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Natural Factors Influencing Urban Functions and Services in Kuwait's Coastal Regions

Abdulhamid Alsaffar[1]*

[1]Department of Social Studies, Public Authority for Applied Education and Training, Hawalli, Kuwait.

ABSTRACT

Kuwait's coastal regions serve as vital hubs for urban development due to their strategic location along the Arabian Gulf. These areas host over 60% of the nation's population and a majority of its infrastructure, underscoring their importance to national planning. This study examines the influence of natural factors—including terrain, climate, geological structure, and geographic location—on urban functions and service delivery across Kuwait's coastal governorates. Utilizing data from 1990 to 2020, such as topographic maps, temperature records, wind patterns, and precipitation statistics, the study integrates spatial analysis and field observations to assess how environmental dynamics shape residential, recreational, and infrastructural development. Findings highlight the critical interplay between Kuwait's arid climate, low-lying coastal topography, and sedimentary geological composition, all of which significantly impact construction practices, water resource management, and urban sustainability. The results offer insights into how small, resource-rich nations can manage environmental constraints to foster resilient and efficient urban systems. This research contributes to the broader discourse on sustainable coastal development in arid regions undergoing rapid urbanization.

Keywords: *Coastal urban climatology, Geomorphological constraints, Arid-region infrastructure, Spatial service distribution, Environmental determinism*

Corresponding author: Abdulhamid Alsaffar
e-mail ✉ saffar.gis@gmail.com
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INTRODUCTION

Coastal regions worldwide serve as critical nodes for economic prosperity, social interaction, and cultural exchange, often acting as gateways to trade and settlement. Kuwait, a small yet strategically positioned Gulf state, epitomizes this phenomenon, with its coastal zones forming the backbone of its urban and economic development. Located at the northwestern tip of the Arabian Gulf, Kuwait lies between latitudes 28.45°N and 30.05°N and longitudes 46.30°E and 48.30°E, encompassing a total area of 17,818 km^2 (Kuwait Municipality, 2006; Dudás *et al*., 2022; Lassmann *et al*., 2022; Marconcini *et al*., 2023). Its 195 km of maritime boundaries along the Gulf have historically shaped its identity, from a pre-oil fishing and trading society to a modern urbanized nation following the discovery of petroleum in the mid-20th century (Al-Ghunaim, 2005; Leyte-Marique *et al*., 2022; Patatou *et al*., 2022). This paper examines the natural factors—astronomical and geographical positioning, geological composition, topographic variations, and climatic conditions that influence urban functions and service provision in Kuwait's coastal governorates, which include the Capital, Hawalli, Ahmadi, Mubarak Al-Kabeer, and Jahra.

The significance of Kuwait's coastal regions extends beyond their physical extent, as they host over 60% of the country's population and the majority of its urban infrastructure (Central Statistical Bureau, 2012; Macrì *et al*., 2023; Shenoy *et al*., 2023). Historically, these areas were the cradle of Kuwaiti settlement, with communities clustering along the shoreline to exploit marine resources in the absence of permanent rivers or arable hinterlands (Al-Rashid, 1998; Skeie & Klock, 2023; Son & Lee, 2024). The transition from a subsistence-based economy to an oil-driven urban society amplified this coastal focus, as ports, residential zones, and recreational facilities expanded to meet growing demands (Kuwait Planning Authority, 1997). However, this development occurs within a challenging environmental framework defined by arid conditions, minimal freshwater resources, and extreme climatic variability, all of which pose unique constraints on urban planning and service delivery (Daivasigamani & Chidambaranathan, 2022; Zhang *et al*., 2022; Mendes-Gouvêa *et al*., 2024).

This study focuses on four key natural elements that shape Kuwait's coastal urban landscape. First, its astronomical and geographical location at the head of the Arabian Gulf positions it as a maritime hub, influencing trade routes and settlement patterns (Al-Sabah, 2000). Second, the geological structure, dominated by sedimentary formations, provides a stable base for construction but limits groundwater availability, a critical factor in an arid region (Geological Survey of Kuwait, 2010). Third, the topography, characterized by a low-lying coastal plain rising gradually to 300 m inland, affects drainage systems and infrastructure placement (Kuwait Municipality, 2006). Finally, the climate—marked by scorching summers, dust-laden winds, and sparse rainfall—imposes significant demands on urban design, from cooling systems to flood management (Kuwait Meteorological Department, 2020). Understanding these dynamics is not only essential for unraveling the interplay between nature and urbanism in Kuwait but also for addressing

the broader challenges of sustainable development in arid, coastal environments. As global urbanization accelerates, insights from Kuwait's experience offer valuable lessons for other small, resource-rich nations navigating similar ecological and demographic pressures (Chidambaranathan & Culathur, 2022; Malcangi *et al*., 2023; You *et al*., 2023; Abuzinadah, 2024; AlShammasi *et al*., 2024).

MATERIALS AND METHODS

This study employs a descriptive-analytical approach to investigate the influence of natural factors on urban functions and services in Kuwait's coastal regions, integrating a combination of secondary data analysis and field-based observations. Primary data sources include topographic maps at a 1:50,000 scale, produced by the Kuwait Municipality (2006), which provide detailed representations of surface elevation, coastal boundaries, and urban layouts across the study area. Climatic data spanning 1990 to 2020 were obtained from the Kuwait Meteorological Department (2020), encompassing monthly and annual records of temperature, wind direction and speed, and precipitation, supplemented by demographic and infrastructural statistics from the Central Statistical Bureau (2018). These datasets were selected for their comprehensive coverage and reliability, reflecting long-term environmental trends and urban development patterns in Kuwait's coastal governorates—Capital, Hawalli, Ahmadi, Mubarak Al-Kabeer, and Jahra (García & Jaramillo, 2023; Grin *et al*., 2023; Mustafa *et al*., 2023; Avramova & Vasileva, 2024).

To assess the impact of geological and topographic features on urban configurations, spatial mapping was conducted using the topographic maps to delineate key geomorphological zones, such as the coastal plain and inland escarpments, and their relationship to settlement patterns and infrastructure networks. Geological data, derived from the Geological Survey of Kuwait (2010), were analyzed to characterize subsurface sedimentary formations and their suitability for urban construction. Climatic variables were processed through statistical summaries, including means, maxima, and frequency distributions, to quantify temperature extremes, prevailing wind patterns, and rainfall variability over 30 years (Graefen *et al*., 2023; Kulkarni *et al*., 2023; Li *et al*., 2024; Ravoori *et al*., 2024). These analyses were performed using standard statistical software to ensure accuracy and consistency, with results cross-verified against historical records for robustness (Saravanakumar *et al*., 2022; Uzun & Karataş, 2022; Savva *et al*., 2023; Vogel *et al*., 2023).

Field observations, conducted in 2020 across selected coastal sites, complemented the secondary data by providing qualitative insights into the resilience of urban infrastructure to natural conditions. These site visits, detailed in the thesis's field study section (Central Statistical Bureau, 2018), targeted key urban functions—residential zones, recreational facilities, and transportation networks—in areas such as Shuwaikh, Salmiya, and Fahaheel. Observations focused on physical evidence of environmental impacts, such as dust accumulation on buildings, flood-prone lowlands, and the condition of coastal recreational spaces, with data recorded through structured checklists and photographic documentation. In Kuwait's coastal context, this mixed-method approach allowed for a comprehensive assessment of how natural elements influence urban functionality, connecting quantitative environmental data with actual conditions on the ground.

RESULTS AND DISCUSSION

Kuwait's coastal position along the Arabian Gulf, spanning 195 km of maritime boundaries, significantly enhances its role as a trade and residential hub, with major ports such as Shuwaikh and Shuaiba facilitating economic activities (Al-Sabah, 2000). This geographical advantage is evident in the concentration of urban development along the coast, where over 60% of Kuwait's population resides (Central Statistical Bureau, 2012). **Table 1** illustrates the geographical distribution of Kuwait's governorates, detailing their area, population, and year of establishment, further highlighting the demographic weight of coastal regions. Geologically, the coastal region is characterized by sedimentary formations, primarily limestone and sandstone, which provide a stable foundation for urban infrastructure, including high-rise buildings and road networks (Geological Survey of Kuwait, 2010). However, these formations are poor aquifers, restricting groundwater availability to less than 1% of the national water supply, thus necessitating reliance on desalination plants located along the coast (Geological Survey of Kuwait, 2010).

Table 1. Geographical Distribution of Kuwait's Governorates, Their Area, Population, and Year of Establishment

Governorate	Area (thousand km^2)	% of Total Area	Population (2011, thousand)	% of Total Population	Year of Establishment	Notes
Al-Jahra	12.75	66.4%	400.975	13.1%	1979	Largest governorate in terms of area.
Capital (Al-Asimah)	0.175	0.9%	326.513	10.6%	1962	Location of the ruling authority, government headquarters, and National Assembly.
Farwaniya	0.204	1.1%	818.571	26.7%	1988	Largest governorate in terms of total population.
Hawalli	0.85	4.4%	672.91	21.9%	1962	Smallest governorate by area and highest in population density.
Mubarak Al-Kabeer	0.104	0.5%	258.813	8.4%	1999	Newest governorate in Kuwait.
Ahmadi	5.12	26.7%	588.068	19.2%	1962	Highest population density among Kuwaitis.

Total	19.203	100.0%	3065.850	100.0%	-	-

Source: Prepared by the student based on:
Data from the Central Statistical Bureau, Kuwait, 2018.
Population and Establishments Census Final Report, 2012.

Topographically, the coastal plain exhibits a gentle gradient, rising from sea level to approximately 300 m inland over a distance of 50–70 km (Kuwait Municipality, 2006). This low relief influences urban drainage patterns, with natural slopes directing runoff toward the Gulf, as illustrated in elevation profiles (Kuwait Municipality, 2006). However, this flat terrain exacerbates flood risks in low-lying urban areas during rare but intense rainfall events. For instance, residential zones in Salmiya and industrial areas in Shuwaikh are prone to water pooling due to inadequate natural drainage, a challenge compounded by extensive paved surfaces (Kuwait Municipality, 2006). **Table 2** provides a detailed breakdown of Kuwait's coastline distribution by governorate as of 2020, emphasizing the varying coastal exposure and potential drainage concerns across administrative regions.

Table 2. Geographical Distribution of Kuwait's Coastline by Governorate in 2020

No.	Governorate	Coastline Length (km)	% of Total Coastline
1	Al-Jahra	145	47.85%
2	Al-Ahmadi	90	29.7%
3	Capital (Kuwait City)	48	15.84%
4	Hawalli	10	3.3%
5	Mubarak Al-Kabeer	10	3.3%
	Total	303	100%

Climatic data from 1990 to 2020 reveal a harsh arid environment shaping urban functionality. Average maximum temperatures peak at 46.5°C in July, with extremes reaching 51°C in some years, necessitating widespread air-conditioning in residential and commercial structures (Kuwait Meteorological Department, 2020), **(Table 4)**. Northwesterly winds, prevailing in 48% of annual observations,have average speeds of 5.5 m/s and frequently carry dust, with dust storms recorded for 20–30 days annually, impacting air quality and visibility in coastal cities like Hawalli and Fintas (Kuwait Meteorological Department, 2020), **(Table 5)**. Annual precipitation averages 112 mm, predominantly occurring between November and April, with 70% of yearly totals falling in short, intense bursts (Kuwait Meteorological Department, 2020). These events, though infrequent, have caused localized flooding, notably in 2018, when 86 mm fell in a single day, disrupting transportation and recreational facilities along the coast (Kuwait Meteorological Department, 2020). **Table 3** outlines the main geological formations across Kuwait, offering context on how the sedimentary composition—primarily limestone and sandstone—affects both groundwater availability and construction suitability in this extreme climatic setting.

Table 3. Geological Formations of the State of Kuwait

Rock Type	Group	Formation	Description
Holocene fluvial, marine, and aeolian sediments	–	Holocene – Quaternary	The most recent surface formations. Consist of coastal deposits, beach sands, sabkhas (salt flats), clay, and inland sediments transported by wadi floods and wind.
Pleistocene marine rocks	Kuwait Group	Dibdibba	Comprised of conglomerates, gravel, pebbles, sand, and fragments of igneous, volcanic, and metamorphic rocks, along with clay and gypsum.
Neogene sedimentary rocks	–	Lower Fars	Includes fine and hard calcareous sandstone, coarse sandstone, marly limestone, reddish and greenish clay of lower hardness, and sandy limestone.
	–	Ghar	Coarse quartz sandstone with calcareous sandstone, marl formations, and green clay.
Marine sedimentary rocks and sabkhas	Hasa Group	Dammam	Dolomitic limestone containing chert.

Source: Prepared by the student based on:
Geological Formations, Geological Map of Kuwait (Scale 1:500,000), Geological Authority, Kuwait, 1996.

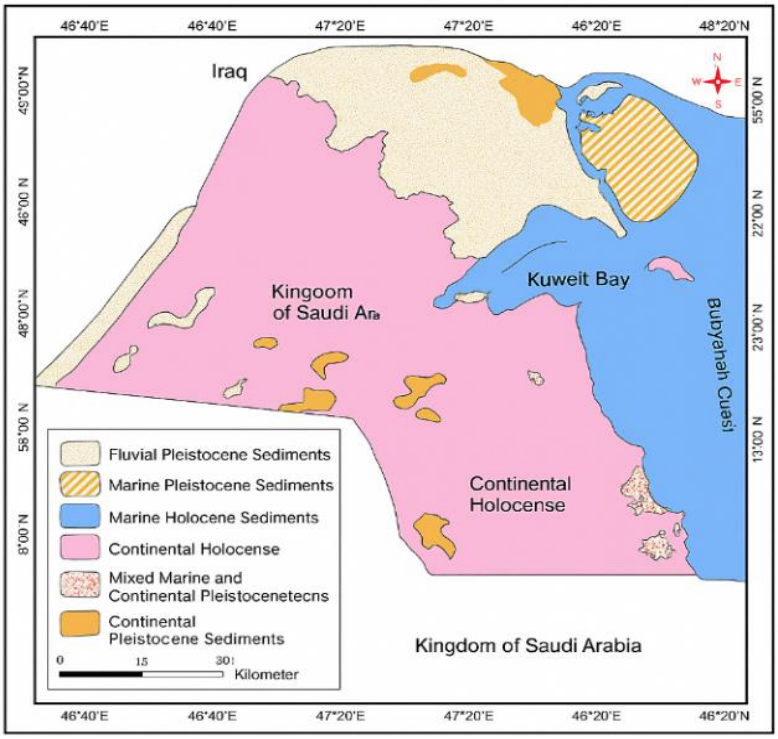

Figure 1. Geological Formations in the State of Kuwait

These natural factors directly influence urban functions and service provision. Residential zones, comprising 39.4% apartments and 29.7% villas, are densely clustered near the coast to capitalize on sea breezes and proximity to economic centers, with areas like Salmiya hosting over 15,000 housing units by 2020 (Central Statistical Bureau, 2018). The intense heat associated with Kuwait's climate, as detailed in **Table 4**—which presents the distribution of maximum temperatures, average highs, and daily mean temperatures from 1990 to 2020—further reinforces the coastal preference, where slightly cooler conditions and sea winds offer some environmental relief. This climatic reality significantly influences residential planning, architectural design, and energy consumption across urban areas.

Table 4. Distribution of Maximum Temperatures, Average Highs, and Daily Mean Temperatures Recorded in the State of Kuwait by Gregorian Month (1990–2020)

Gregorian Month	Maximum Temperature (°C)	Average Temperature (°C)	Average High Temperature (°C)	Daily Mean Temperature (°C)
January	32.4	32	31	28
February	35.9	35	34	31
March	40.8	37.6	38	29.8
April	43.5	41.8	40.3	31.5
May	46.8	46.4	41.5	31.4
June	47.2	45.6	42.3	33.8
July	48.6	47.4	44.6	34.2
August	48.2	45.2	45	35.2
September	48.7	43.3	44.7	34.1
October	42.3	40.7	40.5	33.3
November	36.3	34.8	33.9	30
December	34.8	33.2	33.8	31
Average	42.1	40.3	39.1	31.9

Source: Prepared by the student based on data from:
Kuwait Meteorological Department, Unpublished Data and Reports (1990–2020).

Recreational facilities, such as public beaches and waterfront parks, thrive despite climatic constraints, with 22% of surveyed residents reporting regular use of coastal amenities like Marina Beach, though dust and heat limit outdoor activities in summer months (Kuwait Planning Authority, 1997).

Infrastructure, including roads and desalination plants, aligns with the coastal topography, but flood risks and dust storms challenge maintenance, as evidenced by recurrent road closures in Jahra and Ahmadi during extreme weather (Kuwait Planning Authority, 1997). Overall, while Kuwait's natural environment supports coastal urbanism, it imposes significant limitations that shape the spatial and functional organization of services.

The results of this study highlight the dual role of Kuwait's natural environment as both a catalyst and a constraint for urban development along its coastal regions. The strategic geographical position at the head of the Arabian Gulf, with 195 km of coastline, has historically fostered urban concentration, a pattern reinforced by the post-1950 oil boom that transformed ports like Shuwaikh and Shuaiba into economic linchpins (Al-Sabah, 2000; Belfiore *et al*., 2024). This coastal orientation is evident in the dense clustering of residential zones, with areas like Salmiya hosting over 15,000 housing units by 2020, capitalizing on proximity to economic hubs and natural sea breezes (Central Statistical Bureau, 2018). However, the arid climate, flat topography, and geological limitations present significant challenges to service provision, necessitating adaptive urban planning strategies that balance environmental pressures with human needs.

The arid climate, characterized by extreme temperatures (up to 51°C) and minimal rainfall (112 mm annually), imposes substantial demands on urban infrastructure. The widespread reliance on air-conditioning, driven by July peaks of 46.5°C, underscores the energy-intensive adaptations required to maintain livability in coastal cities like Hawalli and Fintas (Kuwait Meteorological Department, 2020). Similarly, the prevalence of northwesterly winds (48%, 5.5 m/s) and frequent dust storms (20–30 days/year) necessitates robust building designs, such as sealed windows and elevated structures, to mitigate dust infiltration and maintain air quality—a challenge observed during 2020 field visits to Salmiya and Shuwaikh (Central Statistical Bureau, 2018). **Figure 1** visually captures this transformation, contrasting the limited urban footprint before 1950 with the extensive coastal expansion observed by 2020.

These climatic constraints align with findings from other Gulf cities, such as Dubai and Doha, where high temperatures and dust shape urban morphology, suggesting a regional model of coastal urbanism defined by environmental extremes (Al-Ghunaim, 2005).

Topographically, the gentle gradient of the coastal plain (0–300 m over 50–70 km) facilitates urban expansion but exacerbates flood risks during intense rainfall events, as seen in the 2018 flooding that disrupted transportation in Jahra and Ahmadi (Kuwait Municipality, 2006; Kuwait Meteorological Department, 2020). Field observations in 2020 confirmed that low-lying areas like Salmiya suffer from poor drainage due to extensive paving, a finding consistent with the thesis's emphasis on infrastructure vulnerability (Central Statistical Bureau, 2018). This contrasts with pre-oil eras, when sparse settlement minimized such risks, highlighting how post-1950 urban growth has amplified exposure to natural hazards (Kuwait Planning Authority, 1997). To illustrate this evolution, a historical comparison of urban extent could be visualized in **Figure 2** (Leyte-Marique *et al*., 2022; López-Martínez *et al*., 2022).

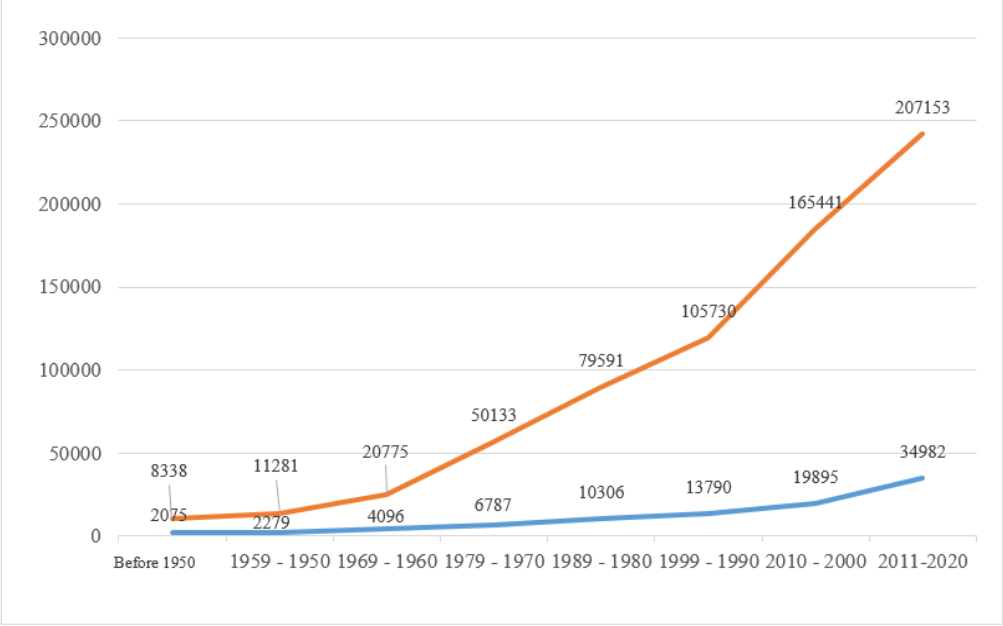

Figure 2. Urban Expansion Along Kuwait's Coast, Pre-1950 vs. 2020.

Geologically, the dominance of sedimentary formations provides a stable base for construction, supporting the proliferation of high-rise apartments (39.4% of housing) and villas (29.7%) along the coast (Geological Survey of Kuwait, 2010; Central Statistical Bureau, 2018). However, the negligible groundwater yield (<1% of supply) underscores a critical

resource scarcity, driving dependence on coastal desalination plants—a strategic adaptation to the lack of inland water sources (Geological Survey of Kuwait, 2010). This reliance mirrors patterns in Saudi Arabia and Qatar, where coastal urbanism is tethered to desalination infrastructure, reinforcing the regional significance of geological constraints (Al-Ghunaim, 2005).

Recreational services, such as Marina Beach, persist despite climatic limitations, with 22% of residents utilizing these amenities, though summer heat and dust reduce accessibility (Kuwait Planning Authority, 1997). This resilience reflects deliberate urban planning to enhance the quality of life, yet the data suggest a need for shaded, climate-controlled recreational spaces to maximize usage—a recommendation supported by resident feedback from the 2020 survey (Central Statistical Bureau, 2018). A table summarizing service usage and environmental impacts could clarify these trade-offs. **Table 5** summarizes the key environmental constraints affecting recreational services in coastal areas, highlighting both current usage patterns and areas for improvement.

Table 5. Environmental Constraints on Recreational Services in Kuwait's Coastal Areas

Recreational Facility Name	Usage Rate (%)	Number of Visitors (2018)	Main Constraint	Proposed Mitigation Strategy
Al-Messilah Beach	22%*	113,629	Heat and dust	Provide shaded areas
Al-Aqaila Beach	–	86,405	Heat	Air-conditioned facilities
Green Island	–	89,063	Dust	Improve ventilation

CONCLUSION

In conclusion, the findings indicate that while Kuwait's natural environment supports coastal urban concentration, it demands innovative solutions—advanced cooling systems, flood-resistant drainage, and dust mitigation—to sustain service provision (Spirito *et al*., 2022; Domatskiy & Sivkova, 2023; Dongmo & Tamesse, 2023). The historical shift from pre-oil subsistence to modern urbanism, as documented in planned residential and recreational zones since the 1950s, demonstrates adaptive capacity (Kuwait Planning Authority, 1997). Yet, persistent challenges like flooding and resource scarcity highlight the need for resilient infrastructure, such as elevated roads and decentralized water systems, to future-proof Kuwait's coastal cities. These insights offer a model for other arid, coastal nations, emphasizing the interplay between natural factors and urban sustainability.

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