Appendices

Appendix 1: Summary of Variables, Definitions, States, Parents, and Rationale for the BNM Selection

No.	Variable Name	Short Definition	Possible Values	Parents	Explanation of Parent Relationships
Environmental & Climate Drivers (Root Nodes)					
1	Temperature Extremes	Annual peak temperatures observed	Low (<40°C), Medium (40-45°C), High (>45°C)	None	Root climatic variable directly impacting infrastructure and comfort levels
2	Precipitation Patterns	Annual rainfall frequency/intensity	Low (Arid), Medium (Seasonal), High (Frequent)	None	Fundamental climatic driver influencing flood risk
3	Water Availability	Amount of renewable freshwater available	Critical (<500 m^3/yr), Scarce (500-1000 m^3/yr), Adequate (>1000 m^3/yr)	None	Essential driver of water security outcomes
4	Groundwater Level	Depth and availability of groundwater resources	Low (Depleted), Medium, High (Shallow)	None	Crucial for water security assessment in GCC due to groundwater dependency
Socio-economic & Governance Drivers (Root Nodes)					
5	Population Density	Number of inhabitants per square kilometer	Low (<5000/km^2), Medium (5000-10000/km^2), High (>10000/km^2)	None	Key driver of resource usage intensity and urban environmental impacts
6	Infrastructure Investment	Level of funding allocated to infrastructure	Low, Medium, High	None	Determines ability to implement and maintain infrastructure effectively
7	Environmental Awareness	Public understanding and support for sustainability initiatives	Low, Medium, High	None	Influences community acceptance and support of resilience measures

8	Governance Capacity	Institutional capability for planning, implementation, and management	Limited, Moderate, Strong	None	Central factor determining the effectiveness of urban planning and policy enforcement
9	Maintenance Regime	Quality and regularity of infrastructure maintenance	Inadequate, Adequate, Optimal	None	Directly affects infrastructure functionality and resilience outcomes
10	Adaptive Management	Capacity of governance to learn and adapt to changing conditions	Poor, Moderate, Strong	None	Enhances infrastructure responsiveness and long-term adaptability
Intermediate Nodes					
11	Urban Heat Island Intensity (UHII)	Degree to which urban areas experience elevated temperatures compared to rural areas	Low, Medium, High	Temperature Extremes, Population Density, Integration level	UHII is influenced by high temperature extremes and population density, which increase urban heating. High Integration Level significantly mitigates UHII impacts.
12	Community Acceptance	Level of public acceptance and participation in resilience projects	Low, Medium, High	Environmental Awareness, Governance Capacity	Awareness and strong governance promote community engagement and acceptance
13	Integration Level	Degree of integration between Nature-Based Solutions (NBS) and Gray Infrastructure (GrI)	None, Partial, Full	Governance Capacity, Infrastructure Investment	Effective governance and adequate funding drive the integration of infrastructure types
14	Nature-Based Solutions (NBS) Performance	Effectiveness of NBS in providing resilience benefits (e.g., cooling, flood mitigation)	Low Effectiveness, Moderate Effectiveness, High Effectiveness	Temperature Extremes, Water Availability, Integration Level, Maintenance Regime	NBS performance influenced by climatic conditions, water availability, integration with gray infrastructure, and maintenance
15	Gray Infrastructure (GrI) Performance	Performance of engineered infrastructure (e.g., drainage, flood barriers)	Poor Performance, Moderate Performance, Good Performance	Infrastructure Investment, Maintenance Regime, Adaptive Management	Quality and flexibility of infrastructure depend on adequate investment, regular maintenance, and adaptive management
Resilience Outcome Nodes					

16	Water Security	Reliability and adequacy of urban water supplies	Low, Medium, High	NBS Performance, GrI Performance, Groundwater Level	Water security outcomes depend on infrastructure performance, and availability of groundwater resources. Improved infrastructure performance and sustainable groundwater levels significantly enhance urban water security.
17	Thermal Comfort	Degree of livability concerning temperature and humidity	Low, Medium, High	UHII, NBS Performance	Comfort influenced by climate extremes and effectiveness of urban cooling strategies
18	Flood Protection	Effectiveness of urban areas in preventing and mitigating floods	Low, Medium, High	Precipitation Patterns, GrI Performance, Maintenance Regime	Flood protection influenced by climate (rainfall), the effectiveness of green/gray infrastructure, and maintenance quality
19	Ecosystem Services	Benefits from natural ecosystems (e.g., cooling, water filtration, biodiversity)	Low, Medium, High	NBS Performance, Integration Level	Quality and extent of NBS and its integration into urban planning directly impact ecosystem services
20	Resource Efficiency	Efficiency in using urban resources (water, energy, materials)	Low, Medium, High	NBS Performance, GrI Performance, Integration Level	Resource efficiency improves through better integrated and adaptive infrastructure management
21	Environmental Impact	Overall environmental footprint (e.g., pollution, ecological degradation) of urban areas	Negative, Moderate, Positive	Population Density, Resource Efficiency, Ecosystem Services	The environmental impact depends on urban density and effectiveness of integrated sustainability measures
22	Economic Viability	Economic sustainability and growth potential of resilience initiatives	Low, Medium, High	Infrastructure Investment, Resource Efficiency	Economic viability determined by investment effectiveness and resource efficiency
23	Social Equity	Fairness and inclusivity of resilience benefits	Low, Medium, High	Community Acceptance,	Strong community acceptance and inclusive infrastructure

		distribution among urban populations		Integration Level	planning ensure equitable benefits
24	Long-term Adaptability	Capacity for sustained resilience in response to future urban challenges	Low, Medium, High	Resource Efficiency, Governance Capacity	Enhanced by adaptive governance, integrated infrastructure, and efficient resource management

Appendix 2: Detailed Conditional Probability Tables (CPTs) used for the BNM

Table 1: Temperature Extremes

State	**Probability**
Low (<40°C)	0.15
Medium (40-45°C)	0.45
High (>45°C)	0.40

Table 2: Precipitation Patterns

State	**Probability**
Low (Arid)	0.70
Medium (Seasonal)	0.25
High (Frequent)	0.05

Table 3: Water Availability

State	**Probability**
Critical (<500 m^3/yr)	0.80
Scarce (500-1000 m^3/yr)	0.15
Adequate (>1000 m^3/yr)	0.05

Table 4: Groundwater Level

State	**Probability**
Low (Depleted)	0.70
Medium	0.25
High (Shallow)	0.05

Table 5: Population Density

State	**Probability**
Low (<5000/km^2)	0.20
Medium (5000-10000/km^2)	0.60
High (>10000/km^2)	0.20

Table 6: Infrastructure Investment

State	Probability
Low	0.20
Medium	0.50
High	0.30

Table 7: Environmental Awareness

State	Probability
Low	0.30
Medium	0.50
High	0.20

Table 8: Governance Capacity

State	Probability
Limited	0.40
Moderate	0.50
Strong	0.10

Table 9: Maintenance Regime

State	Probability
Inadequate	0.30
Adequate	0.50
Optimal	0.20

Table 10: Adaptive Management

State	Probability
Poor	0.50
Moderate	0.40
Strong	0.10

Table 11: Urban Heat Island Intensity (UHII)

Temperature Extremes	Population Density	Integration Level	Low UHII (%)	Medium UHII (%)	High UHII (%)
Low	Low	None	60	25	15
Low	Low	Partial	75	15	10
Low	Low	Full	85	10	5
Low	Medium	None	50	30	20
Low	Medium	Partial	65	25	10
Low	Medium	Full	70	20	10
Low	High	None	40	35	25

Low	High	Partial	55	30	15
Low	High	Full	60	25	15
Medium	Low	None	30	40	30
Medium	Low	Partial	50	35	15
Medium	Low	Full	60	30	10
Medium	Medium	None	20	50	30
Medium	Medium	Partial	40	40	20
Medium	Medium	Full	50	35	15
Medium	High	None	15	35	50
Medium	High	Partial	25	45	30
Medium	High	Full	40	40	20
High	Low	None	10	30	60
High	Low	Partial	20	40	40
High	Low	Full	30	45	25
High	Medium	None	5	25	70
High	Medium	Partial	10	40	50
High	Medium	Full	20	45	35
High	High	None	5	20	75
High	High	Partial	10	30	60
High	High	Full	15	40	45

Table 12: Community Acceptance

Environmental Awareness	Governance Capacity	Low Acceptance (%)	Medium Acceptance (%)	High Acceptance (%)
Low	Limited	80	15	5
Low	Moderate	60	30	10
Low	Strong	40	40	20
Medium	Limited	50	35	15
Medium	Moderate	35	45	20
Medium	Strong	15	40	45
High	Limited	30	45	25
High	Moderate	15	45	40
High	Strong	5	25	70

Table 13: Integration Level

Governance Capacity	Infrastructure Investment	None (%)	Partial (%)	Full (%)
Limited	Low	85	15	0
Limited	Medium	70	25	5
Limited	High	60	30	10
Moderate	Low	60	30	10
Moderate	Medium	45	45	10
Moderate	High	25	50	25
Strong	Low	30	50	20
Strong	Medium	20	50	30
Strong	High	10	20	70

Table 14: NBS Performance

Temperature	Water Availability	Maintenance	Integration	Low Effectiveness (%)	Moderate Effectiveness (%)	High Effectiveness (%)
Low	Critical	Inadequate	None	50.0	30.0	20.0
Low	Critical	Inadequate	Partial	30.0	40.0	30.0
Low	Critical	Inadequate	Full	10.0	40.0	50.0
Low	Critical	Adequate	None	40.0	35.0	25.0
Low	Critical	Adequate	Partial	25.0	40.0	35.0
Low	Critical	Adequate	Full	10.0	30.0	60.0
Low	Critical	Optimal	None	20.0	40.0	40.0
Low	Critical	Optimal	Partial	10.0	30.0	60.0
Low	Critical	Optimal	Full	0.0	15.0	85.0
Low	Scarce	Inadequate	None	35.0	35.0	30.0
Low	Scarce	Inadequate	Partial	25.0	40.0	35.0
Low	Scarce	Inadequate	Full	10.0	35.0	55.0
Low	Scarce	Adequate	None	25.0	40.0	35.0
Low	Scarce	Adequate	Partial	15.0	35.0	50.0
Low	Scarce	Adequate	Full	5.0	30.0	65.0
Low	Scarce	Optimal	None	20.0	35.0	45.0
Low	Scarce	Optimal	Partial	10.0	30.0	60.0
Low	Scarce	Optimal	Full	0.0	10.0	90.0
Low	Adequate	Inadequate	None	25.0	35.0	40.0
Low	Adequate	Inadequate	Partial	15.0	30.0	55.0
Low	Adequate	Inadequate	Full	5.0	25.0	70.0
Low	Adequate	Adequate	None	15.0	30.0	55.0
Low	Adequate	Adequate	Partial	10.0	25.0	65.0
Low	Adequate	Adequate	Full	0.0	15.0	85.0
Low	Adequate	Optimal	None	10.0	25.0	65.0
Low	Adequate	Optimal	Partial	5.0	20.0	75.0
Low	Adequate	Optimal	Full	0.0	5.0	95.0
Medium	Critical	Inadequate	None	65.0	25.0	10.0
Medium	Critical	Inadequate	Partial	40.0	40.0	20.0
Medium	Critical	Inadequate	Full	15.0	35.0	50.0

Medium	Critical	Adequate	None	50.0	30.0	20.0
Medium	Critical	Adequate	Partial	25.0	40.0	35.0
Medium	Critical	Adequate	Full	10.0	35.0	55.0
Medium	Critical	Optimal	None	40.0	30.0	30.0
Medium	Critical	Optimal	Partial	20.0	30.0	50.0
Medium	Critical	Optimal	Full	5.0	20.0	75.0
Medium	Scarce	Inadequate	None	50.0	30.0	20.0
Medium	Scarce	Inadequate	Partial	25.0	50.0	25.0
Medium	Scarce	Inadequate	Full	10.0	40.0	50.0
Medium	Scarce	Adequate	None	30.0	40.0	30.0
Medium	Scarce	Adequate	Partial	15.0	35.0	50.0
Medium	Scarce	Adequate	Full	5.0	25.0	70.0
Medium	Scarce	Optimal	None	20.0	40.0	40.0
Medium	Scarce	Optimal	Partial	10.0	30.0	60.0
Medium	Scarce	Optimal	Full	0.0	10.0	90.0
Medium	Adequate	Inadequate	None	30.0	30.0	40.0
Medium	Adequate	Inadequate	Partial	15.0	35.0	50.0
Medium	Adequate	Inadequate	Full	5.0	25.0	70.0
Medium	Adequate	Adequate	None	20.0	30.0	50.0
Medium	Adequate	Adequate	Partial	10.0	25.0	65.0
Medium	Adequate	Adequate	Full	0.0	15.0	85.0
Medium	Adequate	Optimal	None	10.0	25.0	65.0
Medium	Adequate	Optimal	Partial	5.0	20.0	75.0
Medium	Adequate	Optimal	Full	0.0	5.0	95.0
High	Critical	Inadequate	None	100.0	0.0	0.0
High	Critical	Inadequate	Partial	80.0	15.0	5.0
High	Critical	Inadequate	Full	65.0	25.0	10.0
High	Critical	Adequate	None	75.0	15.0	10.0
High	Critical	Adequate	Partial	50.0	35.0	15.0
High	Critical	Adequate	Full	30.0	45.0	25.0
High	Critical	Optimal	None	60.0	25.0	15.0
High	Critical	Optimal	Partial	40.0	40.0	20.0
High	Critical	Optimal	Full	20.0	50.0	30.0
High	Scarce	Inadequate	None	70.0	20.0	10.0
High	Scarce	Inadequate	Partial	50.0	35.0	15.0
High	Scarce	Inadequate	Full	30.0	45.0	25.0
High	Scarce	Adequate	None	50.0	30.0	20.0
High	Scarce	Adequate	Partial	40.0	50.0	10.0
High	Scarce	Adequate	Full	20.0	50.0	30.0
High	Scarce	Optimal	None	40.0	35.0	25.0
High	Scarce	Optimal	Partial	25.0	50.0	25.0
High	Scarce	Optimal	Full	10.0	40.0	50.0
High	Adequate	Inadequate	None	50.0	30.0	20.0
High	Adequate	Inadequate	Partial	30.0	40.0	30.0
High	Adequate	Inadequate	Full	15.0	35.0	50.0
High	Adequate	Adequate	None	35.0	35.0	30.0
High	Adequate	Adequate	Partial	20.0	45.0	35.0
High	Adequate	Adequate	Full	10.0	40.0	50.0
High	Adequate	Optimal	None	25.0	35.0	40.0
High	Adequate	Optimal	Partial	15.0	35.0	50.0

High	Adequate	Optimal	Full	5.0	25.0	70.0

Table 15: GrI Performance

Infrastructure Investment	Maintenance	Adaptive Management	Poor Performance (%)	Moderate Performance (%)	Good Performance (%)
Low	Inadequate	Poor	80.0	15.0	5.0
Low	Inadequate	Moderate	70.0	25.0	5.0
Low	Inadequate	Strong	60.0	30.0	10.0
Low	Adequate	Poor	65.0	25.0	10.0
Low	Adequate	Moderate	50.0	35.0	15.0
Low	Adequate	Strong	40.0	40.0	20.0
Low	Optimal	Poor	50.0	30.0	20.0
Low	Optimal	Moderate	35.0	40.0	25.0
Low	Optimal	Strong	25.0	45.0	30.0
Medium	Inadequate	Poor	50.0	35.0	15.0
Medium	Inadequate	Moderate	40.0	40.0	20.0
Medium	Inadequate	Strong	30.0	40.0	30.0
Medium	Adequate	Poor	40.0	40.0	20.0
Medium	Adequate	Moderate	25.0	50.0	25.0
Medium	Adequate	Strong	15.0	50.0	35.0
Medium	Optimal	Poor	25.0	45.0	30.0
Medium	Optimal	Moderate	15.0	50.0	35.0
Medium	Optimal	Strong	5.0	35.0	60.0
High	Inadequate	Poor	30.0	40.0	30.0
High	Inadequate	Moderate	20.0	45.0	35.0
High	Inadequate	Strong	15.0	35.0	50.0
High	Adequate	Poor	20.0	40.0	40.0
High	Adequate	Moderate	10.0	35.0	55.0
High	Adequate	Strong	5.0	25.0	70.0
High	Optimal	Poor	10.0	35.0	55.0
High	Optimal	Moderate	5.0	25.0	70.0
High	Optimal	Strong	0.0	10.0	90.0

Table 16: Water Security

NBS Performance	GrI Performance	Groundwater Level	Low Security (%)	Medium Security (%)	High Security (%)
Poor	Poor	Low	95	5	0
Poor	Poor	Medium	90	10	0
Poor	Poor	High	85	15	0
Poor	Moderate	Low	80	15	5
Poor	Moderate	Medium	70	25	5
Poor	Moderate	High	60	30	10
Poor	Good	Low	60	30	10

Poor	Good	Medium	50	35	15
Poor	Good	High	40	40	20
Moderate	Poor	Low	70	25	5
Moderate	Poor	Medium	60	30	10
Moderate	Poor	High	50	35	15
Moderate	Moderate	Low	40	50	10
Moderate	Moderate	Medium	30	60	10
Moderate	Moderate	High	20	60	20
Moderate	Good	Low	25	50	25
Moderate	Good	Medium	15	50	35
Moderate	Good	High	10	40	50
Good	Poor	Low	50	40	10
Good	Poor	Medium	40	40	20
Good	Poor	High	30	40	30
Good	Moderate	Low	30	45	25
Good	Moderate	Medium	20	50	30
Good	Moderate	High	10	50	40
Good	Good	Low	10	40	50
Good	Good	Medium	5	25	70
Good	Good	High	0	20	80

Table 17: Thermal Comfort

UHII	NBS Perf.	Low Comfort (%)	Moderate Comfort (%)	High Comfort (%)
Low	Poor	40	40	20
Low	Moderate	20	50	30
Low	Good	5	25	70
Medium	Poor	60	30	10
Medium	Moderate	40	45	15
Medium	Good	20	50	30
High	Poor	90	10	0
High	Moderate	70	25	5
High	Good	50	35	15

Table 18: Flood Protection

Precipitation Patterns	GrI Performance	Maintenance Regime	Low Protection (%)	Medium Protection (%)	High Protection (%)
Low	Poor	Inadequate	50	30	20
Low	Poor	Adequate	40	40	20
Low	Poor	Optimal	30	40	30
Low	Moderate	Inadequate	30	40	30
Low	Moderate	Adequate	15	45	40
Low	Moderate	Optimal	10	35	55
Low	Good	Inadequate	20	40	40

Low	Good	Adequate	10	30	60
Low	Good	Optimal	5	25	70
Medium	Poor	Inadequate	70	20	10
Medium	Poor	Adequate	60	25	15
Medium	Poor	Optimal	50	30	20
Medium	Moderate	Inadequate	55	30	15
Medium	Moderate	Adequate	40	40	20
Medium	Moderate	Optimal	20	45	35
Medium	Good	Inadequate	35	40	25
Medium	Good	Adequate	15	45	40
Medium	Good	Optimal	10	40	50
High	Poor	Inadequate	95	5	0
High	Poor	Adequate	85	10	5
High	Poor	Optimal	75	15	10
High	Moderate	Inadequate	75	20	5
High	Moderate	Adequate	60	30	10
High	Moderate	Optimal	40	40	20
High	Good	Inadequate	55	35	10
High	Good	Adequate	30	45	25
High	Good	Optimal	20	50	30

Table 19: Ecosystem Services

NBS Perf.	Integration	Low Services (%)	Medium Services (%)	High Services (%)
Poor	None	85	10	5
Poor	Partial	60	30	10
Poor	Full	40	40	20
Moderate	None	50	35	15
Moderate	Partial	25	50	25
Moderate	Full	10	50	40
Good	None	30	40	30
Good	Partial	15	35	50
Good	Full	5	20	75

Table 20: Resource Efficiency

NBS Performance	GrI Performance	Integration Level	Low Efficiency (%)	Medium Efficiency (%)	High Efficiency (%)
Poor	Poor	None	90	10	0
Poor	Poor	Partial	75	20	5
Poor	Poor	Full	60	30	10
Poor	Moderate	None	70	25	5
Poor	Moderate	Partial	60	30	10
Poor	Moderate	Full	40	40	20
Poor	Good	None	65	25	10
Poor	Good	Partial	50	30	20

Poor	Good	Full	40	40	20
Moderate	Poor	None	70	20	10
Moderate	Poor	Partial	55	35	10
Moderate	Poor	Full	40	40	20
Moderate	Moderate	None	50	40	10
Moderate	Moderate	Partial	30	50	20
Moderate	Moderate	Full	15	45	40
Moderate	Good	None	35	45	20
Moderate	Good	Partial	20	50	30
Moderate	Good	Full	10	40	50
Good	Poor	None	50	35	15
Good	Poor	Partial	35	40	25
Good	Poor	Full	20	45	35
Good	Moderate	None	30	45	25
Good	Moderate	Partial	20	45	35
Good	Moderate	Full	10	40	50
Good	Good	None	15	40	45
Good	Good	Partial	10	30	60
Good	Good	Full	5	15	80

Table 21: Environmental Impact

Population Density	Resource Efficiency	Ecosystem Services	Negative Impact (%)	Moderate Impact (%)	Positive Impact (%)
Low	Low	Low	60	30	10
Low	Low	Medium	50	35	15
Low	Low	High	40	40	20
Low	Medium	Low	45	40	15
Low	Medium	Medium	30	45	25
Low	Medium	High	20	40	40
Low	High	Low	30	45	25
Low	High	Medium	20	40	40
Low	High	High	10	25	65
Medium	Low	Low	75	20	5
Medium	Low	Medium	65	25	10
Medium	Low	High	50	35	15
Medium	Medium	Low	60	30	10
Medium	Medium	Medium	50	35	15
Medium	Medium	High	35	40	25
Medium	High	Low	40	40	20
Medium	High	Medium	25	45	30
Medium	High	High	15	40	45
High	Low	Low	95	5	0
High	Low	Medium	85	10	5
High	Low	High	70	20	10
High	Medium	Low	80	15	5
High	Medium	Medium	70	20	10
High	Medium	High	55	30	15

High	High	Low	65	25	10
High	High	Medium	50	35	15
High	High	High	40	40	20

Table 22: Economic Viability

Infrastructure Investment	Resource Efficiency	Low Viability (%)	Medium Viability (%)	High Viability (%)
Low	Low	85	10	5
Low	Medium	70	20	10
Low	High	55	30	15
Medium	Low	60	25	15
Medium	Medium	40	40	20
Medium	High	25	45	30
High	Low	35	35	30
High	Medium	15	35	50
High	High	5	20	75

Table 23: Social Equity

Community Acceptance	Integration Level	Low Equity (%)	Medium Equity (%)	High Equity (%)
Low	None	90.0	10.0	0.0
Low	Partial	70.0	25.0	5.0
Low	Full	50.0	30.0	20.0
Medium	None	70.0	20.0	10.0
Medium	Partial	55.0	30.0	15.0
Medium	Full	30.0	40.0	30.0
High	None	40.0	35.0	25.0
High	Partial	20.0	40.0	40.0
High	Full	5.0	25.0	70.0

Table 24: Long-term Adaptability

Resource Efficiency	Integration Level	Low Adaptability (%)	Medium Adaptability (%)	High Adaptability (%)
Low	None	85.0	10.0	5.0
Low	Partial	70.0	20.0	10.0
Low	Full	50.0	30.0	20.0
Medium	None	60.0	25.0	15.0
Medium	Partial	30.0	50.0	20.0
Medium	Full	15.0	45.0	40.0
High	None	30.0	40.0	30.0
High	Partial	15.0	35.0	50.0
High	Full	5.0	20.0	75.0