Journal of Sustainable Development; Vol. 11, No. 4; 2018
ISSN 1913-9063 E-ISSN 1913-9071
Published by Canadian Center of Science and Education

[Re]covering Jeddah's Wadis – Building the City's Resilience through Green Infrastructure

Hanaa Motasim[1]

[1] Department of Architecture, Hekma School of Design and Architecture, Dar Al-Hekma University, Jeddah, Saudi Arabia

Correspondence: Hanaa Motasim, Department of Architecture, Dar Al-Hekma University, Jeddah 22246, Saudi Arabia. Tel: 966-58-333-8226. E-mail: hmotasim@dah.edu.sa

Received: May 28, 2018 Accepted: June 16, 2018 Online Published: July 29, 2018

doi:10.5539/jsd.v11n4p228 URL: https://doi.org/10.5539/jsd.v11n4p228

Abstract

Jeddah, Saudi Arabia's largest coastal city, is positioned between two prominent natural features: the mountain range on its eastern side and the Red Sea on its west. The city faces many challenges central to which is storm water drainage. The natural drainage of the city through its pre-existing wadis, bringing down the rain water from the steep mountain ranges through the low inclining coastal plane and into the sea, has been interrupted in the last few decades by massive road infrastructural projects cutting through the city and interrupting the natural flow. The outcome of these interventions has been excessive flooding calamities, of which the ones in 2009 and 2011 were the most extreme, causing severe damage to infrastructure, property and lives.

In light of climate change the intensity of flash floods is expected to increase, placing enormous stress on the city. To control the floods the city has pushed forward heavily engineered solutions, canalizing the rich network of wadis, almost 80 in number, into 4 major concrete channels that discharge the rain water accumulated in the mountains directly into the sea. This solution, which has been prohibitive in cost, has robbed the city of any potential of utilizing the precious supply of rain water. This paper explores the potential of recovering Jeddah's wadis and creating green corridors across the city. As opposed to engineered solutions which address singular problematics, green infrastructures could provide numerous benefits to the city and the region as a whole.

Keywords: climate change, floods, green infrastructure, Jeddah, landscape urbanism, resilience, urban design

1. Introduction

1.1 Problem Statement

Jeddah, a city of approximately 4 million inhabitants, is expected to grow in the next two decades to 7.2 million surpassing Casablanca as the 8th largest city in the Arab world. With this rapid growth Jeddah would need to come to terms with its growing urban challenges and should seek to address and correct much of the problems it currently faces if it is to support itself and its populace though the coming decades. The city's greatest challenge in the past decade has revolved around storm water drainage, the consecutive floods witnessed in 2009, 2010 and 2011 provided the city with the wake-up call it needed. A great number of projects have been commissioned since to rectify the problem and to provide the city with the drainage it requires. The solutions have unfortunately been purely within the domain of engineering, and even though they have reduced the threat of flooding, have not been able to address the multi-dimensional environmental problems of the city. Jeddah suffers from underground water pollution caused by a critical absence of sewage networks and air pollution caused by sprawl and the complete reliance on the car. Jeddah is also completely dependent on an environmentally threatening and financially costing process of water production, desalination. There is also a general lack of green areas, and the agricultural lands that once surrounded its major wadis are diminishing due to the increase in water salinity and due to climate change resulting in longer periods of drought.

1.2 Hypothesis

Jeddah's current environmental problems which are expected to increase in light to climate change can be largely addressed by naturalizing Jeddah's wadis, which have been in the past decades transformed into concrete channels. [Re]covering Jeddah's wadis and naturalizing them would enable the development of major east-west green corridors that could restructure the city's development while reducing its vulnerability to climate change.

1.3 Objective of the Research

The objective of this paper is to highlight the role that green infrastructure can play in mitigating the risks of flooding while bringing at the same time multiple benefits to the city in the form of biodiversity conservation, heat-island mitigation, underground water replenishment, remediation of contaminated soils and urban agriculture.

In comparison to cities in the east and center of the country such as Dammam and Riyadh, Jeddah has the opportunity of receiving a good percentage of renewable water though its wadis. This renewable water supply comes in the form of storm water that runs down the Hijaz Mountains through the wadis and towards the coastal plain where the city lies. This paper stresses the need for the city to capitalize on these renewable water sources to support green infrastructure within the city. The paper also attempts to revert the current perception of the wadis from being causes of destruction during intense rains towards being perceived as a source of life, providing the city with the vegetation and water which it critically needs.

2. Method

This article is the outcome of a studio-based investigation which focused on exploring the potential of recovering Jeddah's wadis and creating green corridors across the city. As opposed to engineered solutions which address singular problematics, green infrastructures could provide numerous benefits to the city and the region as a whole. The objective of the studio was to study the major wadis that have been transformed into four concrete channels (Southern Drainage Channel, Northern Drainage Channel, the Airport Channel and Obhur Channel). The wadis/channels were studied in a longitudinal section beginning at the hills and going down up till the sea, and also in cross-section to understand them within context of the fabric that surrounds them. After studying the areas and concluding the major challenges and opportunities of each channel, green strategies were proposed that improved the social, cultural, environmental and economic conditions around the different wadis.

The type of green infrastructure introduced varied depending on the needs of the immediate and broad site conditions. Urban analysis therefore played a central role in determining the exact on-site conditions that enabled the development of targeted strategies and urban design proposals. Urban design has the ability to promote site specific solutions in comparison to urban planning which produces broad solutions that do not clearly differentiate between the different parts of the city and their respective conditions. The city of Jeddah even though having had 5 masterplans in the past 6 decades has invested far less on urban design competitions, particularly ones that engage the city's landscape at a broader scale.

The scale of the urban design projects developed in the studio were in line with many of the landscape urbanism projects taking place across the globe in the past two decades seen clearly in the works of James Cameron, Adriaan Geuze, Bas Smets etc. This scale of urban design has yet to be introduced and developed within the context of Jeddah. National policies and urban planning schemes have already addressed the challenges of environmental sustainability and climate change in Jeddah. These policies and plans however remain rather abstract and distant, and as such face significant difficulties at the implementation phase. Urban design has the power of illustrating the exact physical manifestation of these concepts and enables the citizens to understand the actual impact of such interventions on their cityscape.

2.1 Structure

This paper is structured into three main parts. The first part highlights the value of the wadis and the renewable water they channel into the city of Jeddah. It also discusses the role of the wadis in the development and evolution of the city. The prominent historic role of the wadis will be contrasted with the current conditions of the wadis, shedding light on the complete alteration of the natural landscape that has been caused by rapid unmanaged urbanization. The once rich network of natural wadis which offered multiple benefits to the historic city have been transformed into 4 major concrete channels (at times submerged below the city grade) that only function as drainage channels for the rainwater from the surrounding hills and mountains. In the second part, we shall describe the environmental challenges that Jeddah faces and the impeding challenges that climate change would most likely cause if the issues are left unaddressed. In the third and final part, we shall discuss the role green infrastructure can play in addressing the most pertinent environmental challenges the city faces and will continue to face in the coming decades, particularly in light of climate change. The section then looks at urban design as a strategy that enables the production of site-specific design proposals based on thorough urban analysis of the broad and immediate sites.

3. The Role and Value of Wadis

3.1 The Value of Wadis in the General Saudi Landscape

The Gulf (GCC) is one of the most water-scarce regions in the world. According to the UN Habitat, five of the GCC countries are amongst the ten countries in the world with the lowest per capita renewable water supply (UN Habitat: 2012a). Water scarcity is coupled with high levels of urbanization and water consumption. Since the 60s the population of the GCC had grown sevenfold and with that the amount of water consumption per capita has risen almost tenfold, rising from around 40 liters a day to over 400 liters a day (UN Habitat: 2012a). To meet the water demand of the GCC countries, having overexploited their existing natural resources, heavy investment on costly desalination facilities became prevalent.

Saudi Arabia is one of the largest and most arid countries in the Middle East. Covering an expanse of 2,253,000 km^2, the country is mostly desert with the exception of the ranges of highlands and plateaus occurring in the western margin of the peninsula. The country as a whole has two major natural water sources, renewable in the form of rain water collected in wadis and reservoirs and which filter into shallow aquifers and non-renewable fossil water contained in eleven major aquifers in the eastern part of the country closer to the Gulf. The latter is fossil water which is estimated to have entered the aquifer systems during the wetter conditions of the Quaternary (20,000-24,500 years ago) (Beaumont 1977). With minimal natural discharge into the system this non-renewable water is a valuable resource that may soon be depleted. The aggressive exploitation of this limited water resource for agricultural projects has been costly and conservative estimates assess that over a third of the accessible water has been depleted in the past quarter of a century. As such it is the renewable water sources that are expected to play an increasingly important role in the country as fossil water slowly depletes and desalination no longer becomes financially feasible.

To understand the renewable sources of water in Saudi Arabia, however, one may need to understand the natural conditions of the land, particularly the precipitation totals and concentrations and well as the nature of the terrain. The country as a whole is reported to have a mean precipitation of about 50 mm per annum. This however varies greatly between the lower expanses of desert such as the empty quarter (in the south) which may witness rainless conditions at times extending over a number of years, and the higher lands in the south west which may receive up to 800mm in a single monsoon season (Beaumont 1977). The topography of the land plays an important role in rainwater distribution and aquifer recharge. The regional tilting and uplift of the western and southern margins of the Arabian peninsula have resulted in ranges of highlands and plateaus that exceed 1000m in height (Beaumont 1977). From the highlands the terrain descends swiftly through the western coastal plane and into the Red Sea at a distance of 100 kilometers and more gradually eastwards towards the waters of the Gulf at a distance of over 1000 kilometers away. Due to the nature of the terrain this valuable renewable resource and its watershed is mostly directed towards the steeper slopes in the west and into the Red Sea, with significantly less water directed towards the interior of the country. According to the FAO, 60% of the total runoff occurs in the region west of the highlands an area that covers less than 10% of the total area of the country and in which cities such as Jeddah lie (FAO 2008).

Since the country has no perennial rivers due to the low precipitation totals and high evaporation rates, it is the wadis that tend to support life in the area (people, plants and animals) for a significant amount of time per year. With life happening around these wadis, settlements (towns and villages) tend to position themselves there. The flora and fauna of the region around the wadis have devised natural systems that enable them to store and make use of the stored water over the drier periods of the year. The inhabitants of the area tend to resort to similar solutions; storing water in preparation for the dry season or relying on wells that tap into shallow aquifers during the periods in which the wadis are dry. The wadis in the south-western part of the country, and which includes Jeddah, receive rain water during two rainy seasons; the winter rains which are more prevalent and the summer monsoons, which are shorter yet more intense. The region that comes under the south-western monsoon begins from the line crossing Medina moving southwards, with rains increasing as a proportion of the total in a southward direction. Cities in the higher lands of this region such as Taif (lying east of Jeddah) receive 40% of their annual precipitation during the six-month period from April to September (Beaumont 1977). This summer monsoon period coupled with the more regular winter rains ensures that water runs down through the wadis for a significant portion of the year increasing their importance as life sustainers in an otherwise dry and arid region.

The geological conditions in the mountains which are mostly igneous and metamorphic rocks with low permeability enable the groundwater to concentrate in patches of alluvial deposits along the major wadis (Beaumont 1977). This water can easily be tapped by shallow wells. The quality of the water however differs considerably depending on the natural conditions of the area as well as the overall elevation in relation to the sea.

Water in the lower coastal plains tends to become more saline as the Red Sea is approached. The effect of increased salinity on the lower wadis is being intensified by human activities (such as the brine discharge by desalination plants along the coast) and climate change (rising sea levels and rising temperatures). As a result, a wadi as prominent as Wadi Fatimah which lies within the boundaries of Jeddah has suffered greatly from increased soil and water salinity. This has caused a severe decline in crop yields in the lower segments of the wadi.

Wadis are an extremely valuable resource and should be integral in regional urban planning and design schemes and projects if growing populations of cities such as Jeddah are to be sustained. The value of the wadis has been recognized as early as the 9th century when Ain Zubaidah was established as an aqueduct linking the wettest climatological area (Taif) some 1471 m above sea level and which receives approximately 180 mm of precipitation per annum with the lower lying city of Mekkah where all the pilgrims gather. Since then very few projects of this scale have sought to emulate this undertaking.

3.2 Designing around the Wadis – Sustaining life in Historic Jeddah

Up till the 70s Jeddah was reported to receive an annual average of 65.3mm of rain, since then this figure has dropped and today with the impacts of climate change (which will continue to increase if no serious action is taken) Jeddah receives no more than 55mm of rain per annum. The situation is exacerbated by the sporadic nature of the rains in which longer periods of drought are coupled with intense rainfall causing flash floods within the city.

To understand the nature of the storm water discharge it is important to shed light on the city's geomorphological conditions. Jeddah comprises of three distinctive geomorphological zones, being the Red Sea and its shore, the coastal plain and the coastal hills. The hills contain a number of depressions that form natural reservoirs during periods of rain. The depressions that lie between the hills are almost at a hundred meters above sea level and are covered by alluvial soils which support the flora and fauna in the area (Qari 2009:105). When these natural reservoirs are full (due to heavy rains) the excess water discharges at high speed through the wadis and into the coastal plain. The coastal plain, in which most of the urban development is concentrated, is intersected by a number of wadis that drain the water from the highlands to the sea. The total number of wadis reported in 1956 reached 80, these however have been greatly diminished due to human activities which according to Qari 2009, have played a significant role in "obliterating most of the natural geomorphological features, especially the wadi courses, salt flats and the sabkhas along most of the coastal plain" (Qari 2009:105). In his article 'Geomorphology of Jeddah Governate' Qari (2009) maps the original wadis on aerial photographs dating to 1956. These photographs predate the rapid expansions that the city later underwent. His study thus gives a clear indication of the natural conditions before the wadis were covered by infrastructural developments and urban expansions. It provides the first detailed drainage map available which was based on the interpretation of aerial photography under stereoscope, thickened by an analysis of the drainage systems and their impact on the city (Qari 2009).

The major wadis in Jeddah according to Qari 2009 are: Wadi Al-Kura', Wadi Muraygh, Wadi Ghuraiyah, Wadi Um Hablayn, Wadi Burayman, Wadi Hutayl, Wadi Bani Malik, Wadi Mirayyikh, Wadi Quwayzah, Wadi Ushayr, Wadi Ghulayl, Wadi Al-Khurmah, and Wadi Fatima. The latter having the largest basin area of 356.7 km^2 and thus bringing down the largest amount of water from the highlands (from an elevation of 750 m). The second most significant wadi is that of Bani Malik which has an accumulated length (including channels) of 593 km and drains from an elevation of 750 m (similar to Wadi Fatima) (Qari 2009). These two wadis which are at close proximity to each other have played a significant role in supporting the city throughout its long history.

The historical town of Jeddah developed with an understanding of the potentials of these wadis and the threats they may at times issue. Due to the potential of surface runoff that often occurs during flash flooding and which could be highly erosive especially where the slopes are greatest causing damage to crops and houses sited along or near the wadi beds, the initial settlement in the area of Jeddah (now referred to as Al-Balad) occurred in the only high range along the coastal plain. According to Qari 2009, the elevation of the coastal plain of Jeddah is an almost flat relief which ranges between 2 to 5 meters with the exception of the area around the Al Arbaeen lagoon where the elevation reaches 13 m above the sea level (Qari 2009:104). The choice to locate the old city on this higher land protected the city over centuries from the damages of flooding that impacted the outlying villages and settlements.

The natural wadis that ran through the outlying area had alluvial banks capable of supporting plant-life and agriculture in a somewhat harsh terrain. It was upon this natural system that the port city came to life, the early settlers understood the fragile terrain and worked with the system rather than against it. With the meager amount

of rainfall the region witnessed it was common to build underground reservoirs with rainwater catchment systems channeling the water from the rooftops to the cisterns below. Most of the time however, water was carried into the city from the natural reservoirs amidst the hills and from shallow wells along the wadis.

In his unpublished PhD thesis 'The Development of Housing in Jeddah: Changes in Built Form from the Traditional to the Modern' AlHarbi (1989) describes the water conditions in the historic city. He cites a number of travelers whom while travelling wrote exacting accounts of the conditions within the walled city. According to one of the travelers, Ibn Al Majawir, there were as many as 68 reservoirs in the city positioned, according to Abdul-Quddous Ansari, under the houses and attached to pipes draining rainwater from the rooftops to the cisterns below. Ibn Al Majawir also mentions the reservoirs lying outside of the city which he explains were filled by heavy rainfall. Slaves he explains carried this water on pack animals into the city to fill the house reservoirs. This account was supported by J.L.Burckhardt who described a similar process for water management inside the walled town.

In a number of these accounts it was mentioned that water from outside the town would be obtained from nearby villages such as 'Bani Malik' and 'Al Kandarah', villages that lay along the main wadi courses. The residents it was said continued to depend on water transported and stored in the underground reservoirs until the 16th century when the Mamluk Sultans established a piped water system which brought the water directly into the town from neighboring wadis. This project (Al Ain Alwazeriah) was kept running through the Ottoman period and was even used up till the transfer of power to the Saudi Government in the beginning of the 20th century. The significant population growth in the second half of the 20th century however forced the city to search for other alternatives and desalination was at the forefront of the solutions considered. The first desalination plant was constructed in the beginning of the 70's and produced desalinated sea water that was pumped into the reservoirs and fed to the city through distribution networks.

Even though Jeddah's hydrological cycle may have proved insufficient to service the rapidly growing city, however reliance on desalination, even though having met the increasing demands, has at the same time according to Aljoufie & Tiwari (2015) caused serious disruptions to the natural hydrological cycle of the city (Aljoufie & Tiwari 2015). From that point onwards the value of the wadis was all but ignored and they no longer played the same role they had historically played in supporting the city. Looked upon merely as sources of destruction during heavy rainfall the wadis were covered, changed into concrete channels and diverted away from the city.

3.3 Unmanaged Rapid Urbanization and the Disappearance of the Wadis

The arid conditions of the GCC countries along with their access to large reserves of oil and natural gas fueling their rapid economic development has caused the cities in the GCC to be amongst the fastest growing in the world. Currently over 80% of the population in GCC countries live in urban areas. This is exacerbated by the worsening droughts within the GCC and the past and emerging conflicts in the surrounding region leading to internal and external migration which will continue to place significant pressure on urban infrastructure and services (UN Habitat: 2012a).

Jeddah's population has more than quadrupled since the 80s, at which the population rested at 927,000. The population of Jeddah today exceeds the 4 million mark and is expected to reach 7.2 million by the year 2040 (UN Habitat 2012a). Even though the growth patterns show clear signs of slowing nonetheless the numbers are still quite significant and would require considerable planning and urban management effort for the city to be able to extend basic services to its inhabitants especially in light of climate change which is expected to set new trends of migration in the region. In Jeddah, the situation is also compounded by the reception of the pilgrims throughout the year, the numbers of which have been growing steadily. As a constant and substantial source of revenue the city is encouraged to increase the numbers of pilgrims in spite of the further strain they place on the already strained natural resources.

Urban growth in itself is a driver of economic development and cities in Saudi Arabia are the second largest revenue generators after oil. As such they are expected to play a major role in the diversification of the country's economy as Saudi Arabia is weaned from its almost complete reliance on oil. Cities such as Jeddah will continue to provide options and lifestyles that cannot be experienced elsewhere, they are places for social and economic mobility as well as cultural development. The problem in cities such as Jeddah is not the speed of urbanization per se but the form of unmanaged urbanization that has resulted in sprawl leading to the construction of massive road networks, mainly in the form of north-south highways dissecting the city and interrupting its natural drainage. Similarly, rapid unmanaged urbanization has caused a rapid proliferation of informal settlements many of which were positioned on environmentally sensitive areas such as low-lying lands and along major wadis.

This unmanaged urbanization has thus greatly impacted the natural wadis and radically altered the landscape of Jeddah triggering the violent backlash of nature experienced in the form of flash floods.

The solution pushed forward by the city in the recent years has been to construct massive concrete channels to drain the rainwater safely to the sea, however the impervious nature of the channels has only succeeded in high discharge volume (and velocity) of the rain water during precipitation periods increasing the risk of potential accidents. The solution promoted in this paper is to revert the channels back to their natural state as wadis to support the city's natural drainage system. These wadis would support the development of green parks within the city, enhance social and recreational activities as well as provide ecological services ranging from CO^2 reduction, soil stabilization, air filtration and aquifer recharge. Open vegetated areas in urban centers in Saudi Arabia have dropped in the past 40 years. In Riyadh according to the UN Habitat report (2012a) green areas dropped from $78m^2$ per capita in 1950 to 16 m^2 in 1999. In Jeddah currently there is an average of $2m^2$ of open space per capita, which is significantly deficient when compared with the $8m^2$ WHO standard average (UN Habitat 2012a). Jeddah needs open space, it needs green spaces that can be sustained naturally, as such green in Jeddah should be concentrated along its major wadis rather than dispersed haphazardly across the city costing the city millions to sustain through irrigation relying heavily on desalinated water. Such green fingers would support the city in numerous ways and add significant value to Jeddah, improving urban livability and quality of life and as such attracting investments and promoting sustainable development. Supporting the recovery of the wadis would provide the city with the resilience it requires to face the challenges of the 21st century pertaining to climate change, water and food security in light of urban population growth.

4. Jeddah's Environmental Challenges

To better understand the benefit of recovering and reclaiming the wadis in Jeddah it is important to highlight some of the major environmental challenges the city faces. Only then would we be able to explain how the wadis would serve in reducing or eliminating these significant challenges.

One of Jeddah's most significant challenges lies in relation to its desalination plants, seen both as a source of life (with regards to providing potable water to the city) and a major cause of environmental damage. Jeddah is almost completely reliant on desalination plants for its potable water supply, 97% according to the UN Habitat study in 2012. These plants emit excessive amounts of CO^2 (estimated 1.37 million tons of CO^2 annually) into the air due to the burning of fossil fuels (Abazza 2012). These emissions have great consequences on local air quality leading to air pollution, urban heat gain, as well as an increase in the acidity of the sea water. Desalination plants also have an adverse impact on marine ecosystems as a result of their thermal effects as well as the raised salt and chlorine levels that return into the water (Beaumont 2000). The byproduct of the desalination process (brine), with its high concentration of salts, is particularly damaging to sea life, even though in recent years it has been sprayed at a distance from the shore to ensure even distribution. These measures may slow down the damage but they do not in any way eliminate it. The disposal of excess salt into the sea also increases the coastal soil salinity as well as the underground water salinity forcing many coastal farmers to abandon their land (UN Habitat: 2012a)

The second environmental challenge Jeddah faces is linked to its waste water discharge. Directly correlated to the amount of water consumed per capita, Jeddah's households produce a significantly large amount of wastewater. Unfortunately, however, the city does not have in place the systems required to treat and discharge this wastewater safely. It is only the center of the town which is equipped with a functioning sewage network. The majority of the expansions that took place in the past 3 decades and which cover 52% of the urban development are not connected to any form of network and are as such forced to rely on septic tanks for waste water disposal. The disposal from the tanks would then be through suction trucks that remove the waste water discharging it at times illegally in accessible dumps or directly into the sea. The most serious challenge is presented by the septic tanks which seep contaminants into the already shallow underground water rendering it unsuitable for use. Regarding waste water treatment, a number of plants have been constructed within the city, however collectively they are only able to treat 62% of the wastewater collected in the area serviced by a network, in the remaining areas the untreated water is either discharged into the Red Sea or left to seep into the underground aquifers with more far reaching consequences. The cliché lies in the fact that with 82 outfalls of untreated water pouring into the sea, the water is pumped back in again through the desalination plants raising concerns about the water quality which the city receives.

4.1 Climate Change

Jeddah's already existing problems are expected to be compounded by climate change within the near future. Climate change is no longer a distant concept but one in which the repercussions are felt here and now.

Researchers agree that the anticipated impacts of climate change on urban infrastructure are becoming more evident. This can be seen most clearly in the case of Jeddah with the frequency of flash floods witnessed in the past decade. The key climate change impacts expected to affect Jeddah are not limited to increased storm water runoff and increased risks of flooding but also risks of extreme heatwaves, urban heat island effects as well as rising sea levels. Water scarcity and food insecurity are amongst the most serious concerns the city would need to prepare for. The UN Habitat report (2012a) clearly states that one of the largest challenges facing the Arab world in general and the GCC in particular relate to desertification and threats regarding water and food insecurity (UN Habitat 2012a). The threats related to climate change however are all interrelated, for instance climate change induced temperature rises and precipitation declines are projected to increase water scarcity and the frequency of droughts reducing agricultural productivity as a result by 10 to 40 percent. In an already fragile landscape such as that of Saudi this would directly hasten rural to urban migration, pressuring cities that are themselves unable to cope with the extent of the threats. Similarly, low-lying coastal cities such as Jeddah threatened by rising sea levels would also witness an increase in the salt content of the aquifers rendering the water in the shallow coastal aquifers unsuitable for consumption and farming.

The UN recognizes two approaches towards tackling climate change, the first is mitigation by reducing the GHG emissions and the second is adaptation by ensuring that the urban systems are able to withhold the shocks of sudden climatic upturns and are able to adapt accordingly. Urban design and urban planning can play a central role in mitigation and adaptation strategies, and the reconfiguration of the urban infrastructure may be the first step to ensure the city's resilience to the impacts of climate change

5. Green Infrastructure

5.1 Green Corridors

In response to the environmental challenges the city of Jeddah faces and will continue to face in light of climate change, this section explores the potential of [re]covering Jeddah's wadis to provide the city with the green infrastructure it requires. The wadis would work as green fingers and be used as a mechanism for connecting and integrating the city in an east-west direction reducing the fragmentation caused by its north-south highways. The east-west green corridors will enable the city to reconnect with the sea which is currently difficult to access given the layout of streets and the dominancy of the North-South routes. The corridors will enable the rain water to discharge more efficiently, slowing the speed of the discharge, and allowing for most of the water to filter down and cleanse and replenish the underground aquifers. The corridors will utilize the storm water to irrigate the landscape (larger green areas) needed to clean the city's air, stabilize the soil and provide social, cultural and recreational amenities to the inhabitants of the city. The green corridors will also contribute to the waste management that the city most desperately needs by introducing ecologically friendly biological treatment of the waste water through the use of special vegetation. This would ensure that the waste water is treated before seeping into the aquifers. The green corridors (due to their sheer size) will also play a role in restructuring the city and writing it of in an entirely different manner to its current state.

The argument for recovering Jeddah's wadis is not merely an environmental one, but also economic. The UN Habitat 2012b argues that the cost of replacing an ecosystem service, for example by building and operating a water treatment facility is higher than conserving the ecosystem and enjoying the clean water that flows from it (UN Habitat 2012b). Similarly, the costs of using a natural system to control floods is significantly less and more effective than building concrete flood defenses. The benefits can be sensed and seen more clearly in the long run, where the economic logic becomes most clear. Natural systems live longer and require little to no maintenance, they establish numerous benefits rather than single-use engineered solutions. Their compounded benefits when added up create a solid and substantial economic argument.

The vegetation that can be introduced in these wadis would be crucial for the support of a city which suffers from high levels of air and ground water pollution. The ability of plants to contribute to soil decontamination, air filtration and CO^2 reduction is unparalleled. Plants' abilities to absorb carbon dioxide, store carbon and give off oxygen is an important carbon sequestration strategy that can assist biodiversity and mitigate climate change. Natural vegetation alongside the wadis can protect against erosion, minimize downstream flooding, keep aquifer groundwater clean and facilitate the movement of species.

The survival of a city such as Jeddah relies on its ability to devise sustainable solutions for its water supply that would remain operable in the long run, as such this rules out desalination which not only is environmentally damaging but also financially unsustainable. Capitalizing on Jeddah's potential of receiving rain water through its wadis from the highlands needs to be thoroughly investigated and invested upon. The fact that 60% of the water falling in the Hijaz mountains makes its way westwards toward the coastal plain of the Red Sea, provides a

substantial opportunity for a city like Jeddah. These opportunities can diminish if current approaches towards urban planning are continued and yet can at the same time be reversed if swift positive action is taken to bring the natural wadis back into the city. In the 1973 master plan prepared by Robert Matthew and Johnson Marshal the Bani Malik Wadi (now a concrete covered channel referred to as Northern Channel/Tahlia Channel) was kept as an open waterway in the center of the city. The plan recognized the significance of the wadis and water bodies in sustaining the city environmentally and mitigating the flash floods that the city might experience. Unfortunately, however, this was never implemented and in all the ensuing master plans the wadis and flood plains remained absent. A wadi such as Bani Malik that has sustained the city over hundreds of years is brushed away, swept under infrastructural developments and urban expansions. The city of Jeddah needs to recognize that life is dependent on water and the quality of water is in turn dependent on healthy ecosystems. As such the utilization of the wadis for the supply and the purification of water is crucial for the support of the city in the long run and in light of the threats issued by climate change.

The city of Jeddah needs to understand and take into account the existing ecological systems rather than imposing a standard model of spatial development onto the landscape. Development needs to be located in areas of low ecological value to protect ecological processes that provide ecosystem services. Nonetheless, as explained above, it is never too late, ecosystems that have been weakened by urban fabric can be still be restored. This was seen clearly in the celebrated Cheongyecheon River Restoration Project in Seoul, Korea.

5.2 Urban Design Strategies

With the aim of exploring the potential for broad city-scale approaches that may impact an even wider region we proposed that the Fall ’18 Urban Design Studio concentrate on the natural drainage systems as an opportunity to develop green corridors for the city of Jeddah. The objective of the studio titled “[Re]covering Jeddah’s Natural Wadis” was to study the four channels (southern drainage channel, northern drainage channel, the airport channel and Obhur channel) and the areas that surround them to understand the different challenges each channel faces and to then propose strategies that improve the social, cultural, environmental and economic conditions in the different areas.

The aim of the studio was to:

1) Investigate the current conditions of the storm water drainage systems in the city
2) Trace the city’s natural wadis using old cartographic maps
3) Assess the conditions of the lands and their uses in the areas surrounding the wadis
4) Investigate the natural flora and fauna that had existed or may still exist in the region
5) Design solutions that address the multiple challenges that the different wadis face

Upon examining the urban watershed and hydrologic contexts, ecological and climatic conditions, a number of design solutions were developed. The solutions adopted varied according to the conditions of the different wadis and the areas that surrounded them. This created a particularity for each wadi, nonetheless when all the different projects were viewed together they provided a comprehensive environmental, economic, social and cultural solution for the city as a whole. To tackle the challenges in their respective wadis the students chose from a palette of environmentally sensitive strategies that included: floodplain storage, low impact development, resilient planting design/ ecological resilience, landscape connectivity, urban heat island mitigation, circular metabolism, infrastructural adjustment and urban agriculture among others.

Below is a brief description of two of the four projects developed in the studio:

5.2.1 Project 1 - South Channel - Reviving Jeddah's Food Basket

Historically the area south of Jeddah and surrounding Wadi Fatima was the main source of freshwater and agricultural produce for the city. Since then the city has burst out of its seams and the provisions of both became inadequate to support the growing metropolis. The southern wadis have since been plagued by infrastructural development, informal settlements, land use alterations and misguided agricultural practices.

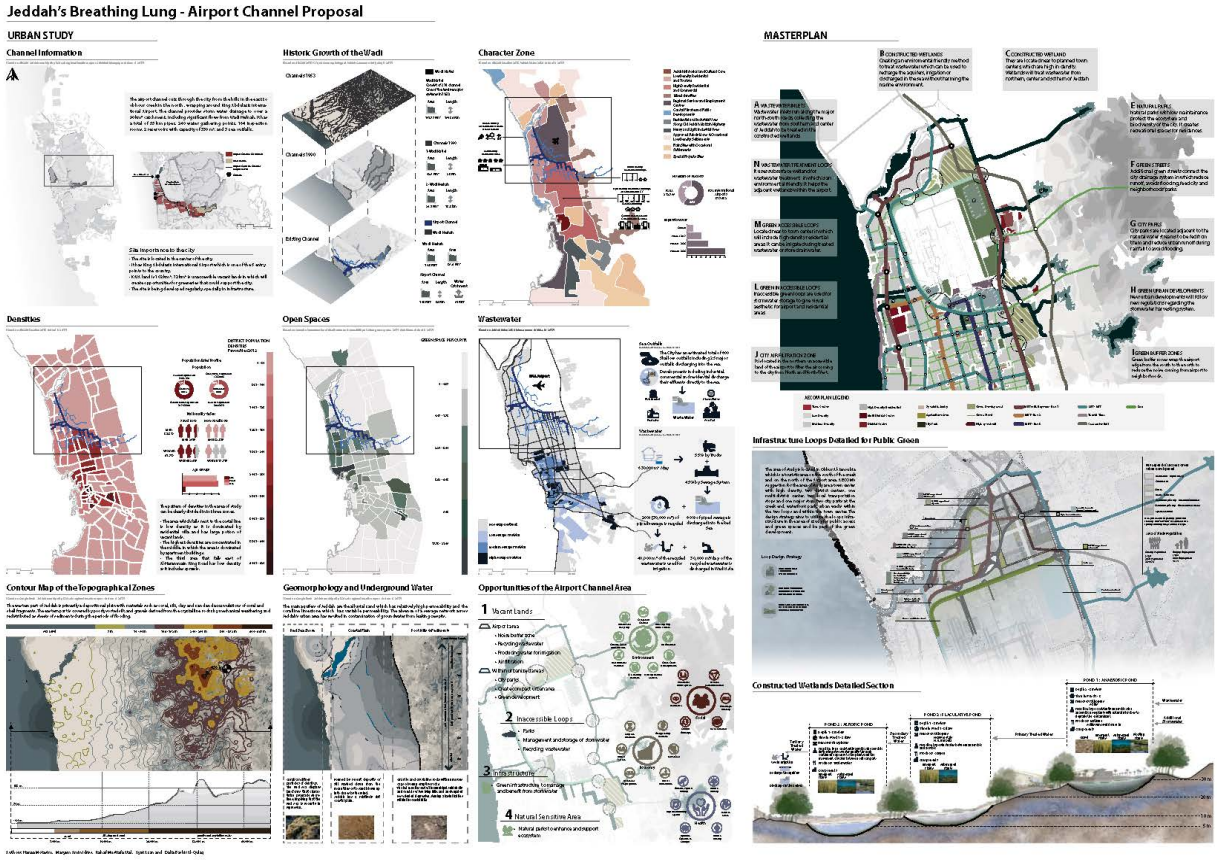
The southern channel area is also plagued by the pollution since it has the largest concentration of industrial buildings in the city as well as the Islamic Sea Port. It has large areas of unplanned settlements housing many of Jeddah's lower income groups with low formal employment and a clear lack of basic services. The opportunities within the area lie predominantly in the large tracts of empty land and the proximity to Wadi Fatima, the largest wadi in Jeddah with significant aquifers and the great agricultural potential. The fact that the majority of the women in the unplanned settlements are unemployed or underemployed allows for a readily available workforce to exploit the agricultural potential of the area. Jeddah imports over 80% of its food stuff particularly vegetables and fruits, this increases the city's vulnerability in light of climate change and global food shortages that will be witnessed in the coming years.

Wadi Fatima, which has been central to the growth and development of the city, providing both the water as well as the agriculture needed to sustain it, has lost its role in the 70s after desalination was introduced. Today, Wadi Fatima along with Wadi Ghulail, Wadi Qus, Wadi Metheweb and Wadi Al-Khumra are all threatened by infrastructural developments, informal settlements and general pollution. The lower reaches of most of these wadis were changed into concrete channels, with the channel length increasing from 10 km in 1985 to 37.3 km in 2017.

The students explored the possibility of recovering and naturalizing the channels then utilizing them to support urban agriculture in order to build up the city's resilience. In their proposals productive landscape is explored in the form of conventional land-consuming agriculture, high-intensity agriculture (vertical farming), and fish farming to support the fish market which is at close proximity to the site. The fact that the site has the largest concentration of industrial buildings in the city can be at the same time an advantage, food produced in and

around the wadis can be processed in the nearby industries. Similarly the position of the port to the west of the site encourages the possibility of exporting excess produce. The organic waste produced by the city (markets, supermarkets, hotels and restaurants) can be collected and recycled, transforming it into fertilizer to support the agriculture. The largest waste water treatment plant in Jeddah (Al-Khumra) is also located within site and the treated water upon reaching a certain level can be used also for agriculture and the fish farms. The south of Jeddah is a concentration of markets, therefore the proximity between production and selling makes the proposal more financially viable. The intervention is seen as a complete loop, with the agriculture consuming organic waste and waste water produced by the city and giving back in return food which after supporting the city itself becomes organic waste which is returned to the site once again. As a whole, the system would be able to sustain the city in light of the threats issued by climate change particularly food insecurity. Similarly, the image of the area is transformed from a highly polluted site with concentrations of informality towards an area of food production and a place of great social opportunities for the city's residents.

5.2.2 Project 2 - Airport Channel – Jeddah's breathing Lung



Curiously in the shape of a lung the 10,000 hectare (102 km^2) airport in the north of Jeddah provides the largest open land in the city. According to the nature of airports, this landscape is inaccessible and yet provides great opportunity for greenery that could support the entire city. The areas around the airport (mostly new developments 90s onwards) suffer from one major problematic, lack of sanitation infrastructure. The consumption of water and thus the production of waste water within that area of the city is significantly higher than the rest of Jeddah due to its large concentration of high end compounds, villas and palaces. The airport landscape could potentially provide the opportunity to handle this problematic. The area of the KAIA airport is about 3-5 times the size of international airports with the same capacity, this means that there are huge tracts of under-utilized land within its vicinity. Currently under construction on the eastern side of the airport is a large waste water treatment plant. Such a plant would rely on chemical processes serving a singular purpose of

reducing water toxicity to a level that enables its reuse for secondary functions such as landscaping. The strategy the team produced looked into the inversion of this process, instead of utilizing waste water for landscaping the team proposed a natural system that utilizes the 'landscape' for the treatment of waste water, sidelining the need for chemical processes which are often just as harmful as they are beneficial. The fact that the majority of airport landscape is inaccessible makes this the most suitable landscaping option for the area. Another challenge that the area faces are the massive bundles of road infrastructure dominating the landscape around the airport area. These massive highways (70 -90 m in width) along with all the supporting loops for interchange eat up huge tracts of land. The team intends to push forward strategies that utilize these infrastructure bundles for waste water treatment and productive landscape, taking advantage of the significantly large areas of inaccessible landscape particularly between the loops and on the buffer sides of the major highways.

6. Conclusion

At the end of the 15-week studio the students had accrued sufficient knowledge about the environmental challenges in Jeddah and had come to understand how these challenges can be addressed through green infrastructure. The green infrastructure proposals varied according to the location and position of the wadis with respect to the city. These sensitivities, which are difficult to be addressed through urban planning which can be too broad, can easily be picked up through urban design. One of the most significant challenges the city of Jeddah faces with regards to environmental projects and their implementation is the challenge of scale. The conceptualization of urban design as restricted to public plazas and waterfronts, which is the current practice in Jeddah needs to be readjusted. Urban design has no specific scale, it mediates between the scale of urban planning and architecture taking whichever scale is needed to address the problematic. Urban design solutions cannot be considered as patchwork projects that do not address the broader context. This discussion regarding scales of intervention will need to be researched and adequately addressed if more lasting and sustainable solutions are to be devised.

The design proposals touched upon a number of aspects that needed attention in the city, storm water discharge, water treatment, food production, job creation, soil decontamination, recreational and social space provision etc. Each wadi managed to address its own set of challenges and to provide its own unique contribution to the city. Nonetheless all the proposals had in common general green infrastructure approaches such as floodplain storage, low impact development, resilient planting, landscape connectivity, urban heat island mitigation, and infrastructural adjustment. These strategies when applied to the scale of the four channels/wadis crossing the city from east to west have provided the opportunity of re-writing the city in an entirely new way, allowing it to respond to climate change challenges faced in the 21st century, while improving lifestyles for the inhabitants of the city in the present.

References

Abazza, H. (2012). *Economic Considerations for Supplying Water Through Desalination in South Mediterranean Countries, Report of EU Funded Project, SWIM.* Retrieved from http://www.swimsm.eu/files/Economic_Considerations_on_Desalination_Final.pdf

AlHarbi, T. H. (1989). The Development of Housing in Jeddah: Changes in Built Form from the Traditional to the Modern (Unpublished PhD Thesis), Newcastle University, Newcastle.

Aljoufie, M., & Tiwari, A. (2015). Climate Change Adaptations for Urban Water Infrastructure in Jeddah, Kingdom of Saudi Arabia. *Journal of Sustainable Development, 8*(3), 52-66. https://doi.org/10.5539/jsd.v8n3p52

Al-Sefry, A. S., & Şen, Z. (2006). Groundwater Rise Problem and Risk Evaluation in Major Cities of Arid Lands – Jedddah Case in Kingdom of Saudi Arabia. *Water Resources Management, 20*(6), 91-108. https://doi.org/10.1007/s11269-006-4636-2

Beaumont, P. (1977). Water and Development in Saudi Arabia. *The Geographical Journal, 143*(1), 42-60. https://doi.org/10.2307/1796674

Beaumont, P. (2000). The quest for water efficiency-restructuring of water use in the Middle East. *Water Air Soil Pollution, 123*, 551-564. https://doi.org/10.1023/A:1005225302371

Cerra, J. F. (2016). Inland Adaptation: Developing a Studio Model for Climate-adaptive Design as a Framework for Design Practices. *Landscape Journal, 35*(1), 37-55. https://doi.org/10.3368/lj.35.1.37

Czechowski, D., Hauck, T., & Hausladen, G. (Eds.). (2015). *Revising Green Infrastructure.* London: Taylor & Francis Group.

Haddadin, M. J. (2003). Water issues in the Middle East challenges and opportunities. *Water Policy, 4*(3), 205-222. https://doi.org/10.1016/S1366-7017(02)00028-4

Joardar, S. D. (1998). Classification of Landscape Plants for Environmental Design Uses. *Journal of Architectural and Planning Research, 15*(2), 109-132.

Mortada, H. (2005). Confronting the Challenges of Urban Water Management in Arid Regions: Geographic, Technological, Sociocultural, and Psychological Issues. *Journal of Architectural and Planning Research, 22*(1), 69-81.

Qari, M. H. T. (2009). Geomorphology of Jeddah Governate, with Emphasis on Drainage Systems. *JKAU; Earth Sci, 20*(1), 93-116. https://doi.org/10.4197/Ear.20-1.6

Subyani, A. M. (2012). Flood Hazards Analysis of Jeddah City, Western Saudi Arabia. *JAKU: Earth Sci., 23*(1), 35-48. https://doi.org/10.4197/Ear.23-1.3

Subyani, A. M., & Hajjar, A. F. (2016). Rainfall Analysis in the Context of Climate Change for Jeddah Area, Western Saudi Arabia. *Arab J GeoSci., 9*(122), 1-15.

Tarawneh, Q. Y., & Chowdhury, S. (2018). Trends of Climate Change in Saudi Arabia: Implications on Water Resources. *Climate, 6*(1). https://doi.org/10.3390/cli6010008

UN-HABITAT. (2012a). *The State of Arab Cities, Challenges of Urban Transition.* UN-Habitat.

UN-HABITAT. (2012b). *Urban Patterns for a Green Economy: Working with Nature.* UN-Habitat.

Vesey-Fitzgerald, D. F. (1957). The Vegetation of the Red Sea Coast North of Jedda, Saudi Arabia. *Journal of Ecology, 45*(2), 547-562. https://doi.org/10.2307/2256935

Vincent, P. (2003). Jeddah's Environmental Problems. *Geographical Review, 93*(3), 394-412. https://doi.org/10.1111/j.1931-0846.2003.tb00039.x