 5.1	-
Gestational Age	Third trimester (28-36 weeks)	68	66.7
	Term (≥37 weeks)	34	33.3
	Mean ± SD (weeks)	35.6 ± 2.8	-
Residence	Rural	78	76.5
	Urban	24	23.5
Education Level	No formal education	52	51
	Primary (1-5 years)	28	27.5
	Secondary (6-10 years)	16	15.7
	Higher (>10 years)	6	5.9
Antenatal Care	Regular ANC (≥4 visits)	31	30.4
	Irregular ANC (1-3 visits)	45	44.1
	No ANC	26	25.5
Booking Status	Booked (registered at facility)	38	37.3
	Unbooked	64	62.7

3.3 Clinical Presentation and Timing of Eclampsia

Most seizures occurred in the antepartum period, with 56.9% developing before the onset of labor, highlighting the critical role of effective prenatal surveillance. Multiple seizure episodes were common, as 66.7% of patients experienced more than one seizure, reflecting severe disease. The mean blood pressure at presentation was 172/112 mmHg, and 76.5% met criteria for severe hypertension (≥160/110 mmHg). Significant

proteinuria was observed in 72.6% of cases, with 3+ or 4+ levels, indicating marked renal involvement. Prodromal symptoms were documented in 62.7% of patients—most commonly headache (87.3%) and visual disturbances (74.5%)—suggesting missed opportunities for earlier recognition and prevention through timely management of severe preeclampsia features. Table 3 details the timing of eclampsia onset relative to delivery and the clinical features at presentation.

Table 3: Clinical Presentation & Timing of Eclampsia

Parameter	Category	Number (n)	Percentage (%)	
Timing of Eclampsia	Antepartum	58	56.9	
	Intrapartum	24	23.5	
	Postpartum (≤ 48 hours)	20	19.6	
Number of Seizures	Single episode	34	33.3	
	2-3 episodes	48	47.1	
	>3 episodes	20	19.6	
Post-ictal Status	Conscious within 30 min	62	60.8	
	Prolonged unconsciousness	40	39.2	
Blood Pressure	Systolic BP (mmHg), mean \pm SD	172 \pm 18	Range: 140-220	
	Diastolic BP (mmHg), mean \pm SD	112 \pm 14	Range: 90-145	
	Severe hypertension ($\geq 160/110$)	78	76.5	
Proteinuria	2+	28	27.5	
	3+	52	51	
	4+	22	21.6	
Associated Symptoms	Headache	89	87.3	
	Visual disturbances (blurred vision, scotomata)	76	74.5	
	Epigastric/right upper quadrant pain	52	51	
	Oliguria (< 400 mL/24 hours)	38	37.3	
	Nausea/vomiting	45	44.1	
	Warning Signs Prior to Seizure	Yes (documented prodrome)	64	62.7
		No warning signs	38	37.3

3.4 Maternal Outcomes & Complications

The case fatality rate was 6.9% (7 deaths), which is comparable to figures reported from other low- and middle-income countries. Overall, 44.1% of patients developed at least one major complication, with acute kidney injury being the most frequent (14.7%), likely secondary to severe hypertension and hypovolemia. HELLP syndrome occurred in 11.8% of cases, reflecting significant multi-organ involvement. Cesarean delivery was common (62.7%), predominantly for maternal indications (65.6%). All patients received magnesium sulfate as standard therapy,

and most women (89.2%) recovered well and were discharged in stable condition. The mean hospital stay was 5.1 ± 2.7 days, although 21.6% required prolonged hospitalization exceeding seven days. Among the seven maternal deaths, causes included cerebral hemorrhage (three cases), multi-organ failure (two cases), aspiration pneumonia with respiratory failure (one case), and disseminated intravascular coagulation (one case). Table 4 summarizes maternal outcomes, complications, and management approaches for the 102 eclampsia cases.

Table 4: Maternal Outcomes, Complications, and Management (N=102)

Outcome/Parameter	Category	Number (n)	Percentage (%)
Primary Maternal Outcome	Discharged in stable condition	91	89.2
	ICU transfer required	4	3.9
	Maternal death	7	6.9
Maternal Complications	HELLP syndrome	12	11.8
	Acute kidney injury (Cr >1.1 mg/dL)	15	14.7
	Pulmonary edema	8	7.8
	Disseminated intravascular coagulation	6	5.9
	Cerebral hemorrhage	5	4.9
	Aspiration pneumonia	7	6.9
	Posterior reversible encephalopathy syndrome	4	3.9
	Placental abruption	9	8.8
	Postpartum hemorrhage	13	12.7
Any Major Complication	Yes	45	44.1
	No	57	55.9
Mode of Delivery	Vaginal delivery	38	37.3
	Cesarean section	64	62.7
Indication for Cesarean	Eclampsia/maternal indication	42	65.6*
	Fetal distress	15	23.4*
	Failed induction	7	10.9*
Duration of Hospital Stay	<3 days	22	21.6
	3-7 days	58	56.9
	>7 days	22	21.6
	Mean ± SD (days)	5.1 ± 2.7	Range: 1-14
Magnesium Sulfate Use	Yes (Pritchard regimen)	102	100
Antihypertensive Use	Labetalol	68	66.7
	Hydralazine	52	51
	Nifedipine	34	33.3

3.5 Monthly Distribution and Meteorological Correlations

Monthly analysis revealed a clear seasonal pattern, with the highest incidence of eclampsia observed in January and December (18 cases each, 17.6%), corresponding to a relative risk of 2.12. In contrast, June recorded the lowest incidence, with only two cases (2.0%) and a relative risk of 0.24. The coldest months (December to February; 12.5–15.2 °C) were associated with the highest case

counts, demonstrating an inverse relationship between ambient temperature and eclampsia incidence. Higher humidity levels during these months (68–72%) also coincided with increased incidence, suggesting a positive association with humidity. Overall, there was an almost ninefold difference in case numbers between the peak month (January) and the lowest-incidence month (June), while consistently low rates were observed during the summer months despite high

temperatures and low humidity. Table 5 presents the month-by-month distribution of eclampsia

cases alongside corresponding meteorological data, revealing clear temporal patterns.

Table 5: Monthly Distribution of Eclampsia Cases with Meteorological Parameters

Month	Cases (n)	Percentage (%)	Avg Temp (°C)	Avg Humidity (%)
January	18	17.6	12.5	72
February	16	15.7	15.2	68
March	9	8.8	21.8	58
April	6	5.9	26.5	48
May	3	2.9	28.3	42
June	2	2	32.1	38
July	3	2.9	33.8	45
August	3	2.9	31.5	48
September	5	4.9	28.2	52
October	4	3.9	23.7	58
November	15	14.7	17.3	65
December	18	17.6	13.8	70
Total/Mean	102	100	23.7	55.3

3.6 Comparative Analysis: Winter vs. Summer Eclampsia Cases

To determine whether seasonal variation affects only disease incidence or also influences clinical characteristics and outcomes, we compared eclampsia cases occurring in winter versus summer (Table 7). Maternal outcomes were comparable across seasons, with no significant differences observed in maternal mortality (7.5% vs. 0%, $p = 0.478$), ICU admissions, cesarean delivery rates, or duration of hospital stay. These findings suggest that seasonal variation primarily influences the timing and incidence of eclampsia rather than its clinical severity or outcomes. Women who developed eclampsia during the summer had similar clinical characteristics and prognoses to those presenting in winter. This pattern indicates that environmental factors may act as triggering influences in susceptible women, affecting disease occurrence rather than altering the underlying pathophysiology once eclampsia has developed. The principal findings of this study reveal significant seasonal and meteorological patterns in eclampsia occurrence, along with distinct

demographic and clinical characteristics. This study demonstrated marked seasonal clustering of eclampsia cases, with 65.7% occurring during winter months (November-February), representing a 3.3-fold increase compared to summer months ($p < 0.001$). This temporal distribution showed strong meteorological associations, including a robust inverse correlation between temperature and eclampsia incidence ($r = -0.782$, $p < 0.001$) and a strong positive correlation between humidity and eclampsia incidence ($r = +0.694$, $p < 0.001$). Peak incidence was observed in the coldest and most humid months, specifically January and December. The demographic profile of affected women revealed a high-risk population characterized by primigravid status in 74.5% of cases, with 41.2% being between 20-25 years of age. Rural residence predominated at 76.5%, and inadequate antenatal care was documented in 69.6% of cases, highlighting significant healthcare access disparities. Clinical presentation patterns showed that antepartum eclampsia was most common (56.9%), with the majority of patients experiencing multiple seizures (66.7%) and severe

hypertension (76.5%). Prodromal symptoms were documented in 62.7% of cases, suggesting potential opportunities for earlier intervention. Maternal outcomes revealed a case fatality rate of 6.9%, with major complications occurring in 44.1% of cases. The most common complications included acute kidney injury (14.7%) and HELLP

syndrome (11.8%), while cesarean delivery was performed in 62.7% of cases. Importantly, seasonal comparison analysis revealed no significant differences in clinical severity or outcomes between winter and summer cases, suggesting that environmental factors primarily influence disease incidence rather than severity.

Table 6: Comparative Analysis of Winter and Summer Eclampsia Cases

Parameter	Winter (Nov-Feb) n=67	Summer (Jun-Aug) n=8	Difference	p-value
Average Temperature (°C)	14.7 ± 2.1	32.5 ± 1.2	-17.8	<0.001
Average Humidity (%)	68.8 ± 4.3	43.7 ± 5.8	25.1	<0.001
Mean Maternal Age (years)	24.6 ± 4.8	25.3 ± 5.2	-0.7	0.682
Primigravida, n (%)	51 (76.1%)	5 (62.5%)	0.136	0.361
Rural residence, n (%)	52 (77.6%)	6 (75.0%)	0.026	0.853
No/irregular ANC, n (%)	47 (70.1%)	5 (62.5%)	0.076	0.654
Mean Gestational Age (weeks)	35.4 ± 2.9	36.2 ± 2.4	-0.8	0.432
Mean Systolic BP (mmHg)	174 ± 17	168 ± 21	6	0.334
Mean Diastolic BP (mmHg)	113 ± 13	108 ± 16	5	0.283
Multiple seizures (>1), n (%)	46 (68.7%)	5 (62.5%)	0.062	0.714
Severe proteinuria (3-4+), n (%)	50 (74.6%)	6 (75.0%)	-0.40%	0.982
HELLP syndrome, n (%)	8 (11.9%)	1 (12.5%)	-0.60%	0.962
Acute kidney injury, n (%)	11 (16.4%)	1 (12.5%)	0.039	0.773
Any major complication, n (%)	30 (44.8%)	3 (37.5%)	0.073	0.681
Maternal mortality, n (%)	5 (7.5%)	0 (0%)	0.075	0.478
ICU admission, n (%)	3 (4.5%)	0 (0%)	0.045	0.585
Cesarean delivery, n (%)	43 (64.2%)	5 (62.5%)	0.017	0.921
Mean hospital stay (days)	5.2 ± 2.8	4.6 ± 2.1	0.6	0.545

4.0 Discussion

This prospective study of 102 eclampsia cases demonstrates striking seasonal variation, with 65.7% occurring during winter months (November-February), representing a 3.3-fold increase compared to summer. Strong inverse correlation between temperature and eclampsia incidence ($r=-0.782$, $p<0.001$) and positive

correlation with humidity ($r=+0.694$, $p<0.001$) support environmental influences on disease

timing. Critically, while incidence varied dramatically by season, clinical severity and outcomes showed no seasonal differences, suggesting environmental factors trigger disease onset in susceptible women rather than modifying pathophysiology. Our findings align with multiple studies documenting seasonal eclampsia patterns. Indian studies consistently report winter-monsoon predominance: Neela and Raman (1993) first documented this pattern, confirmed by Ghosh et al. (2013) with 52.7% of cases in November-

January [1] Pakistani studies corroborate these findings, with Akhtar et al. (2023) reporting 58% winter incidence 3, Jamelle (1998) showing November-January peaks 4, and Malik et al. (2014) documenting similar patterns 8. International evidence strengthens these associations [8]. Tam et al. (2008) in Hong Kong found 9% increased preeclampsia risk per 1°C temperature decrease [9]. Xiong et al. (2020) analyzed 2.4 million Chinese pregnancies, demonstrating U-shaped temperature-risk relationships 6. Part et al. (2022) in South Africa reported time-to-event associations between temperature and hypertensive disorders 10. Mao et al. (2023) confirmed these patterns through systematic review and meta-analysis 13. However, tropical Nigerian studies show conflicting results [14,15], likely reflecting minimal temperature variation in equatorial regions, methodological differences, and population-specific factors. Our correlation coefficients ($r=-0.782$ for temperature, $r=+0.694$ for humidity) are among the strongest reported, possibly due to prospective design, concurrent meteorological monitoring, and pronounced seasonal variation (12-35°C range) in semi-arid Khyber Pakhtunkhwa.

Several mechanisms may explain temperature-humidity associations with eclampsia: Cardiovascular stress: Pregnancy increases cardiac output and blood volume by 40-50% [16.] Cold exposure triggers peripheral vasoconstriction, increasing systemic vascular resistance and blood pressure [11]. In women with preeclamptic endothelial dysfunction, this additional stress may precipitate eclampsia. Conversely, heat causes vasodilation but also increases risk through dehydration and hemoconcentration [13]. Humidity effects: High humidity impairs evaporative cooling and may affect fluid homeostasis. In preeclamptic women with compromised renal function and reduced plasma volume, elevated humidity may exacerbate fluid retention and hypertension, explaining the positive correlation ($r=+0.694$). Vitamin D deficiency: Reduced winter sunlight decreases vitamin D synthesis, which has been linked to preeclampsia through immune dysfunction, vascular impairment, and abnormal placentation

[11]. However, rapid seasonal clustering suggests acute triggers rather than gradual vitamin D depletion. Integrated hypothesis: Chronic factors (low vitamin D, inadequate antenatal care, primigravidity) create baseline susceptibility, while acute environmental stressors (cold, high humidity) and seasonal factors (infections, dietary changes) trigger eclampsia in vulnerable individuals. This explains why environmental factors affect incidence but not severity once disease.

Season-specific surveillance: Healthcare facilities in similar climates should implement intensified surveillance during November-February, including increased staffing, augmented medication stockpiles (magnesium sulfate, antihypertensives), and enhanced intensive care capacity. Targeted interventions: High-risk women (primigravidas, inadequate antenatal care, rural residents) should receive enhanced monitoring during high-risk seasons, including more frequent screening, earlier aspirin prophylaxis (reduces preeclampsia by 50-60%), calcium and vitamin D supplementation, and education about warning signs [17]. Community engagement: Community health workers should be trained to recognize preeclampsia symptoms, measure blood pressure, and facilitate rapid referral. Weather-based early warning systems could alert providers and communities to elevated risk periods, similar to cardiovascular heat warnings. Antenatal care strengthening: With 69.6% of cases having inadequate/no antenatal care, interventions should include community-based care, mobile health monitoring, financial incentives for attendance, and targeted rural outreach.

Climate change adaptation: As climate patterns shift, maternal health programs must incorporate meteorological monitoring and develop flexible response systems. Establishing routine linkage between weather data and maternal outcomes enables real-time risk assessment and evidence-based resource allocation [12]. Strengths include prospective design reducing bias, concurrent meteorological monitoring ensuring accurate exposure assessment, comprehensive clinical data collection, focus on understudied semi-arid climate, and strong statistical associations ($r=$

0.782, $r=+0.694$) among the highest reported. Limitations warrant consideration. Single-center design may limit generalizability, though the large catchment area is representative of northwestern Pakistan. Observational design cannot establish causality despite strong associations; unmeasured confounders (seasonal diet, agricultural cycles, healthcare-seeking patterns) may contribute. Ambient meteorological measurements don't capture individual exposures (indoor temperature, occupational factors, housing quality). Small summer sample ($n=8$) limits seasonal comparison power, though differences remain highly significant. Lack of mechanistic data (vitamin D, inflammatory markers, cardiovascular parameters) prevents pathway elucidation. The study examined eclampsia incidence but not preeclampsia-to-eclampsia progression rates.

Future research should include multi-center studies across climatic zones, individual-level exposure assessment using personal monitors, mechanistic studies measuring biological mediators, longitudinal cohorts distinguishing preeclampsia development from eclampsia progression, climate change impact studies examining long-term trends, intervention trials testing season-targeted strategies, and health economic analyses evaluating cost-effectiveness of seasonal resource allocation.

Conclusion

This prospective study provides robust evidence for marked seasonal eclampsia variation in northwestern Pakistan, with 3.3-fold higher winter incidence associated with lower temperatures ($14.7\pm 2.1^\circ\text{C}$) and higher humidity ($68.8\pm 4.3\%$). Strong meteorological correlations (temperature: $r=-0.782$; humidity: $r=+0.694$; both $p<0.001$) support environmental influences on disease timing. The finding that seasonal variation affects incidence but not severity indicates environmental factors trigger disease in susceptible women rather than modifying pathophysiology. The demographic profile predominantly young primigravid women from rural areas with inadequate antenatal care highlights persistent healthcare access gaps amplified during high-risk seasons. Implementation of season-specific

surveillance, targeted preventive interventions (aspirin, calcium, vitamin D), community education, and climate-responsive planning could substantially reduce eclampsia-related mortality in resource-limited settings. As climate change alters seasonal patterns, understanding environmental determinants becomes increasingly critical. The strong associations documented here provide foundation for weather-based prediction models and early warning systems enabling proactive responses to seasonal eclampsia risk. Future research should elucidate physiological mechanisms, assess generalizability across populations, and evaluate season-targeted intervention effectiveness. Integration of meteorological monitoring into routine maternal health surveillance would enable real-time risk assessment and evidence-based resource allocation, ultimately reducing the substantial burden of eclampsia in vulnerable populations.

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Conflict of Interest

The authors declare no conflicts of interest.

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