Risk Assessment, Remediation and Sustainable Rehabilitation in Jeddah City, Saudi Arabia

Bright ideas. Sustainable change.

AUTHORS

Tom Øyvind Jahren, Eivind Dypvik, Aud Helland, Hanne Vidgren, Suhair Majdalawi, Richard Wenning, Victor Magar, Ramboll

ABSTRACT

Background

Jeddah is an urban city situated in Saudi Arabia at the East Coast of the Red Sea. In recent years, due to the city's rapid expansion, the amount of wastewater and other types of pollution generated from household, industrial and commercial facilities have seen a significant increase. Untreated wastewater discharges to sea and ambient air transport can lead to unacceptable environmental risks, including impacts to fish and wildlife, and adverse effects to human health. This has been especially significant in constricted water bodies which experience increasing levels of contaminants (pollutants) and deteriorating environment due to increased biological and chemical oxygen demands (BOD/COD) and low dissolved oxygen (DO), as well as the increased deposit of solids and presence of algae. This has been prominent across three marine lagoons in the Red Sea, in Jeddah – Al Salam, Al Shabab and Al Arbaeen. As part of the Saudi Arabian Vision 2030, the General Authority of Meteorology and Environmental Protection (GAMEP) has initiated a large rehabilitation project to restore the environmental quality of the three lagoons and the surrounding marine environment.

Approach

Ramboll was hired by GAMEP to conduct a comprehensive study of the environmental status of the project area, culminating in a risk assessment of the environmental state, and to develop a concept design and action plan for remediating the marine environment in the three lagoons as well as in areas outside these lagoons, including the Islamic Port of Jeddah and the western tip of the Royal Palace property.

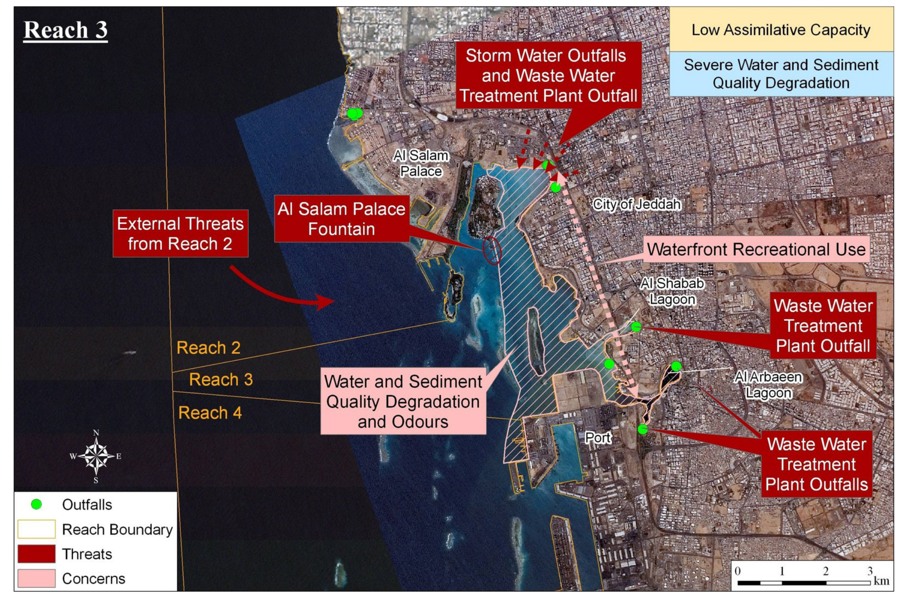
Results and lessons learned

The study revealed unacceptable risks associated with organic and inorganic contaminants and high-BOD/COD waste in the lagoon sediments. Work is being initiated on land to address ongoing upland sources before remediating contaminated sediments. An action plan has been developed to address the sediment contaminants. Some areas will be dredged, while others will be capped to help determine whether to remediate via dredging, capping or another available technology. This poster focuses on the characterization, risk assessment and remedy planning for marine sediments in Jeddah, Saudi Arabia. We also focus on lessons learned, planning exercises to educate GAMEP and stakeholders on the science of risk assessment and remedy technologies for contaminated sediments and surface water. We discuss our experience communicating our understanding of the nature and extent, risk, and remedy alternatives to GAMEP through a series of workshops that form the basis for their decisions on how to meet the goals of Saudi Arabian Vision 2030.

INTRODUCTION

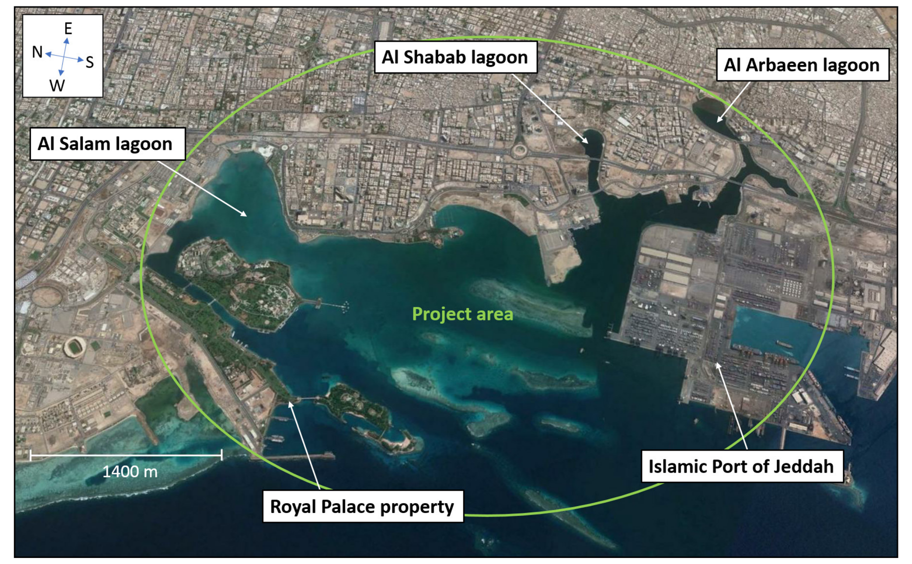
The open lagoons are located north, northeast and east of Jeddah's Islamic Port (Figure 1). These lagoons are constricted water bodies and limited water exchange is likely to worsen the effect of the discharges of treated and untreated wastewater. GAMEP has initiated a large project to assess the current environmental quality in the lagoons and adjacent areas (Figure 2). The final goal is to initiate a remediation project to obtain adequate environmental quality in the project area.

Figure 1. The coastline of downtown Jeddah, including Al Salam, Al Arbaeen and Al Shabab lagoons



The figure is a modified version of a figure presented in the presentation of the JCAP report 2007. Outfalls of stormwater and wastewater are marked in green circles, and outfalls considered as an environmental threat are marked with red squares. Areas where the environmental quality of water and sediment is a cause of concern are marked in pink hatching.

Figure 2. Overview of the project area for environmental assessment of contaminated sediments and design of an action plan for handling contaminated sediments and environmental restoration



SCOPE

We conducted a detailed environmental study of these areas and considered possible methods and alternatives for remediation of the polluted parts of each of these areas.

- Water, sediment, air quality and groundwater sampling
- Bathymetry mapping
- Ecological assessment
- Water current and discharge survey and modeling

The results from the water and sediment analyses have been used to conduct an environmental risk assessment of the project area and different sub-areas within the project area. The environmental risk assessment has formed the basis for developing three concept designs for remediation of the polluted areas in the project area.

METHODS

For the survey, studies were conducted by sub-contractors (Exova and Environmental Balance):

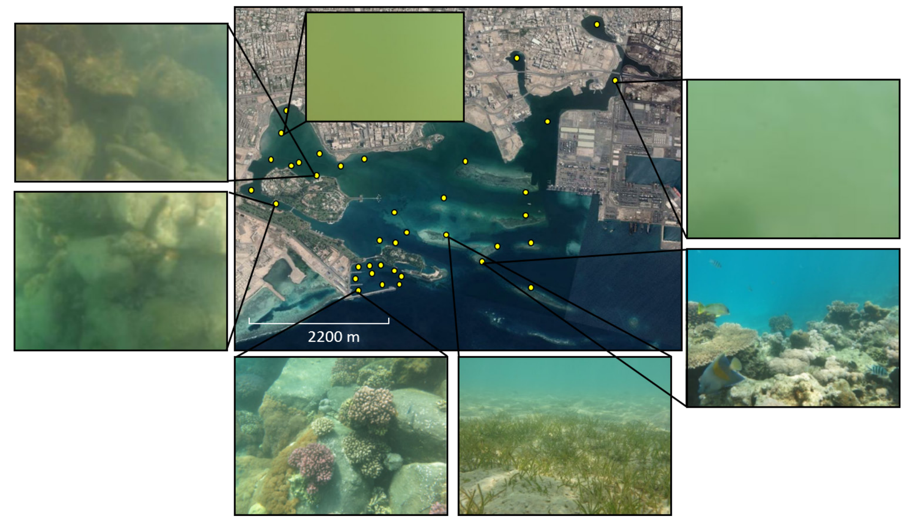
- Habitat survey at 38 stations within the study area
- Air quality survey: double set of sampling tubes deployed at 3 sampling stations
- Bathymetry mapping in all 3 lagoons
- Groundwater sampling
- Water sampling in lagoons at 25 stations for seven consecutive days
- Hydrographical measurements with current profiler at 6 stations
- Hydrographic modeling
- Sediment sampling at 55 stations within the study area

RESULTS

Habitat survey

The habitat survey indicates little or no biological activity in the areas of the lagoons and in the channel by the Royal Palace. These areas are dominated by very turbid waters and most of or all the observed corals were dead (Figure 2). The outer area, however, is home to different coral colonies, areas with sea grass on the seabed and fish (Figure 3). Some of the coral colonies were dead, while some were alive.

Figure 3. Images from the habitat survey indicating lower turbidity and more biological activity in the outer area (represented by pictures of live corals, sea grass meadows and fish), than in the lagoon areas (represented by pictures of very turbid waters and rocks with dead corals)



Air quality

The levels of hydrogen sulfide (H_2S) in air were higher at the sites close to Al Arbaeen than close to Al Salam and Al Shabab, while the calculated amount of H_2S per cubic meters was somewhat higher in Al Shabab than in Al Salam.

Based on the results from this survey, it is unlikely that H_2S causes a health effect on citizens living near the project area.

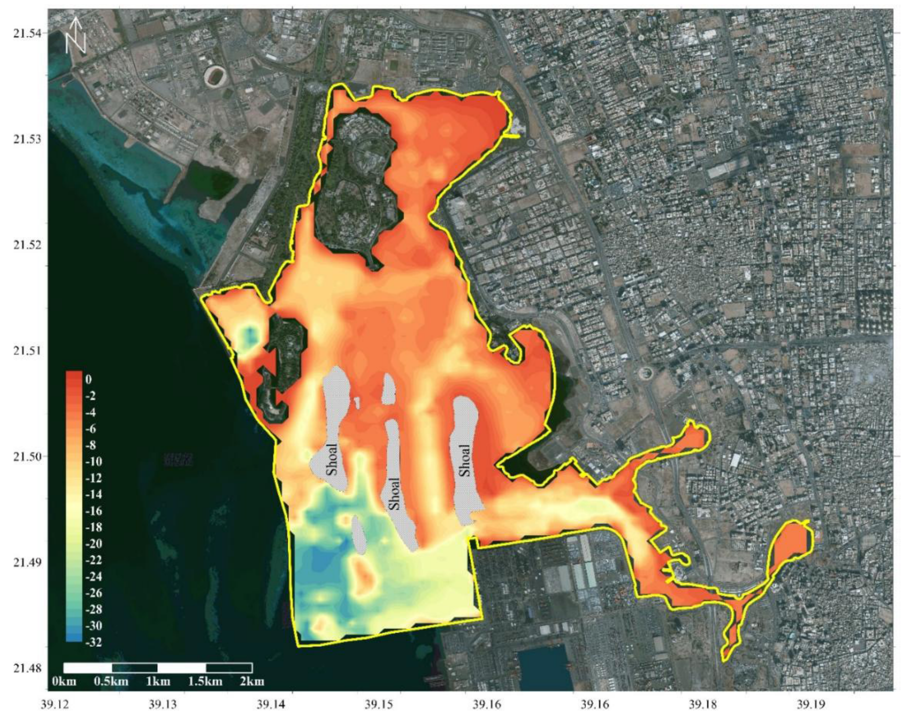
Bathymetry

A bathymetrical map of the project area is shown in Figure 4.

Groundwater

Salt water intrusion does affect the groundwater in the project area and it may add to the potential stressors of the water quality in the lagoons.

Figure 4. Bathymetric map of the project area



The coloration indicates the depth at the specific locations. The color scale is depicted in the left of the figure (eg red indicates shallow waters and blue indicates deeper waters in the project area).

Water quality

Salinity

Salinity of the water was lowest in Al Arbaeen where values under 36 psu were recorded constantly, likely due to the fresh water outfalls (effluent discharge). In Al Salam, the average recorded salinity was 39.5 psu. However, the minimum recorded salinity in Al Salam was 35 psu, indicating a fresh water influence.

Total nitrogen

Concentration of total nitrogen was highest in Al Arbaeen, where concentration varied between 2,200–5,600 μg/l. On the other stations, the measured concentration of total nitrogen was significantly lower and mainly under 1,000 μg/l, and under the detection limit (500 μg/l) in many samples.

The concentration of ammonia was also highest in Al Arbaeen, where concentrations reached up to 360 μg/l. In Al Shabab, we also detected high levels of ammonia (120 μg/l). In the other sub-areas, the concentration was significantly lower and under the detection limit (10 μg/l) in most samples.

BOD/COD

Concentrations of BOD and COD were highest in Al Arbaeen, where concentrations up to 81 and 118 mg/l were measured, respectively. In the other areas, the concentration of BOD and COD were mainly under the detection limits, 2 and 5 mg/l, respectively.

Hydrography

Current measurements from the outer part of the lagoon area showed current velocities between 4.8 and 6.0 cm/s on average in the different water depths. Current velocities are relatively low also in the outer part of the area, this is due to the low tidal energy in the central part of the Red Sea.

Hydrographical modeling

Modeling showed limited water circulation in the shallow lagoons. In the outer area, the water exchange was more pronounced. Modeling showed that discharges of effluents can be diluted 20 times before reaching the outer area. This will however not be sufficient for creating acceptable water quality in the lagoons.

Sediment quality

Sediments in the lagoons and areas close to these lagoons contain sediments with acute toxic levels of metals (Figure 5). Sediments in most of the outer area, and areas close to the Port of Jeddah do not contain toxic levels of metals (Figure 5).

The most adverse levels of pollution in Al Arbaeen are caused by mercury, zinc, copper and oil; in Al Shabab by copper, zinc and oil, and in Al Salam by copper. Table 1 presents the limit values for chemical quality of sediments.

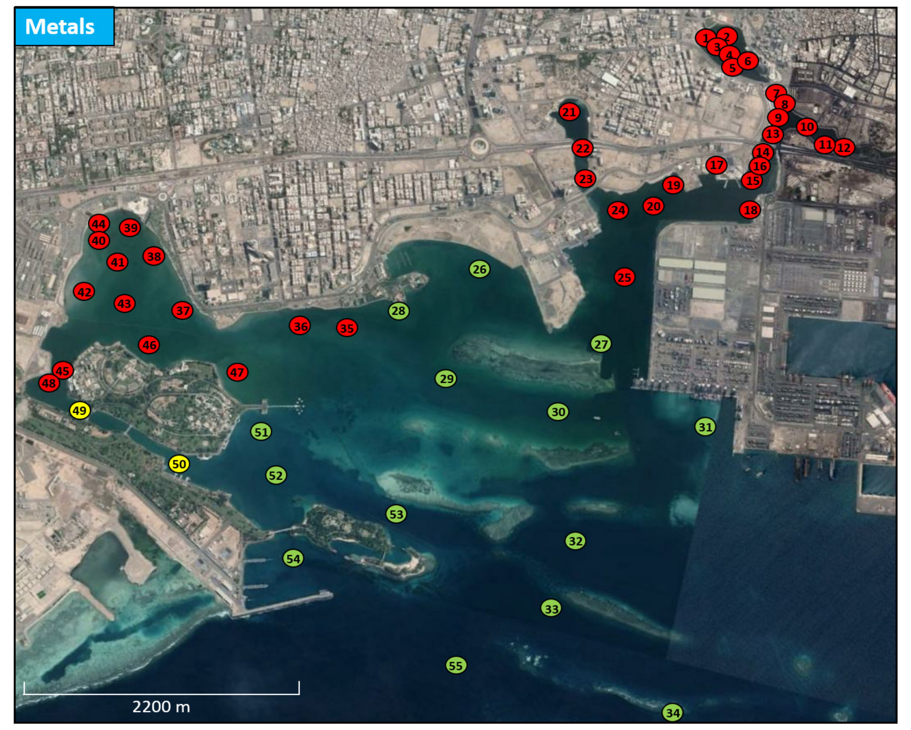
The most polluted areas apear to correspond with the areas which contain the highest levels of nutrients and the areas where the C:N ratio indicate influence from land-based sources.

Table 1. Limit values for chemical quality of sediments

Parameter	Unit	PNEC-value	No toxic effect	Chronic toxicity	Acute toxicity	Reference
Metals						
Arsenic	mg/kg	18	<18	18–71	>71	Norwegian Environment Agency (M-608/2016)
Lead	mg/kg	150	<150	150–1480	>1480	
Copper	mg/kg	84	<84	84–84	>84	
Chrome	mg/kg	660	<660	660–6000	>6000	
Cadmium	mg/kg	2,5	<2,5	2,5–16	>16	
Zinc	mg/kg	139	<139	139–750	>750	
Mercury	mg/kg	0,52	<0,52	0,52–0,75	>0,75	
Methyl mercury	μg/kg		no PNEC used in this report			
Polycyclic aromatic hydrocarbons (PAH)						
Naphtalene	μg/kg	27	<27	27–1754	>1754	Norwegian Environment Agency (M-608/2016)
Acenaphytylene	μg/kg	33	<33	33–85	>85	
Acenaphtene	μg/kg	96	<96	96–195	>195	
Flourene	μg/kg	150	<150	150–694	>694	
Phenanthrene	μg/kg	780	<780	780–2500	>2500	
Anthracene	μg/kg	4,6	<4,6	4,6–30	>30	
Flouranthene	μg/kg	400	<400	400–400	>400	
Pyrene	μg/kg	84	<84	84–840	>840	
Benzo[a]anthracene	μg/kg	60	<60	60–501	>501	
Chrysene	μg/kg	280	<280	280–280	>280	
Benzo[b]fluoranthene	μg/kg	140	<140	140–140	>140	
Benzo[k]fluoranthene	μg/kg	135	<135	135–135	>135	
Benzo[a]pyrene	μg/kg	183	<183	183–230	>230	
Dibenzo[ah]anthracene	μg/kg	27	<27	27–273	>273	
Benzo[ghi]perylene	μg/kg	84	<84	84–84	>84	
Indeno[123cd]pyrene	μg/kg	63	<63	63–63	>63	
Oil compounds						Stronkhorst & van Hattum, 2003
THC (C10–C40)	mg/kg	100*	<100*	100–1000*	>1000*	
Nutrients						
Total nitrogen	mg/kg		no PNEC			
Phosphorus (P)	mg/kg					
Other			No separation between chronic and acute toxicity			
Selenium	mg/kg	6,2	<6,2	>6,2		https://echa.europa.eu
Total organic carbon	%		no PNEC			

* Not PNEC levels, but levels based on toxicity tests, and Dutch maximum permissible concentrations and intervention values for oil in sediments (Stronkhorst & van Hattum, 2003)

Figure 5. Classification of the maximum value of heavy metals (arsenic, lead, cadmium, chrome, copper, zinc or mercury) in sediments in the project area



The circles illustrate the stations with the station number depicted in the figure. The coloration of the circles illustrates if concentrations of any metals at the stations corresponds to acute toxic levels (red), toxic levels above PNEC, but not acute toxic (yellow) or no toxic levels detected (green).

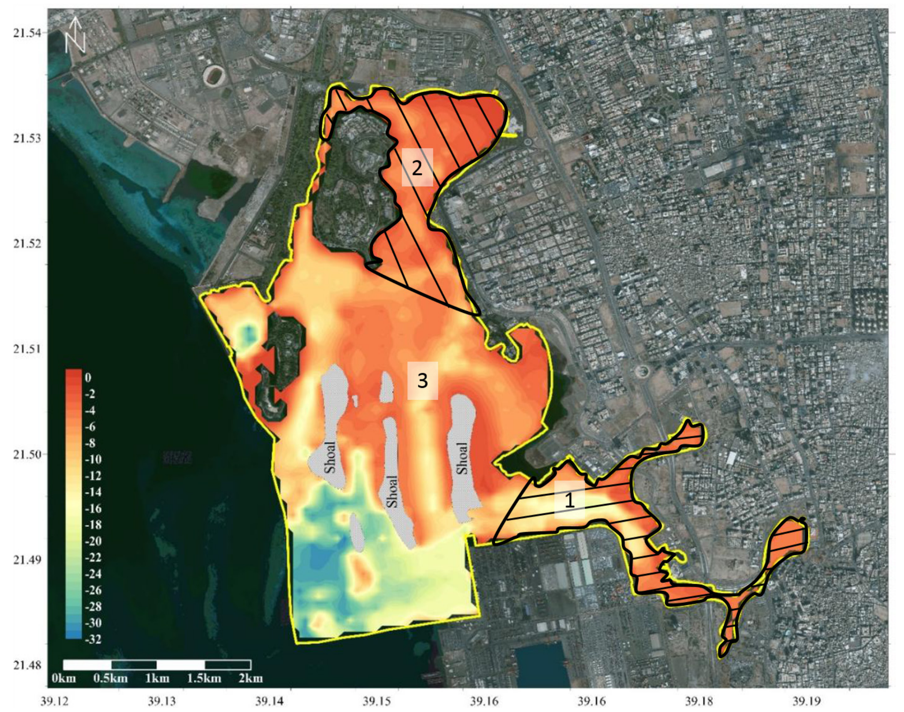
DISCUSSION

Ramboll recommended remediation of sediments in all 3 lagoons, including some parts of the adjacent project area.

Based on the results of the surveys conducted in 2018, we identified 2 sub-areas of the project area where remediation of sediments should take place:

- Al Shabab and Al Arbaeen lagoons, including most of the area inside the main inlet/outlet of the lagoons
- Al Salam lagoon and part of the sediments in the outer area close to the lagoon (Figure 6)
- For the remaining parts of the project area (mainly the outer area), we suggest that no remediation action is initiated (Figure 6)

Figure 6. Bathymetrycal map of the project area with areas in need of sediment remediation depicted in a black line pattern



Area 1 is the remediation area of Al Arbaeen and Al Shabab, while area 2 is the remediation area of Al Salam and adjacent areas. Area 3 is the parts of the outer area where sediment remediation is not considered as necessary. The coloration indicates the water depth of the project area. The color scale (depth in meters) is depicted at the left side of the figure.

CONCLUSIONS

We found the following pollution in the project area:

- Unacceptable levels of metals, oil and PAHs in sediments
- Unacceptable levels of turbidity and nutrients in water
- No biological activity was detected in areas where aquatic organisms should thrive
- Unacceptable amounts of litter and waste along the shoreline and in the water

Remediation actions must be initiated in the lagoons to improve the environmental quality. Ramboll recommends:

- Dredging in Al Arbaeen lagoon, capping of sediments in Al Arbaeen and Al Salam, backfilling in Al Shabab lagoon and installation of mechanical solutions to increase water circulation and flow in Al Arbaeen lagoon

The quantities for capping and dredging are shown in Tables 2-4.

Table 2. Calculation of total volume of the loose top layer, including dredging factor (increase in volume due to dredging)

		Volume (m^3)
Total Net Volume		130,000
Dredging factor	10%	13,000
Total volume loose to player		**143,000**

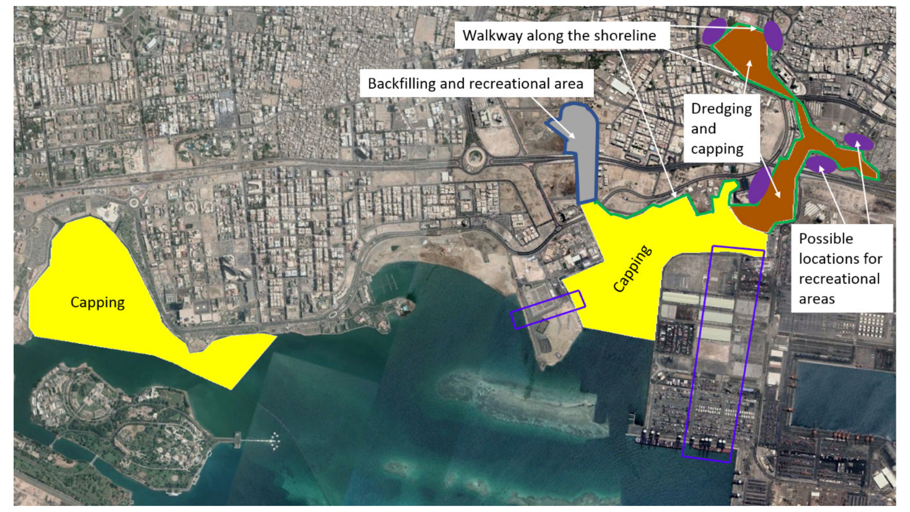
Table 3. Calculation of total volume of polluted sediments in Al Arbaeen lagoon including dredging factor

		Expected minimum volume (m^3)	Expected maximum volume (m^3)
Total Net Volume		300,000	400,000
Dredging factor	10%	30,000	40,000
Total volume contaminated sediments		**330,000**	**440,000**

Table 4. Estimation of the need for capping materials

	Al Arbaeen & Al Shabab	Al Salam	Total
Area (m^2)	1,550,000	980,000	2,530,000
Clay/silt and activated carbon (m^3)	31,000	19,600	50,600
Silt/fine sand (m^3)	77,500	49,000	126,500
Erosion layer of silt/fine sand (m^3)	155,000	98,000	253,000

Figure 7. Illustration of the different remediation measures implemented in design 1.



The sediments in Al Arbaeen will be dredged and capped with clean materials (brown coloration), the dredged materials will be backfilled in Al Shabab lagoon (grey area), the sediments in Al Salam east of the Royal Palace and outer Al Arbaeen will be capped with clean materials (yellow coloration), walkway along the shoreline of Al Arbaeen is depicted in a green line and possible locations for larger recreational areas such as parks or playgrounds are depicted in purple. Two subsurface tunnels/pipelines for increasing water exchange (areas depicted as boxes with blue line) were initially considered in this concept design, but discarded as the currents at the inlet of these tunnels/pipelines were too weak to improve the water circulation in the lagoons.