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Enviro News

Environmental Protection

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A Message From EP General Manager

Over the years, Saudi Aramco has continued advancing the effort to reduce its environmental footprint through powerful programs such as: decarbonization, greenhouse gas (GHG) emissions management, air quality, marine and land protection, waste management, health protection, and water conservation programs. The company is also committed to protecting biodiversity and ecosystem services in operational areas, to achieve a net positive impact by avoiding negative effects and offsetting any loss in biodiversity and ecosystem services.

However, our top concern is our people, therefore the company is investing in their skills through encouraging innovations and use of technologies and best practices aimed at solving environmental issues, and continuing energy production with minimum negative impact.

Toward a lower carbon future, our leaders have set ambitious initiatives and strategies to limit negative effects on climate and scale up its decarbonization program by reducing GHG and increasing Saudi Arabia's renewable energy, recycling and reuse capacity. Promoting a circular economy approach, rather than a linear economy, will help to conserve the Kingdom's valuable natural resources. Tree planting is playing important role in improving air and life quality, providing a natural barrier against sand movement, countering desertification, lowering temperatures in adjacent areas, and enhancing native biodiversity. To align with the Kingdom's ambitious vision, a new department has been established that focuses on minimizing our environmental foot print, and supporting these great initiatives toward a future with lower-emissions.

The key for success is cooperation, and we have built a successful relationship with various organization within the company. They are our partners helping us to achieve environmental compliance, performance, and stewardship for the protection of our most valuable natural resources.

Rubblization of Shaybah Airport Runway pavement- a sustainable circular economy solution

Nezar H. Al-Khalifah, Helder M. Martins, Hussain I. Al-Aithan, Oil Facilities Projects Department

Abstract

On October 20, 2020, the Project Management Institute (PMI), during its PMI Virtual Experience Series, announced the selection of the Shaybah Airport Runway Project, executed by the Oil Facilities Projects Department, as the winner for the Project Excellence Award 2020 in Europe, Africa and the Middle East region.

Shaybah airport runway upgrade construction work was successfully completed in 77 days, four (4) months ahead of the original 7-month project schedule. Rubblization of the existing concrete pavement was one of the key factors for the early completion and project achievements and awards.

This article presents rubblization as a practical, cost effective, and more sustainable option for repairing deteriorated airfield concrete pavement, and will also demonstrate how the implementation of rubblization of runway pavement contributes to the Saudi Aramco initiative to adopt circular economy principles. The circular economy unlocks economic opportunities, preserves natural resources, and improves environmental performance. This initiative is sponsored by Saudi Aramco executive management.

Background

Old Shaybah Airport Runway pavement

Shaybah Oil Field, a major and iconic Saudi Aramco production field located in the remote Rub' al-Khali desert, is visited by high delegates from countries and companies worldwide. This makes Shaybah Airport an indispensable transportation hub to access the Shaybah Oil Field.

Shaybah Airport is situated within one of the many salt flats (sabkha or dry lake bed) present in the Rub' al-Khali desert. Shaybah Airport was constructed in early 1997 and consisted of a runway with a paved

Figure 1: Deteriorated conditions of the old Shaybah Airport runway concrete pavement.

length of 3,048 meters (10,000 ft) and a width of 30.1 meters with unpaved hardened shoulders of a 7.5 meter width on either side, which classifies it as a Code 3C runway in accordance with the International Civil Aviation Organization (ICAO).

Old Shaybah Airport Runway suffered from initial poor joint construction, which worsened over time by extreme temperature stresses, low quality of repatching work, and windblown sand weather that led to joint seal deterioration, requiring extensive maintenance and repetitive repairs to maintain safe flight operations. Figure 1 shows examples of old pavement conditions.

The project scope included the rehabilitation of the 3,048-meter long concrete runway, using the rubblization method, as well as the upgrade of the Airfield Ground Lighting (AGL) system and runway pavement markings to meet international codes and Saudi Aramco standards. Figure 2 shows the newly surfaced Shaybah Runway after the rehabilitation work.

Figure 2: New Shaybah Airport Runway pavement after implementation of rubblization and overlay with polymer modified hot mixed asphalt (HMA).

Project Scope selection – rehabilitation options

Several investigations were carried out by a number of engineering offices, including Saudi Aramco Consulting Services Department (CSD) and Facilities Planning Department. All studies indicated that the deterioration of the concrete joints (usually expansion joints) was the major cause of the runway deterioration.

Several rehabilitation options were studied, based on their influence on the continuous aviation operations at Shaybah, operational safety, cost, schedule, ground operations and logistical requirements, including: a) Do nothing; b) continue with routine repair; c) complete replacement using concrete runway; d) concrete overlay on existing concrete pavement; e) asphalt overlay on existing concrete pavement; f) volumetric concrete (rapid set); and g) rubblization of existing concrete pavement and overlay with polymer modified hot mixed asphalt.

The Integrated Project Team (IPT) decided for full closure of the Shaybah Airport runway and to transfer all aviation operations to an alternative airport, to allow the full rehabilitation of the Shaybah runway. This option posed a reduced aviation operational safety risk for Shaybah community and Saudi Aramco Aviation operations.

The runway pavement rehabilitation demanded the closure of the old Shaybah airfield and utilization of a government airfield (Shabitah) located 1.5 hours driving distance from the Shaybah community. However, Shabitah airfield was shorter than the recommended operational requirements, which restricted its use during the hotter months. Therefore, the constructions work had to be completed during the few months where the temperature was below 30 - 35 °Celsius, from November to April. The above described constraints forced the project team to assess all possible scenarios and mitigate all risks, and to ensure the Shaybah rehabilitation works had to be completed between January and April 2019.

The rubblization of existing concrete pavement ended up as one of the most important decisions taken by the project during the scope definition phases. The process fully supported the execution schedule by rubblizing the full 112,000 square meter and 30 cm thick concrete in 10 days, with almost zero environmental waste and material disposal, and reduced the cost by to a third when compared with full reconstruction of a runway pavement.

Rubblization of concrete pavement – pre-assessment

Rubblization of concrete pavement was implemented for the first time at Saudi Aramco, after mitigating all the risks associated with the novelty construction technology, initial learning stage, lack of company standards, and ultimately the possible impact on construction schedule.
In the Kingdom of Saudi Arabia, rubblization of concrete pavement was previously implemented at the King Abdulaziz International Airport

(KAIA) in Jiddah. A site visit and interaction with the KAIA team took place to collect all the lessons learned from the sole previous in-Kingdom rubblization experience.

Furthermore, advanced and comprehensive site investigations and concrete evaluation testing were carried out in 2017 and 2018 to assess and conclude about the feasibility of the rubblization technique. Several workshops with a rubblization specialist – Antigo Construction, Inc.- and a long-term engineering agreement with Saudi Aramco CSD was put in place to ensure full support throughout all the project phases.

Rubblization of Concrete Pavement

Definition and Benefits

Rubblization is a process of breaking existing concrete pavement as per specific particle sizes, without damaging the pavement subgrade, by using heavy-duty equipment such as multihead breakers (Figure 3), hammer guillotines, and a Z grid roller. It is a process whereby the existing worn-out concrete pavement, which normally is only used as disposal material, is converted into a high-quality aggregate base, by breaking the concrete pavement into small pieces, thereby eliminating any slab action in the pavement and eliminating the reflective cracking in exiting concrete pavements. The slab action is eliminated by breaking the concrete pavement into small particles ranging from sand size to 75 mm (3 in) at the surface, 150 to 230 mm (6-9 in) on the top half, and 305 to 380 mm (12-15 in) at the bottom half of the concrete pavement layer. This rubblized base layer is the perfect starting point to build a perpetual asphalt pavement. More details can be found through references (1), (2), (3) and (4).

Compared to the re-construction of existing concrete pavement, the rubblization repair method is more cost effective (materials and transportation cost), much faster, more sustainable, requires negligible waste disposal, and has a lower risk of disturbing the existing subgrade of the repaired structure. Rubblization benefits and advantages are summarized below:

Figure 3: Multihead breaker and hammer guillotine in action at Shaybah Airport Runway.

- Rubblization extends the life of the pavement to a further 20 or 40 years based on the design criteria
- Elimination of concrete slab actions and reflection cracking
- Improvement in smoothness with the placement of hot mix asphalt as the new surface
- Elimination of alkali silica reactivity (ASR) and D-cracking problems with the existing concrete pavement
- Decrease in construction time relative to concrete pavement reconstruction, reduction in cost versus reconstruction of concrete pavement
- Improved maintenance of traffic and increase in service life of the asphalt overlay pavement, increasing the period required for preventive or corrective maintenance

Through the elimination of concrete slab actions and reflection cracking propagation, rubblization contributed to the mitigation of the initial root cause for the continuous deterioration of the old Shaybah Airport runway pavement.

Furthermore, the implementation of rubblization of concrete pavement is expected to result in less environmental impact when compared with other options. This is a process whereby the existing worn-out concrete pavement, which normally is only used as disposal material, is converted into a high-quality aggregate base. This offers a benefit in terms of environmental protection, cost benefits, and therefore the circular economy initiative and parameters.The reduced number of specialist suppliers worldwide is one of the bottlenecks for the implementation of rubblization of concrete pavements. Rubblization is a trial process and it requires site investigation and adjustments during the execution process.

Project Cost and Schedule Impact

During the study phases, Design Basis Scoping Paper (DBSP) and Project Proposal (PP) phases, the rehabilitation of Shaybah Airport using rubblization of concrete pavement and overlay with polymer modified hot mix asphalt was estimated to cost of one third to one half of the alternative of alternative options that entailed the full reconstruction of concrete pavement or expansion of existing runway pavement to allow partial rehabilitation. In addition, the full reconstruction of Shaybah Runway (or alternatively the expansion to allow partial rehabilitation) was estimated to be 24 months for the construction work, while the rehabilitation of Shaybah Airport using rubblization of concrete pavement and overlay with hot mix asphalt was estimated to be seven months.

The overall project cost saving (or cost avoidance) by selecting and successful implementing the rubbilization of runway pavement estimated was 25% of project budget (CAPEX), and resulted in operation cost (OPEX) reductions equivalent to 9% of project budget (related to the reduced costs for the leasing of an alternative airport runway). Refer to Table 1 for a CAPEX cost savings comparison.

Table 1: Cost comparison between full reconstruction of runway pavement and rehabilitation using the rubblization technique.

Using rubblization of concrete pavement for runway pavement rehabilitation	Full reconstruction of existing runway pavement
Construction related costs	
Rubblization execution costs – 112,000 m^2 or 35,000 m^3.	Concrete pavement dismantling, demolition and disposal, and transportation to an approved landfill – 35,000 m^3.
Rubblization testing and third-party quality control	Removal of loose sub-grade, disposal and transportation to an approved landfill – 20,000 m^3.
Additional aggregate material for shoulders enlargement – 8,800 m^3.	Additional aggregate material for new pavement and shoulders – 85,000 m^3.
Hot mix asphalt overlay costs – 30,000 m^3.	Hot mix asphalt overlay costs – 30,000 m^3.
Construction logistics and overhead costs	
Direct and indirect manpower for construction duration of four months – 350 manpower avg.	Direct and indirect manpower for construction duration of 12 months – 550 manpower avg.
Accommodations and services for four months	Accommodations and services for 12 months
Other indirect costs and logistics	Other indirect costs and logistics

Impact of Rubblization on the Circular Economy

Circular Economy – Definition

The Circular Economy initiative is sponsored by Saudi Aramco's executive management, and documented through the Circular Economy Process OE 5.4 Document Template (by Saudi Aramco's Operational Excellence Department). This initiative marks the transition from a linear business model of "take, make, dispose" to a circular framework where the design, production, distribution, use and consumption of materials are performed, to accomplish the following: a) Wastes are prevented, minimized, used as a resource, or recycled; b) product efficiencies and life cycles are maximized; c) energy production is shifted to be from renewable sources; and d) natural systems are regenerated. The Circular Economy Framework is supported by seven strategies (Figure 4).

Rubblization – also a Circular Economy testimony

Implementation of the rubblization of concrete pavement for the Shaybah Airport Runway upgrade, by utilizing wastes (rubblized concrete) as a raw material for rehabilitation of existing deteriorated concrete pavement, demonstrates adherence to the following circular economy strategies:

- Designing for the circular economy, "Designs employing recycled content in a product, includes utilizing byproducts or wastes as raw material."
- Improving environmental performance, by: "Facilitating the recovery of industrial waste and diverting it from landfills."
- Extending resource and asset life-cycles, by: "Extending assets and materials life cycles, by maximizing: 1. Reuse; 2. Repair; 3. Upgrade."
- Turning waste into resources, "Capturing opportunities to convert waste and byproducts of a system into secondary resources used as inputs for the same or another system, and minimizing waste throughout the processes."

Circular Economy Principle Strategies

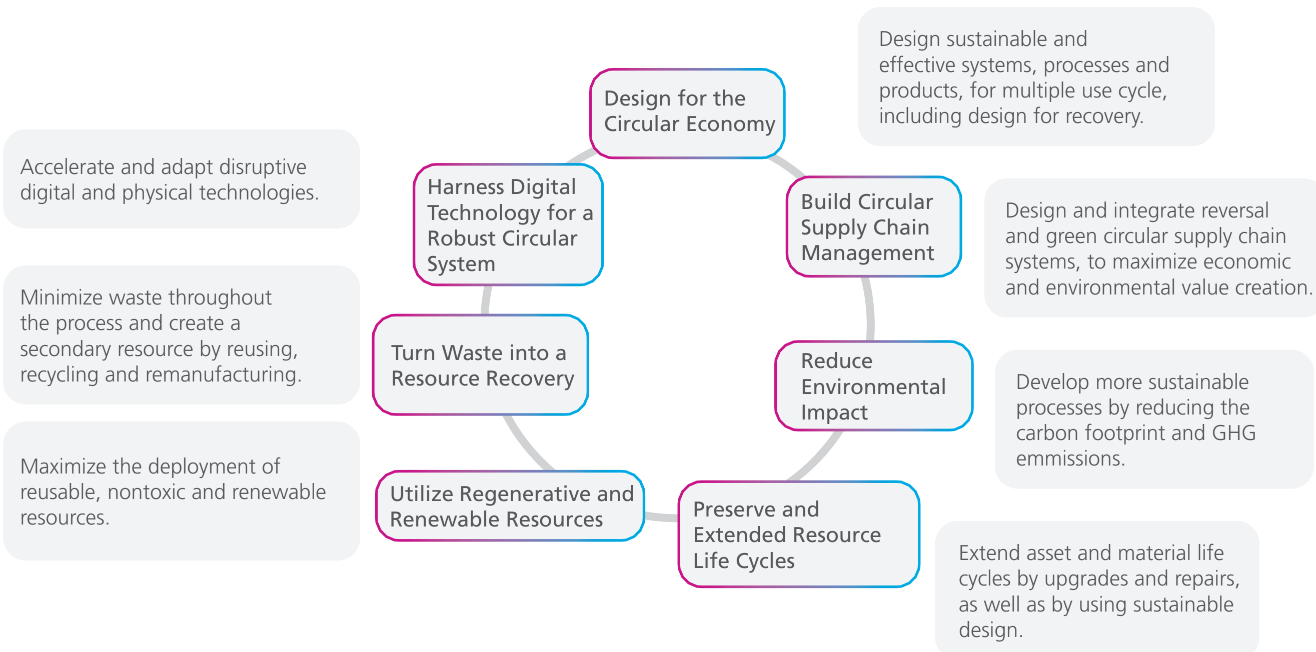

Figure 4: Circular Economy - 7 principal strategies.

The performance measurement of the circular economy implementation for the Shaybah Airport Runway Upgrade project has been fulfilled by many factors, including the cumulative cost saving, avoidance, and revenue generation. The cost savings due to implementation of this technology are estimated as 25% of the project budget (CAPEX), and have resulted in operation cost (OPEX) reductions equivalent to 9% of the project budget.

Rubblization of concrete pavement has been effectively implemented in Saudi Arabia. As an effective cost and schedule process, rubblization is a more sustainable technique that supports the Circular Economy Operational Excellence initiative.

References

1. Engineering Brief No. 66, Rubblized Portland Cement Concrete Base Course, Federal Aviation Administration (FAA), Airport Engineering Division, Circular AAS-100.

2. Antigo Construction Inc., https://www.antigoconstruction.com/rubblization (accessed 30th May 2021).

3. Resonant Machines, https://www.rubblization.com/rubblization-machine.html (accessed 30th May 2021)

4. Decker.D, Design and Construction Guidelines on Rubblizing and Overlaying PCC Pavements with Hot-Mix Asphalt.

Ranking Saudi Arabia's High Conservation Priority Bird Species

Biodiversity Protection Division, Environmental Protection

Approximately 500 bird species have been recorded in Saudi Arabia – but which of these is the most important?

This may seem like a strange question – after all, they are all important. Nonetheless, there's a need to prioritize which species require additional protection, which species should be the focus of special mitigation measures, and which species conservation agencies should spend their limited money on.

The reason why we need to ask these questions is as stark as it is simple: global biodiversity is experiencing an extinction rate a thousand times greater than the natural rate, thus heralding only the sixth mass extinction event in the long history of life on earth. Yet the resources currently made available for conservation are not sufficient to prevent the impending loss of much of the world's threatened biodiversity. Therefore, conservation agencies must prioritize which species receive active protection and which miss out—a concept known as conservation triage.

Identifying the High Conservation Priority Birds of Saudi Arabia

But how do conservation biologists, industries and land managers determine which species in the landscape should receive conservation priority?

Within Saudi Arabia, there have been limited attempts to prioritize our biota; and globally there is no standard method for ranking the conservation priority of a nation's plants and animals. So, it was decided to develop a species priority scoring system for Saudi Arabia, using birds as a case study.

National conservation prioritization systems often vary greatly in what attributes are used, scored and weighted. Most systems score species based on some measure of extinction risk plus other variables, such as cost effectiveness, likelihood of success, and cultural, economic or flagship value. It was decided to use only objective measures for which we have reasonably reliable data.

First, a list was compiled of all species that should be regarded as a high conservation priority. Specifically, they needed to meet one or more of the following criteria to be included in the list:

- Globally or regionally threatened (i.e., vulnerable, endangered, critically endangered, regionally extinct, or reintroduced), according to the International Union for the Conservation of Nature (IUCN).
- Regionally endemic (i.e., they occur entirely within the Arabian Peninsula), near endemic (more than 95% of their range occurs within the Arabian Peninsula), or contain regionally endemic subspecies.
- More than half of the global population lives in Saudi Arabia or migrates to or through Saudi Arabia at some stage in the year.

In short, if a species is endangered, or occurs only in Arabia, or more than half of the world's population occurs in Saudi Arabia, then they are of high conservation priority to the Kingdom.

In total, 102 out of Saudi Arabia's bird species met these criteria as being nationally a high conservation priority species.

Scoring the High Conservation Priority Birds of Saudi Arabia

The next step was to rank these 102 species in order of conservation priority. Ten attributes were considered to be of conservation importance; each one was scored out of 10 (Table 1). The scoring system prioritizes species that are of high conservation concern (Table 1).

The most important species for conservation would be a bird that is critically endangered and decreasing both globally and regionally, endemic to Saudi Arabia, but with a population of less than 10 birds, and is the only member of its genus and family. Such a species would score the maximum score of 100. Conversely, the best-case scenario (a species that is of least concern, increasing both globally and regionally, has more than 300,000 breeding pairs in the Kingdom, is not endemic to Arabia, comprises less than 1% of the global population, and is a member of a genus with dozens of species) would score 0.

Some of the attributes are obvious: for instance, a bird that is critically endangered globally should be considered of higher conservation priority than a bird that is listed as least concern by the (IUCN). Likewise, species with large populations in Saudi Arabia are obviously at a lower risk of becoming nationally extinct than birds that have very few birds in the Kingdom. So, a bird like the crested lark that has four million annual breeding pairs in Saudi Arabia scored 0 for this attribute; conversely, birds like the bearded vulture (which has not been recorded breeding in Saudi Arabia for years) scored 10. Similarly, birds like the hoopoe, that occur across a large percentage of Saudi Arabia, are less likely to go extinct nationally than a species that is confined to a small area (such as the Asir Magpie, which only occurs in a tiny patch of forest in the Asir highlands).

One interesting attribute is the level of evolutionary distinctness. The nontechnical explanation for this is simple: while any extinction is a tragedy, it would be particularly tragic to lose a species that is the only member of its family (such as the crab-plover, hypocolius or hamerkop, three wonderfully unique birds that live in Saudi Arabia and have no other living relatives anywhere on earth). More technically, evolutionary distinctness is a gauge of a species' isolation on its phylogenetic tree and thus a measure of its contribution to the total evolutionary history of its clade. This is important for conservation because the loss of a species in an old, monotypic or species-poor clade would result in a greater loss of biodiversity than that of a young species with many close relatives.

The 20 highest conservation priority bird species in Saudi Arabia are listed in Table 2. (The full list can be found online at https://www.ace-eco.org/vol15/iss2/art18/)

The Asir magpie was ranked as the bird of highest conservation priority within Saudi Arabia—by a considerable margin. Its high score is due to its endangered status (both globally and regionally), its small and decreasing population size (perhaps 100 pairs), tiny range (around 3,000 km2), and the fact that its global population occurs entirely within the Kingdom. The Asir magpie's ranking underlines the need to mount an urgent conservation program to protect and restore the species, which to date has received almost no specific conservation effort.

Table 1: Attributes used to score conservation priority for the birds of Saudi Arabia.

Attribute	Lowest conservation concern	Score	Highest conservation concern	Score
Global conservation status	Least Concern	0	Critically Endangered	10
Global population trend	Increasing	0	Decreasing	10
Regional conservation status	Least Concern	0	Critically Endangered	10
Regional population trend	Increasing	0	Decreasing	10
Number of breeding pairs	> 300,000	0	< 10	10
Nonbreeding abundance	Abundant	0	Possibly extinct	10
National distribution	> 10% of KSA	0	< 0.5% of KSA	10
% global population in KSA	< 1%	0	100	10
Level of endemicity	Widespread	0	Regional endemic	10
Evolutionary distinctness	> 20 species in the genus	0	Only species in the family	10
Overall score		**0**		**100**

The Asir Magpie is the Highest Conservation Priority bird in Saudi Arabia (Photo: Jem Babbington).

The ranking system also draws attention to the importance of Saudi Arabia to the conservation of the endangered Basra reed-warbler, which ranked second. More than 90% of the global population is likely to pass through the Kingdom each year; in addition, ten pairs breed along the Riyadh River (an artificial wetland). This species, as yet, has not received any conservation attention within Saudi Arabia. Four of the ten highest ranked species are in imminent danger of extinction within Saudi Arabia: Asir magpie (1), Asian houbara (6), Arabian bustard (9), and northern bald ibis (10)—indeed the latter two may already be nationally extinct, while the common ostrich (15) went extinct across Arabia in the 20th century, but has since been reintroduced into fenced reserves within the Kingdom. The scoring system identified many species that tend to be overlooked: of the 20 highest ranked species only the Asian houbara (6) has received any direct conservation attention within Saudi Arabia.

The scoring system also highlighted that some species often assumed to be of great importance do not rank as highly as one might expect. For example, the sooty falcon (12), which is not so well known amongst Arabian falconers, ranked as a much higher conservation priority than the revered saker falcon (40), lanner falcon (43) or peregrine falcon (96).

Table 2: The 20 highest conservation priority bird species in Saudi Arabia.

Rank	Species	Score	Rank	Species	Score
1	Asir magpie	87.8	11	Bearded vulture	51.7
2	Basra reed-warbler	62.0	12	Sooty falcon	51.5
3	Socotra cormorant	61.6	13	Crab-plover	51.0
4	Arabian woodpecker	60.8	14	Common ostrich	50.5
5	Yemen warbler	60.2	15	Lappet-faced vulture	49.7
6	Asian houbara	59.8	16	Arabian waxbill	49.6
7	Yemen thrush	59.0	17	Tawny eagle	48.7
8	Arabian grosbeak	58.8	18	Arabian lark	48.3
9	Arabian bustard	58.3	19	Cinereous bunting	47.5
10	Northern bald ibis	52.3	20	Philby's partridge	47.3

The Basra reed-warbler is usually overlooked within the Kingdom, but it is ranked as the second highest conservation priority bird in Saudi Arabia (Photo: Philip Roberts).

The famous Asian houbara bustard is ranked as the 6th highest conservation priority bird in Saudi Arabia. It has received more conservation attention than any other bird in Saudi Arabia (Photo: Chris Boland).

Mapping Saudi Arabia's high conservation priority birds

Environmental Protection worked with the Operational Excellence Department to map the distribution of all 102 high conservation priority bird species across Saudi Arabia (Figure 1). By overlaying each range map on top of one another, the team used ArcGIS to create a heat map showing the summed overall conservation priority scores for every point in the Kingdom. As shown in Figure 1, the areas of highest conservation priority for birds occur in the southwest of Saudi Arabia, particularly in the Asir Mountains, Asir foothills, Tihama coastal plains, and Red Sea coast. This has implications for Saudi Aramco – as a company that cares for biodiversity, we need to take extra precautions when operating in these high priority areas. This approach of summarizing conservation data enables complicated datasets to be accessible to our decision makers. This facilitates the company's protection of the environment, biodiversity and sensitive habitats in which it operates.

Further reading

The research was published in Avian Conservation and Evolution you should check it out – it's brilliant!

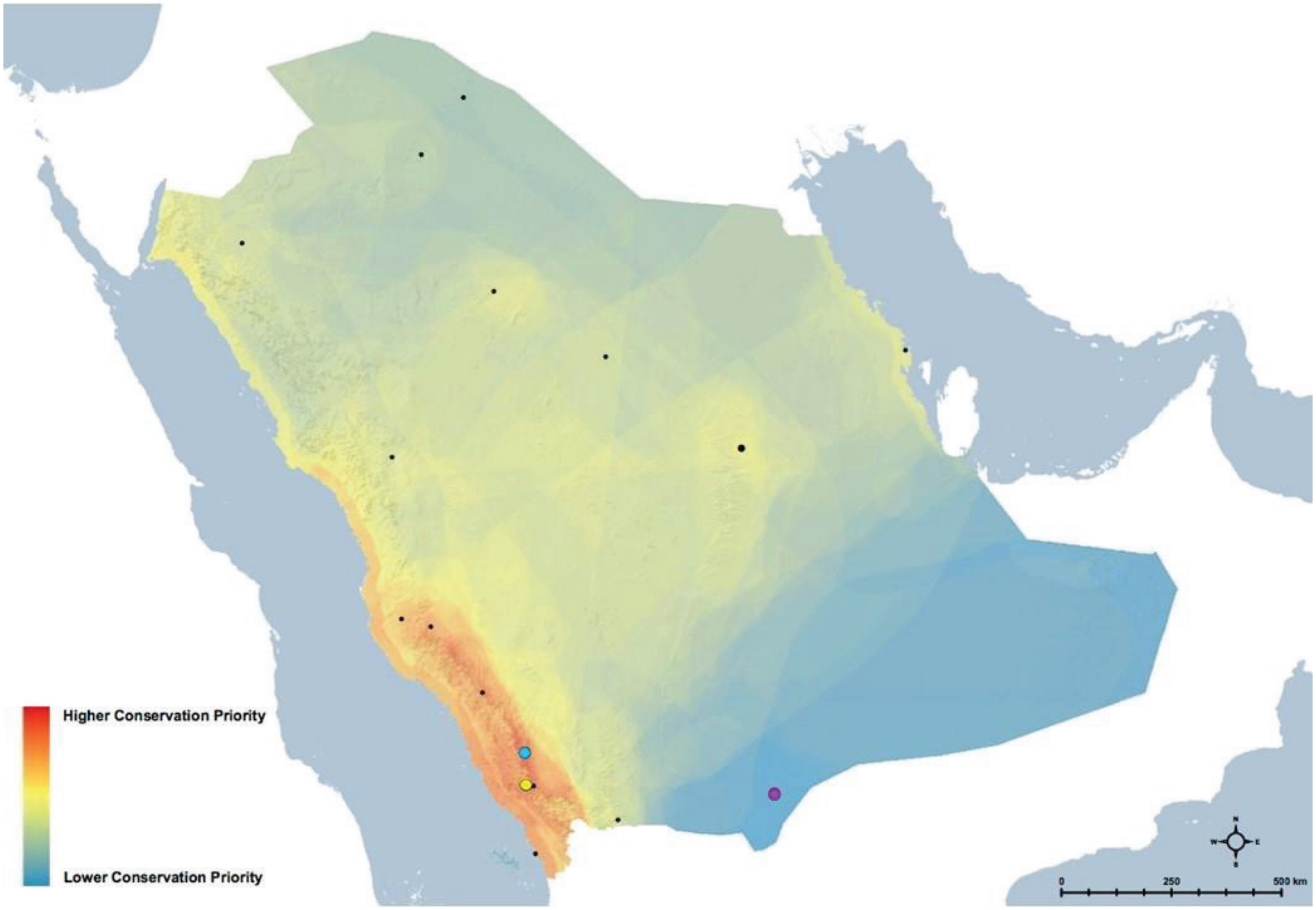

Figure 1: A heat map of the summed conservation scores for all high conservation priority bird species per location across Saudi Arabia. Locations with higher summed conservation priority scores are depicted in redder colors, whereas locations with lower scores are shown in bluer colors. The yellow dot denotes the individual point with the highest summed conservation priority score. The blue dot represents the 100- km² patch with the highest average summed conservation priority scores. The purple dot represents the point and the 100-km² patch with the lowest average summed conservation priority scores. Black dots represent provincial capitals (Map: EP & OED).

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Optimization of reverse osmosis multimedia filter backwashing, resulting in reduced ground water consumption

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Saudi Aramco is committed to the conservation of water resources to minimize pressure on water systems and to maximize availability for future generations. The company strives toward sustainable water resource usage through optimizing water consumption, minimizing water losses, maximizing water reuse, promoting use of alternative water resources, and the use of renewable energy for more sustainable water treatment and conveyance systems.

Further, the company is committed to protecting and restoring biodiversity and ecosystem services in operational areas. The company strives to achieve a net positive impact on biodiversity by restoring biodiversity and ecosystem services.

Abqaiq Plants is the largest oil and gas stabilization processing facility in the world as Abqaiq Plant produces 5% of the oil world production.

The oil and gas industry, as a whole, aims to play a major role in furthering initiatives for a more sustainable future sustainable future. In alignment with the oil industry's

role, the company ensures that it also has an important role to play to meet Saudi Arabia's objectives for a more sustainable future. As such, the company aims to identify initiatives that positively impact the environment and seeks change from a linear economy to a circular economy through innovative solutions. Abqaiq Plants is committed to using resources more efficiently to reduce impact on the environment and aligning itself with IPIECA oil and gas roadmap for delivery of the UN Sustainable Development Goals (SDG). This is evident in our plans to implement a number of environment-improving initiatives in our vast array of facilities.

Abqaiq Plants is committed to the conservation of water consumption to minimize the pressure on water resources, including groundwater, and maximize their availability for future generations. Examples of this include Southern Area Oil Operations (SAOO) adopting an initiative to utilize 1st pass RO reject water, which has a total dissolved solid (TDS), equal to 7,000 ppm, in the backwash of the multimedia filters (MMF) instead of using raw water. The result was groundwater savings of up to 34 MM gallons per year. This aligns the company operations with Saudi Arabia's vision to preserve the integrity of the environment and sustain its resources, especially, non-renewable ones.

Abqaiq Plants recognizes this initiative as a circular opportunity. By adopting the right design parameters, the company minimizes externalities by optimizing water usage, thereby minimizing ground water usage. The process keeps water resource in use and optimizes the value generated in interfaces of water systems with other systems. Diagram 1 references the Water and Circular Economy white paper by the Ellen MacArthur Foundation, and illustrates the general intent of Abqaiq Plants when designing or optimizing water systems.

There is a positive impact on water systems by enhancing circularity for water conservation and avoidance of depletion of aquifers. The initiative provides more lead time for aquifer replenishment. The conservation of water also reduces soil saturation, reduces waste water flow and pollution. SAOO has realized through this initiative that similar principles may be applied in other water systems to increase circularity of water. This is a paradigm shift, which is expected to have a positive impact on generations in the future in line with the Kingdom's Vision 2030.

One of the main elements to evaluate the enhancement results was to check and inspect the internal material for multimedia filters for any damage to the multimedia filter materials and its associated equipment (valves, pipe, XVs …).

During the turnaround and inspection, the condition of multimedia filters material, including internal materials, valves, pipes, backwash pump and XVs were evaluated and checked to pump, and ensure there is no damage.

This process improvement resulted in a tangible outcome. This initiative reduced Abqaiq Plants raw water consumption by 34 MM gallons annually, at the wastewater treatment plant, leading to reduced operation and maintenance cost.

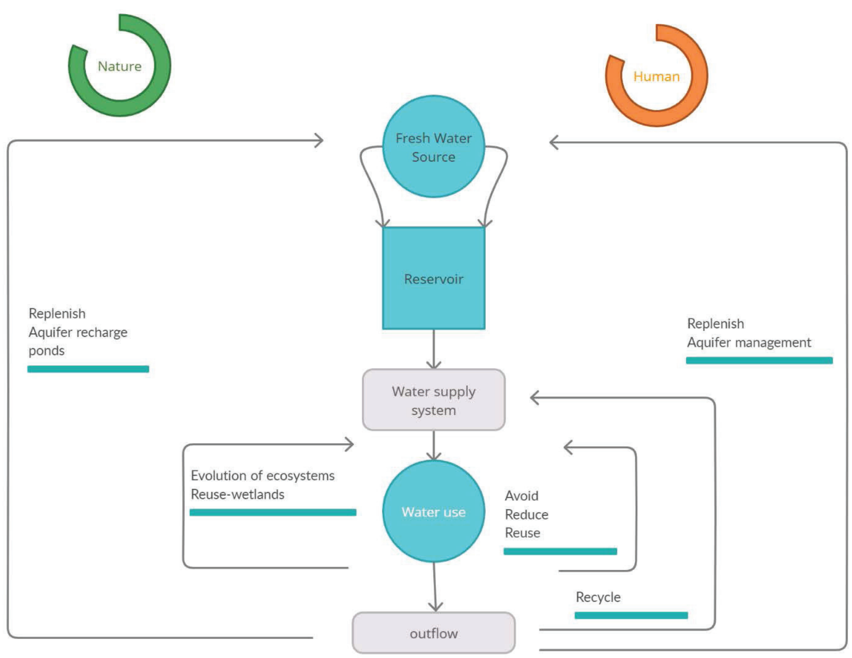
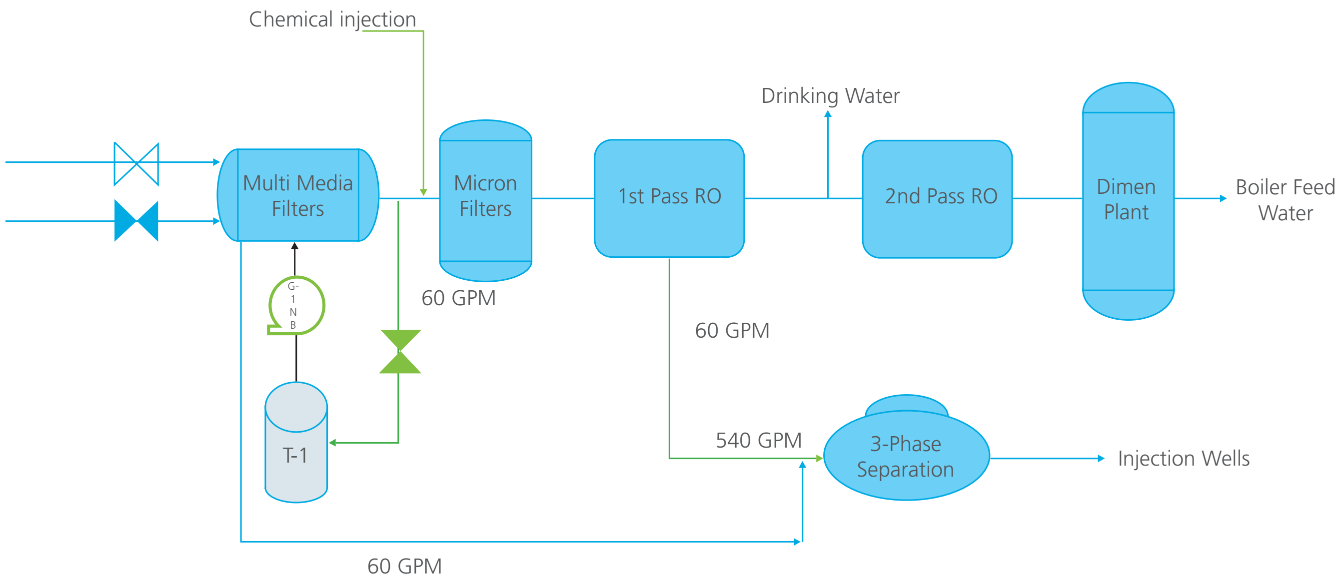


Diagram 1: Water and Circular Economy.

Before Implementation



After Implementation

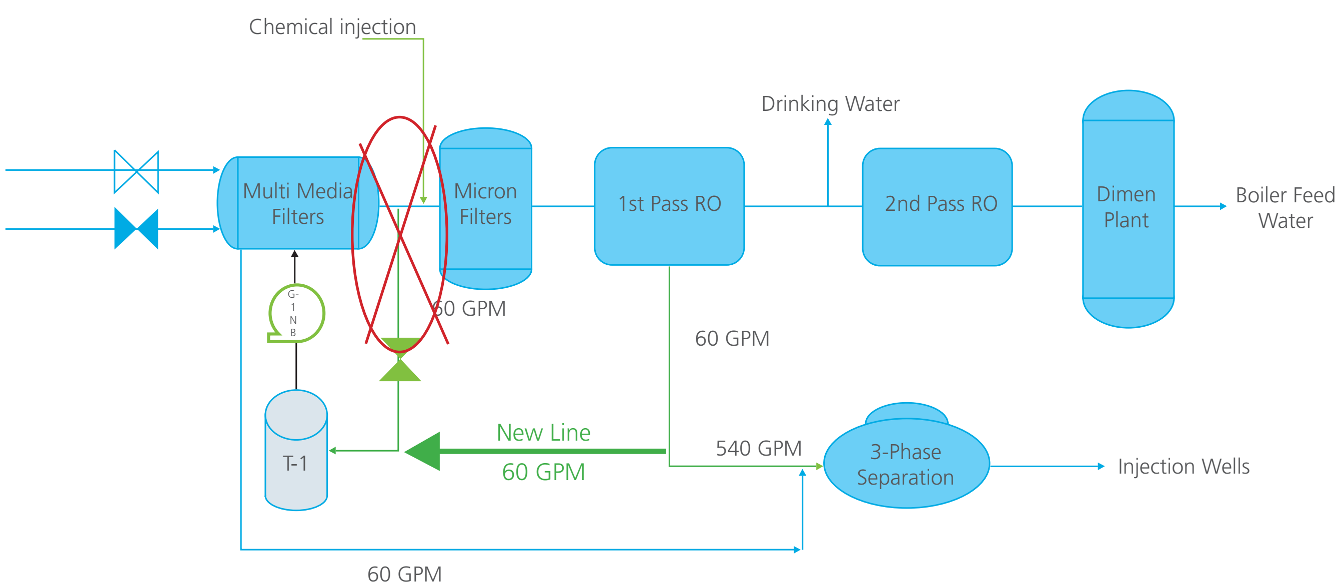


Diagram 2: Water treatment system flow diagram inside Abqaiq Plant (before and after).

Groundwater vulnerability and usage of Geographic Information System based assessment methods

Mohammed B. Al Rayaan, Rayan M. Al Nasser, and, Abdulmogni M. Althubiti

Abstract

An important concern in urbanization is the contamination of groundwater since remediation involves long-term, complicated processes. The groundwater vulnerability concept describes an aquifer's sensitivity to contamination and provides the basis for evaluation. In fact, groundwater vulnerability evaluation is the first step in pollution hazard assessment. This study focuses on evaluating the most popular methods used to assess groundwater vulnerability in addition to their GIS applications. Finally, the methods have been ranked based on their implementation applicability and accuracy. The five groundwater vulnerability assessment methods in this study are DRASTIC, GOD, AVI, SINTACS, and EPIK. A comparison between groundwater vulnerability methods shows that there are different parameters in each method; however, most of them use key hydrogeological parameters (e.g., hydraulic conductivity) and layer conditions. Moreover, the study demonstrated that integrating the groundwater vulnerability maps in all five methods with GIS applications is vital since all methods focus on overlaying several layers. Therefore, since updating databases for all layers is easier in GIS, a combination of various vulnerability parameters maps in GIS can easily be done through the map calculator feature in the GIS spatial analysis tool. Moreover, the graphical features of GIS and rapid visualization of the selected elements or attributes are considered additional advantages.

Keywords: Groundwater, GIS, Vulnerability, rating and index

Introduction

An important concern in urbanization is the contamination of groundwater since remediation involves long-term, complicated processes [1]. The groundwater vulnerability concept describes an aquifer's sensitivity to contamination and provides the basis for evaluation. There are various methods for assessing groundwater vulnerability; some of them describe the elements of the models [2], while others analyze the applications of the assessment techniques [3]. Moreover, the use of different tools such as GIS and spatial analysis has been considered in previous studies [4]. This study aims to assess the most popular methods used to evaluate groundwater vulnerability in addition to their GIS applications. Finally, the methods have been classified based on their implementation, applicability, and accuracy.

Literature review

Groundwater vulnerability

The term vulnerability explains the degree to which human activity or the environment is expected to experience damage due to stress and can cause a hazard or group of hazards for a determined organization [5]. The concept of groundwater vulnerability typically describes the ability of a specific aquifer to be contaminated and is implemented by categorizing a region based on its vulnerability to groundwater contamination [6]. Groundwater vulnerability provides the basis for evaluation of important aquifers and is the first step in pollution hazard assessment [4]. The assessment factors in groundwater vulnerability

An effective tool for assessing groundwater vulnerability is intrinsic vulnerability, which is based on innate features of a region such as hydrological, hydrogeological, and geological characteristics and is independent of specific contaminants [7]. A comprehensive groundwater vulnerability model must include factors to determine the contamination risk at a site and the risk of groundwater pollution from the contamination site [8]. The most important factors include lithology, depth to groundwater, net recharge, aquifer media, soil media, topography, vadose zone (unsaturated zone), hydraulic conductivity [4].

The assessment methods for groundwater vulnerability

For groundwater vulnerability assessment, intrinsic vulnerability that is based on the innate features of a region including hydrological, hydrogeological, and geological characteristics and is independent from the specific contaminants can be an effective tool, [7]. A comprehensive groundwater vulnerability model must include factors to determine the contamination risk at a site, and the risk of groundwater pollution from the contamination site, [8]. The most important factors include Lithology, Depth to groundwater, Net Recharge, Aquifer Media, Soil Media, Topography, vadose zone Unsaturated zone), Hydraulic Conductivity, [4].

The developed approaches for assessing groundwater vulnerability can be categorized into three areas as follows [4]:

- Index and overly methods
- Process-based simulation models
- Statistical methods

In index and overly methods, a vulnerability map based on the existing or predicted data will be provided for a region. The factors in the map are the parameters which control the movement of contaminants from the surface to the groundwater. The values or ranks of each parameter would be determined according to the importance of the parameters in pollutant circulation [4]. To assess groundwater vulnerability by index and overlay methods, there are several techniques. Among them is the DRASTIC method by Aller et al., 1987, which is widely used and is an index and overlay method. The implementation of the DRASTIC method is easy, and the results provide a good assessment tool in groundwater vulnerability evaluation [9]. The GOD method is the second popular method, which is an empirical method developed in the U.K. [10].10].

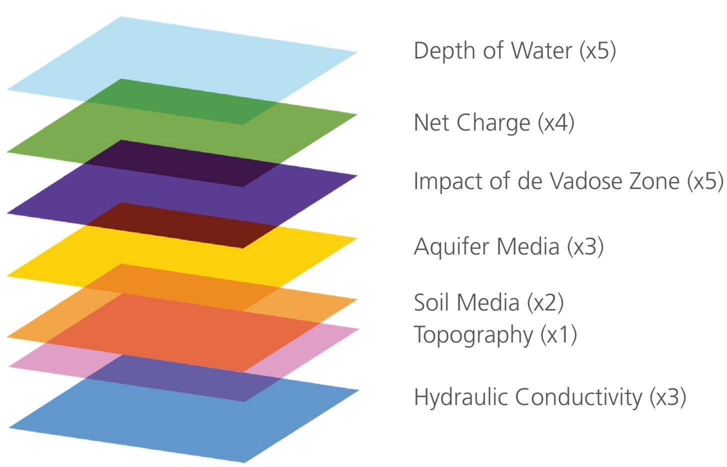


Figure 1: Overlaying of indicators in the DRASTIC method [4].

Application of GIS in groundwater vulnerability methods

To evaluate groundwater vulnerability, several approaches have been developed, and GIS and remote sensing have been used to provide the index maps in many studies [11, and 12]. To provide the contamination risk maps, certain operations are required in overly and index methods, and with GIS technology, adoption of groundwater vulnerability methods and providing the layers and maps is easier. The most popular index methods using GIS include DRASTIC, GOD, AVI, SINTACS, EPIK, the German method, and the Irish perspective as follows [4]. The layers in the DRASTC method are shown in Figure (1). It is clear that the scales of the data used to generate the vulnerability index map are different. The various maps need to be generated and the overlay of all indicator maps would provide the final index map [4].

Table 1: The selected methods for assessment of groundwater vulnerability.

Method	Date	Developer
DRASTIC	1987	Aller et al., [8]
GOD	1987	Foster, [10]
AVI	1993	Van Stempvoort et al., [13]
SINTACS	1993	Civita, [14]
EPIK	1999	Doerfliger, [15]

The main advantages of using GIS based methods [4]

- Ease of database updates for all layers.
- Consolidation of various maps in GIS can easily be done through the map calculator from the spatial analysis tool.
- GIS graphical advantages and rapid visualization of the selected elements or attributes

Methodology

The methodology is based on an analysis of the assessment methods for groundwater vulnerability. In this regard, after describing the most important methods and their elements, the use of GIS has been analyzed. Moreover, the advantages and disadvantages of the methods have been determined. The selected methods are presented in Table (1).

Table 2: Attribution of parameters in the DRASTIC method [8].

Range	Rating		Range	Rating		Range	Rating	
Confining Layer	1	Vadose Zone Material	0-1.5	10	Depth to Water	0.04-4.1	1	Conductivity (m/d)
Silt/Clay	3		1.5-4.5	9		4.1-12.3	2	
Shale	3		4.5-9	7		12.3-28.7	4	
Limestone	3		9-15	5		28.7-41	6	
Sandstone	6		15-22	3		41-82	8	
Bedded Limestone, Sandstone	6		22-30	2		>82	10	
Sand and Gravel W.silt	6		>30.4	1		0-2	10	Topography (Slope %)
Sand and Gravel	8		Thin or Absent	10	Soil Media	2-6	9	
Basalt	9		Gravel	10		6-12	5	
Massive Shale	2	Aquifer Media	Sand	9		12-18	3	
Meramorphic/Igneous	3		Peat	8		>18	1	
Weathered Meramorphic Igneous	4		Shrinking Clay	7		0-50	1	Recharge (mm)
Glacial Till	5		Sandy Loam	6		50-100	3	
Bedded Sandstone, Limestone	6		Loam	5		100-175	6	
Massive Sandstone	6		Silty Loam	4		175-225	8	
Massive Limestone	8		Clay Loam	3		>225	9	
Sand and Gravel	8		Muck	2				
Basalt	9							
Karst Limestone	10		No shrinking Clay	1				

Results and discussion

In this section, the different groundwater vulnerability GIS-based methods have been analyzed. DRASTIC method and equation based on 7 parameters, [16]

DRASTIC method and equation based on 7 parameters, [16]:

DRASTIC index = Dp×Dc + Rp×Rc + Ap×Ac+ Sp×Sc + Tp×Tc + Ip×Ic+ Cp×Cc D: Depth to groundwater;

R: Recharge; A: Aquifer Media;

S: Soil Media; T: Topography;

I: Impact of vadose zone (Unsaturated zone); C: Conductivity.

The attributes of the parameters are presented in Table (2).

GOD method and equation based on three parameters, [10]:

IGOD = Ci×Ca×Cp

Ci: Aquifer type;

Cp: Depth to groundwater; Ca: Lithology type.

The attributes of the parameters are presented in Table (3).

AVI method and equation based on three parameters, [17]:

The method is based on two parameters, including the thickness (d) of each sedimentary layer in the unsaturated zone and hydraulic conductivity (K). The AVI index can be calculated by the relationship between the hydraulic resistance and the aquifer vulnerability index (AVI) as presented in Table (4).
The hydraulic resistance c = ∑d/K

SINTACS method and equation based on three parameters, [18]:

SINTACS Intrinsic Vulnerability Index (SIVI) $=\sum_{i=1}^{7}$ Pi x Wi

Table 3: Attribution of parameters in GOD method [10].

Range	Rating		Range	Rating		Range	Rating	
None aquifer	0	Aquifer type C_i	<2	1	Depth to C_a (m)	Residual Soil	0.4	Lithology type C_a
Artesian	0.1		2-5	0.9		Limon alluvial; Loess; Tufa; Igneous rock	05	
Confined	0.2		5-10	0.8		Aeolian Sand; Siltite; Tufa; Igneous rock	0.6	
Semi-confined	0.3		10-20	0.7		Sand and gravel; Sandstone; Tufa	0.7	
Free with Cover	0.4-0.6		20-50	0.6		Gravel	0.8	
Free with Cover	0.7-1		50-100 >100	0.5 0.4		Limestone Fractured or karstic Limestone	0.9 1	

Table 4: Relationship between AVI and Hydraulic Resistance [13].

Hydraulic resistance (c)	Log(c)	Culnerability
0-10	<1	Extremely high
10-100 100-1000	1-2 2-3	High Moderate/Medeium
1,000-10,000	3-4	Low
>10,000	>4	Extremely low

Table 5: SINTACS rating and weighting values [14].

Water table depth (m)		Effective infiltration (mm)		Aquifer media		Soil Media		Topo-graphy (% slope)		Unsaurated zone		Hydraulic conduct-ivity (m/day)	
Inter-val	R	Inter-val	R	Perme-ability Class	R	Pedologic Classes	R	Inter-val	R	Classes	R	Inte-rval	R
2.60-4.57	9	0-50.8	1	Gneiss	4	Sandy loam	6	0-2	10	Confining layer	1	0.45-4.89	1
4.57-6.50	7	50.8-101.6	3	Sand-stone	3	Clay loam	3	2-6	9	Silt/clay	3	4.89-8.3	2
		101.6-103.12	6			Non shrinking	1	>18	1	Sandstone	6		
										Sand and gravel	8		
Weight	5	Weight	4	Weight	3	Weight	4	Weight	2	Weight	5	Weight	3

Pi : the rating of each of the seven parameters;

Wi : the relative weight, (high, moderate, low and very low)

SINTACS specific vulnerability index (SSVI) =SIVI+AIr ×AIw

AI: the anthropogenic parameter

subscripts r and w: the corresponding rating and weight

EPIK method and equation based on three parameters, [19]:

Protection factor Fp= 3E+1P+3I+2K

E (Epikarst): the surface and subsurface karstic features; P (Protective cover): the soil thickness;

I (Infiltration): the relation among slope and different land use patterns; K (Karst): the develop degree of the karst network

The comparison among the methods and use of GIS:

The comparison between the methods and usage of GIS is presented in Table (7). The analysis shows that in providing the groundwater vulnerability maps in all five methods, the use of GIS is vital since all are based on the overlanding of several layers.

Conclusion

The comparison of groundwater vulnerability methods shows that there are different parameters in each method. However, most of them use hydraulic conductivity and layer condition. The analysis also shows that in providing the groundwater vulnerability maps in all five methods, the use of GIS is vital since all methods are based on the overlay of several layers. Therefore, since the combining of various maps in GIS can be easily done through the map calculator from the spatial analysis tool, it can be useful in the methods described in this article.

Table 6: EPIK Vulnerability Classes.

Protection Factor (Fp)	Vulnerability Class
Fp < or = 19	Very high
Fp = 20 - 25	High
Fp > 25	Moderate
Presence of P4	Low

Table (7): The comparison among the methods and usage of GIS.

Method	Number of assessments parameters	Usage of GIS	Method of producing final map
DRASTIC	7	√	Index and overly
GOD	3	√	
AVI	2	√	
SINTACS	7	√	
EPIK	4	√	

Moreover, the graphical features of GIS and rapid visualization of the selected elements or attributes are additional advantages. In conclusion, the analysis shows that the selection of the method is based on the available data and the size and type of the soil layer in the region. Also, the role of GIS in making vulnerability maps for all methods can make the analysis easier.

References

1. Foster, S.S.D., Chilton, P.J., (2003), Groundwater: the processes and global significance of aquifer degradation. Philos Trans R Soc Lond B 2003; Vol. 358: pp 1957–72.

2. Thapinta, A. Hudak, P.F., (2003), Use of geographic information systems for assessing groundwater pollution potential by pesticides in central Thailand. Environment International, Vol. 29, pp 87-93.

3. Abdeslam, I., Fehdi, C., Djabri, L., (2017), Application of drastic method for determining the vulnerability of an alluvial aquifer: Morsott - El Aouinet north east of Algeria: using ArcGis environment, Energy Procedia, Vol. 119, pp 308-317

4. Oroji, B., (2018), Groundwater vulnerability assessment using GIS-based DRASTIC and GOD in the Asadabad plain, J. Mater. Environ. Sci., Vol. 9, Issue 6, pp 1809-1816.

5. Popescu, I.C., Gardin, N.N., Brouye're, S., Dassargues, A., (2008), Groundwater vulnerability assessment using physically based modeling: from challenges to pragmatic solution. Proceedings of the 6th International Conference on Calibration and Reliability in Groundwater Modeling: Credibility in Modelling, Copenhagen, Sep. 9-13, pp 83-88.

6. Vrba, J. Zaporozec, A., (1994), Guidebook on Mapping Groundwater Vulnerability. International Association of Hydrogeologists, International Contributions to Hydrogeology, 16, 131 p.

7. Zwahlen, F., (2004), Vulnerability

and risk mapping for the protection of carbonate (karst) aquifers, final report (COST action 620). European Commission, Directorate XII Science, Research and Development, Report EUR 20912, Brussels; 2004. 297 pp.

8. Aller, L., Bennet, T., Lehr, J. H. & Petty, R. J. (1987), DRASTIC: A standardized system for evaluating groundwater pollution potential using hydrogeologic settings. US Environ. Protection Agency EPA/600/2-85-018.

9. Baalousha, H., (2010). Assessment of a groundwater quality monitoring network using vulnerability mapping and geostatistics: a case study from Heretaunga Plains, New Zealand. Agric Water Manage, Vol. 97: pp 240-246.

10. Foster, S.S.D., (1987), Fundamental concepts in aquifer vulnerability, pollution risk and protection strategy. In: van Duijvenbooden, W. and van Waegeningh, H.G. (eds.), TNO Committee on Hydrological Research, the Hague. Vulnerability of Soil and Groundwater to Pollutants, Proceedings and Information, Vol. 38, pp 69-86.

11. Adnan, S., Iqbal, J., Maltamo, M., Valbuena, R., (2018), GIS-based DRASTIC model for groundwater vulnerability and pollution risk assessment in the Peshawar District, Pakistan, Arabian Journal of Geosciences, Vol. 11: 458.

12. Al-Abadi, A.M., Al-Shamma'a, A.M., Aljabbari, M.H., (2017), A GIS-based DRASTIC model for assessing intrinsic groundwater vulnerability in northeastern missan governorate, southern Iraq. Applied Water Science, Vol. 7, pp 89-101.

13. Van Stempvoort, D., Ewert, D., Wassenaar, L., (1993), Aquifer vulnerability index: a GIS compatible method for groundwater vulnerability mapping. Canadian Water Resources Journal, Vol. 18, pp 25-37.

14. Civita, M., (1993), Groundwater vulnerability maps: a review. In Proceedings of the IX symposium on pesticide chemistry, mobility and degradation of xenobiotics, 11–13 October, Italy, pp 587-631.

15. Doerfliger, N., Jeannin, P.Y., Zwahlen, F., (1999), Water vulnerability assessment in karst environments: a new method of defining protection areas using a multi-attribute approach and GIS tools (EPIK method). Environment Geology, Vol. 39, pp 165–175.

16. Saidi, S., Bouri, S., Ben Dhi, H., (2011), Sensitivity analysis in groundwater vulnerability assessment based on GIS in the Mahdia-Ksour Essaf aquifer, Tunisia: a validation study, Hydrol. Sci. J. Vol, 56(2), pp 288-304

17. Putranto, T.T., Santi, N., Widiarso, D.A., Pamungkas, D., (2018), Application of Aquifer Vulnerability Index (AVI) method to assess groundwater vulnerability to contamination in Semarang urban area, MATEC Web of Conferences, 159. https://doi.org/10.1051/matecconf/201815901036

18. Kumar, S., Thirumalaivasan, D., Radhakrishnan, N., Mathew, S., (2013), Groundwater vulnerability assessment using SINTACS model, Geomatics, Natural Hazards and Risk, Vol, 4(4), pp 339-354, DOI: 10.1080/19475705.2012.732119

19. Awawdeh M., Nawafleh A., (2008), GIS-based EPIK Model for Assessing Aquifer Vulnerability in Irbid Governorate, North Jordan, Jordan Journal of Civil Engineering, Vol. 2, (3), pp 267-278

Evaluation of sound level meters and smartphone applications as a monitoring tool for measuring environmental noise.

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Yousef Reshaidan, Abdullah S. Alsubaie, Environmental Protection**

Background

Noise can be described as "unwanted sounds," while sound is a term used to describe the sensation the brain experiences when the ear senses pressure changes in the air. An example is environmental noise (also known as community noise and noise pollution), which can be defined as noise emitted from all sources except industrial workplaces (WHO, 2011; IOSH, 2018). It is a global occupational health hazard with notable social and physiological impacts. Excessive noise can seriously affect people's health and daily activities at home, work, school as well as during leisure time. It is a pervasive environmental pollutant that can lead to various adverse effects including disturbance of rest and sleep, interference with speech communication and intended activities, effects on performance, behavior, mental-health as well as psycho-physiological effects. Along with being the key causative environmental agent for sensorineural hearing loss, noise has also been linked with an increased prevalence of cardiovascular disease (e.g., myocardial infarction) and hypertension (Girard et al., 2009; Basner et al., 2014; Kerns et al., 2018).

Worldwide, as reported by the WHO (2011, 2020), noise-induced hearing impairment is the most prevalent irreversible occupational hazard, and it is estimated that 466 million people have disabling hearing loss. Hence, there is an increase in monitoring of noise exposure mandated by occupational health and safety regulations worldwide, in order to assess and control noise levels and protect public health.

Smartphone Applications

Although traditional sound level meters (SLMs) are deemed effective in providing accurate, objective means for assessing noise levels, they can be expensive, particularly for small businesses, and require calibration and maintenance. Such factors may limit the feasibility of monitoring noise and thus constitute an obstacle to conducting noise risk assessments. A recent breakthrough in smartphone technology is use of noise measurement applications (apps). The inclusion of noise measuring apps within smartphones bestows. A number of benefits such as portability, ease of use, as well as low cost. Additionally, the ubiquity of smartphones allows such apps to extend the scope of people being able to measure noise levels.

The effectiveness of noise measuring apps and their capability of replacing traditional SLMs have only recently begun to receive some attention in academic literature. Several research studies have investigated the precision and accuracy of smart devices (e.g., phones and tablets) and suggested that smartphones are capable of replacing SLMs in the near future. In 2014, Kardous and Shaw reported, after testing 4 Android and 10 iOS apps, that certain iOS apps made measurements within 2.0 dB(A) of a Type 1 microphone. In 2016, another study assessed the three most accurate iOS apps that were reported by Kardous and Shaw when paired with commercially available, inexpensive, external microphones (Roberts, Kardous and Neitzel, 2016). The results revealed that the apps made measurements within 1.0 dB(A) of a Type 1 SLM, which indicates that, in some cases, smartphones can measure noise levels as accurately as traditional SLMs. Additionally, King and Murphy (2016), who have tested over 100 models of smartphones, asserted that iOS apps were superior to Android apps, and certain iOS apps measured noise levels within 1.0 dB(A) of an ANSI Type 1 SLM. In 2016, another extended study by Kardous and Shaw highlighted that the gap between smartphone-based apps and professional instruments was swiftly narrowing, which concurred with the findings of Roberts et al. (2016). Moreover, Roberts and Neitzel (2017) field-tested Apple iPods and reported that iPods made reasonably accurate noise measurements in the workplace, on average, 1.7 dB(A) higher than measurements made by the dosimeter.

Recently, the National Institute for Occupational Safety and Health (NIOSH) released the NIOSH SLM app, which has a tested and validated accuracy of ± 2.0 dB(A) of an ANSI Type 1 SLM when calibrated and fitted with a calibrated external microphone (CDC, 2019). In 2020, Jacobs et al., systematically compared measurements made by a traditional SLM to measurements by the NIOSH app in five different environments in order to assess the accuracy of the app. The mean difference of the apps' measurements, without calibration or an external microphone, was less than 2.0 dB(A) in three locations. The findings indicated that, in some settings, the app can be an effective monitoring instrument, particularly when noise levels are stable and exceed 75 dB(A). Such findings are particularly timely as wearables (e.g., watches and fitness bands) start utilizing internal microphones to measure noise levels.

In-House Testing

To further assess the accuracy and validity of smartphone technology, EP professionals conducted a series of noise measurements using both a traditional SLM (Brüel & Kjær Type 2250 Light) and smartphone apps. Noise levels were measured in laboratory and industrial settings in order to evaluate the effectiveness of smartphone apps in both environments. A total of three different apps were utilized in three different smartphone devices, Galaxy S10+ and iPhone 7 and 12. The results varied between the used apps and SLM. Notably, the noise measurements obtained using iPhone (iOS apps) were reasonably accurate and closer to those obtained by traditional SLM in all tested environments. The difference between iPhone 7 and 12 was insignificant (i.e., 1dB(A)). This indicates that iPhone devices (i.e., iOS) can give more reliable noise measurements, which is consistent with the findings of King and Murphy (2016). On the other hand, the difference for the Galaxy device (Android apps) from the SLM was quite significant (i.e., 6dB(A)), as illustrated in Figures 1 and 2 below. Additionally, the tests showed that the NIOSH SLM app reported valid and consistent results, which is in agreement with the findings of Jacobs et al. (2020).

Figure 1: Industrial environment. (galaxy: 83dB(A), SLM: 78.2dB(A), Iphone:81dB(A)).

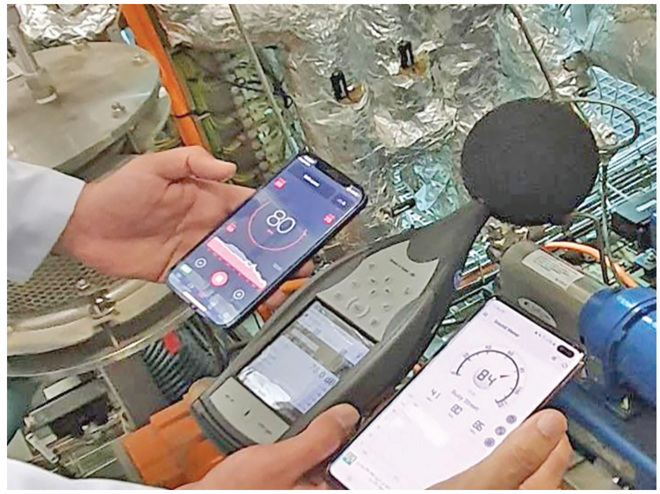

Figure 2: Pilot plant. (Iphone:80dB(A), SLM: 78dB(A) galaxy: 84dB(A)).

Figure 3: EP professionals at a pilot plant

Figure 4: EP professionals at a laboratory

Recommendations

As the findings of the experiment were limited to the number of tested locations and used smart devices, it may not be prudent to make recommendations for public health practitioners solely on the basis of these findings. However, considering the aspects presented in this article, the following recommendations can be made:

- Reliance on smartphone devices to get accurate and precise measurements of noise levels is not recommended, particularly in industrial settings.
- Smartphone devices can be used to get an approximate estimate of noise levels in most environments where noise levels are stable and exceed 75 dB(A).
- NIOSH SLM app can be used as an effective screening tool in certain settings as it gave reasonably more accurate noise measurements in comparison to other noise measuring apps, when using mobile device's built-in microphone.
- Usage of external, calibrated microphones can increase the accuracy and effectiveness of noise measurement applications on smartphones (e.g. NIOSH external microphone).

References

1. Basner, M., Babisch, W., Davis, A., Brink, M., Clark, C., Janssen, S. and Stansfeld, S. (2014) Auditory and non-auditory effects of noise on health. The Lancet (British Edition) [online], 383(9925), 1325-1332. Available at: https://www.sciencedirect.com/science/article/pii/S014067361361613X#:~:text=%20Auditory%20and%20non-auditory%20effects%20of%20noise%20on,The%20most%20investigated%20non-auditory%20health%20endpoints...%20More%20 [Accessed: 22nd

November 2020]

2. Celestina, M., Hrovat, J. and Kardous, C. (2018) Smartphone-based sound level measurement apps: Evaluation of compliance with international sound level meter standards. Applied Acoustics [online], 139, 119-128. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0003682X17309945 [Accessed: 22nd November 2020]

3. Celestina, M., Kardous, C. and Trost, A. (2021) Smartphone-based sound level measurement apps: Evaluation of directional response. Applied Acoustics [online], 171, Applied acoustics, 2021-01-01, Vol.171. Available at: https://www.sciencedirect.com/science/article/pii/S0003682X20307775 [Accessed: 22nd November 2020]

4. Centers for Disease Control and Prevention (CDC) (2019) Noise and Hearing Loss Prevention [online]. Available at: https://www.cdc.gov/niosh/topics/noise/app.html [Accessed: 28th November 2020]

5. Crossley, E., Biggs, T., Brown, P. and Singh, T. (2020) The Accuracy of iPhone Application to Monitor Environmental Noise Levels. The Laryngoscope: the American Laryngological, Rhinological and Otological Society, Inc. [online]. Available at: https://www.researchgate.net/publication/339566256_The_Accuracy_of_iPhone_Applications_to_Monitor_Environmental_Noise_Levels [Accessed: 22nd November 2020]

6. Girard, S. A., Picard, M., Davis, A. C., Simard, M., Larocque, R., Leroux, T. and Turcotte, F. (2009) Multiple work-related accidents: Tracing the role of hearing status and noise exposure. Occupational and Environmental Medicine (London, England) [online], 66(5), 319-324. Available at: https://oem.bmj.com/content/66/5/319 [Accessed: 22nd November 2020]

7. Ibekwe, T., Folorunsho, D., Dahilo, E., Gbujie, I., Nwegbu, M. and Nwaorgu, O. (2016) Evaluation of mobile smartphones app as a screening tool for environmental noise monitoring. Journal of Occupational and Environmental Hygiene [online], 13(2), D31-D36. Available at: https://www.tandfonline.com/doi/abs/10.1080/15459624.2015.1093134 [Accessed: 22nd November 2020]

8. Institution of Occupational Safety and Health (IOSH) (2018) Noise [online]. Available at: https://iosh.com/resources-and-research/our-resources/occupational-health-toolkit/noise/ [Accessed: 22nd November 2020]

9. Jacobs, N., Roberts, B., Reamer, H., Mathis, C., Gaffney, S. and Neitzel, R. (2020) Noise exposures in different community settings measured by traditional dosimeter and smartphone app. Applied Acoustics [online], 167, 107408. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0003682X20305120 [Accessed: 22nd November 2020]

10. Kerns, E., Masterson, E. A., Themann, C. L. and Calvert, G. M. (2018) Cardiovascular conditions, hearing difficulty, and occupational noise exposure within US industries and occupations. American Journal of Industrial Medicine [online], 61(6), 477-491. Available at: https://onlinelibrary.wiley.com/doi/abs/10.1002/ajim.22833 [Accessed: 22nd November 2020]

11. King, E. and Murphy, E. (2016) Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise. Applied Acoustics [online], 106, 16-22. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0003682X15003667 [Accessed: 28th November 2020]

12. Murphy, E. and King, E. (2016) Testing the accuracy of smartphones and sound level meter applications for measuring environmental noise. Applied Acoustics [online], 106, 16-22. Available at: https://www.sciencedirect.com/science/article/abs/pii/S0003682X15003667 [Accessed: 22nd November 2020]

13. Roberts, B. and Neitzel, R. L. (2017) Using smart devices to measure intermittent noise in the workplace. Noise Health [online], 19, pp. 58-64. Available at: https://pubmed.ncbi.nlm.nih.gov/29192614/ [Accessed: 28th November 2020]

14. Roberts, B., Kardous, C. and Neitzel, R. (2016) Improving the accuracy of smart devices to measure noise exposure. Journal of Occupational and Environmental Hygiene [online], 13(11), 840-846. Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5017896/ [Accessed: 22nd November 2020]

15. World Health Organization (WHO) (1999) Guidelines for Community Noise [online]. Available at: https://www.who.int/docstore/peh/noise/Comnoise-1.pdf [Accessed: 22nd November 2020]

16. World Health Organization (WHO) (2011) Burden of Disease from Environmental Noise: Quantification of Healthy Life years lost in Europe [online]. Available at: https://www.who.int/quantifying_ehimpacts/publications/e94888.pdf [Accessed: 22nd November 2020]

17. World Health Organization (WHO) (2018) Environmental Noise Guidelines for the European Region [online]. Available at: https://www.euro.who.int/__data/assets/pdf_file/0008/383921/noise-guidelines-eng.pdf [Accessed: 22nd November 2020]

18. World Health Organization (WHO) (2020) Deafness and Hearing Loss [online]. Available at: https://www.who.int/en/news-room/fact-sheets/detail/deafness-and-hearing-loss [Accessed: 22nd November 2020]

Occupational Health Within Saudi Aramco

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Occupational Health (OH) is about the interaction between health and work. It has been an integral part of Saudi Aramco's (SAO) responsibility to protect the health and well-being of its most valuable asset, its workforce.

Until recently, all OH services were provided by JHAH – a third-party service provider. There have been concerted efforts to restore critical OH functions within the company aligning with international peers. Now Environmental Protection's Occupational Health Group (OHG) is an in-house entity that collaborates with external medical service providers (e.g., JHAH and BUPA) to oversee occupational health and wellbeing matters. OHG's functions are governed by the Health Protection Policy (CP-43), GI 150.110 (Occupational Health Functions of Saudi Aramco), and GI 151.005 (Occupational Health/Medical Assessment Referral Process).

The OHG aims to help the company evaluate health risks to its workforce and maintain corporate health protection programs and standards. External medical providers, such as JHAH and BUPA, will continue to provide OH-related clinical assessments based on guidelines set by the OHG. Some of the OHG services include:

- Develop and revise SAO OH standards
- Provide consultation and guidance to third-party providers
- Conduct quality reviews of OH third-party providers
- Consult on work-related health, injuries & illnesses
- Conduct Direct Hire, Non-Employees programs (CDPNE, APNE, VCGNE, etc.) Fitness for Duties, M-time, Chapter 8 and 14 - for Western and Central regions
- Consult on requests such as occupational vaccinations and health surveillance for the workforce
- Provide health promotion interventions

The spectrum of OHG is expected to expand in the coming months and years as it strives to attain excellence in occupational health and well-being through delivering OH programs, promoting best practices, and leveraging innovation.

For any queries, you may reach out to OHG on the email: occupational.health@aramco.com

Food Safety and Food Poisoning: A Brief Snapshot

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What is food safety and why is it important?

Food is an indispensable part of people's lives as it provides them with the energy and nutrients to grow, develop, perform and maintain daily life activities and survive. Until the twentieth century, the process of obtaining food in most countries was highly localized. However, the rapid expansion and development of technology and science stretched the scope of food production, distribution and transportation systems from national to international. The contemporary food system extends from producers to consumers, which makes the process of ensuring its safety and nutritional sufficiency more complex, demanding considerable efforts from food business operators as well as the government. Although food businesses bear moral obligations to provide safe food for consumers, many focus more on maximizing their profits and neglect the financial impacts of poor hygiene and potential food poisoning. These costs, financial and social, affect both employers and employees, as they have led many businesses to close down, and have significant impacts on those people who may become ill (Sprenger, 2017).

Food safety is a wide spectrum of standard practices that primarily aim to promote and protect public health. Food safety is an imperative health, economic and social issue. It has become a major global concern for decades as the devastating public health impacts of food-related illnesses have been increasing, leading to higher rates of morbidity. According to the Department of Health (2010), food poisoning, also known as foodborne illness, may result from consuming unsafe food contaminated with physical, chemical or microbiological hazards. Hazard examples include:

- **Physical:** Sharp Metal or Wooden Pieces in food.
- **Chemical:** Chemical Detergents.
- **Microbiological**: Salmonella in Chicken.

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Figure 1: Examples of physical contaminants.

Figure 2: Examples of chemical contaminants.

Figure 3: Examples of microbiological contaminants.

While many foodborne illnesses are mild and self-limiting, some can be very critical and even lead to death. Contaminated food can be the cause of or contribute to various diseases, ranging from diarrhea, stomach cramps, high temperature to some cancers. It can weaken people's immune system, exposing their bodies to various disease-causing infections. It can also reduce the body's response to treatments, particularly for chronic diseases and conditions such as diabetes, kidney and heart diseases, AIDS and cancer (Mayo Clinic, 2017; NHS, 2018). In today's world, food safety has the attention of global agencies such as the World Trade Organization, United Nations Conference on Trade and Development, World Health Organization, and the World Bank. Public and private organizations play a key role in instituting policies and establishing systems of managing the collective objective that meets food safety goals. The role of environmental health scientists and Food Safety Specialists/Auditors is important to ensure the quality and proper constitution of food by implementing legislation and enforcement against any unsafe food product and promoting awareness within the food industry about safer food. At Saudi Aramco, the contribution of all professionals in this field of practice assure that Saudi Aramco employees and their dependents from company-approved food service establishments.

Figure 4: EP professionals conducting food safety inspection at Saudi Aramco facilities to ensure compliance with food safety regulations.

What is the Impact of Food-Related Illnesses Globally?

"Foodborne illness sees no boundaries," which represents a vital impediment to socio-economic development globally (Tucker, Larkin and Akers, 2011 p.1). Numerous reports have shown that impacts of unsafe food can spread quickly, affecting millions of people annually- sometimes with severe and fatal outcomes. As reported by the World Health Organization (WHO) (2002), approximately 2.2 million people die annually because of foodborne and waterborne diarrheal illnesses, 1.9 million of them are children. In 2010, thirty-one types of foodborne illness agents (e.g., bacteria, viruses, helminths and chemicals) caused around 600 million foodborne illnesses and 420,000 deaths worldwide, with 125,000 of them being children under the age of five. The most frequent causes of foodborne illnesses were diarrheal disease agents (i.e., 230,000 deaths). Annually, the World Health Organization estimated that 33 million healthy life years are lost because of eating unsafe food, and this figure is likely underestimated, (Figure 5). (WHO, 2015).

Figure 5: shows global burden of foodborne diseases.

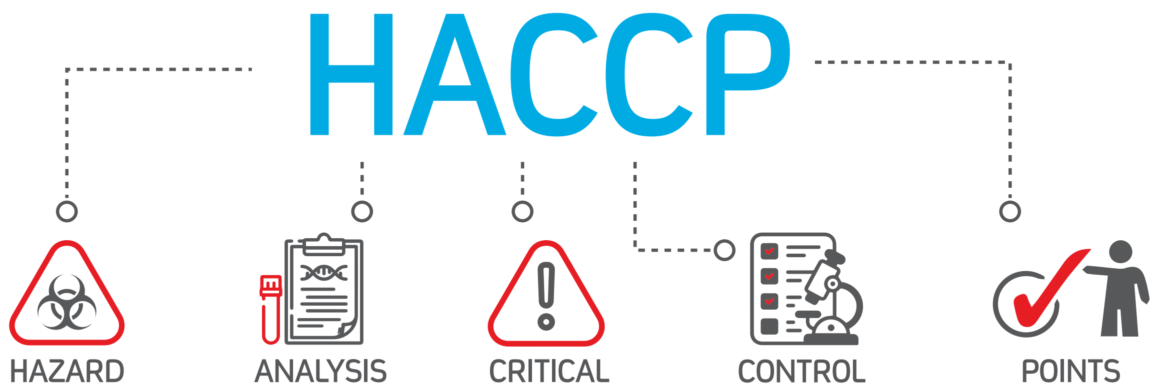
What are the National and International Regulations & Programs to Ensure Food Safety?

Although all food businesses bear a moral and ethical responsibility to provide safe food for consumers, many countries set legal requirements on food businesses to ensure food safety. For instance, in article 14 of the General Food Regulation (EC) 178/2002 (superseded section 8 of FSA 1990), it is an offence to advertise, release or sell food that is not safe to eat (Food Standards Agency, 2009). In addition, the principles (articles) of EC Regulation 852/2004, impose obligations on food business operators to ensure that all stages of food production, processing and distribution are under control and follow the required food hygiene standards.

Nationally, Articles 4, 27, and 28 of the Food Act & Regulation 2017 bylaws establish common rules and principles, particularly in relation to the responsibilities of manufacturers and competent authorities, structural, operational, and hygiene requirements for establishments, procedures for licensing and approval of establishments, and requirements for food storage and transportation (SFDA, 2020).

To ensure food safety, there are also several food safety management systems that are endorsed worldwide as effective tools. One of the most recognized ones that has also become a part of food safety legislation in the EU is known as, Hazard Analysis and Critical Control Point (HACCP) (Overbosch and Blanchard, 2014). It has been internationally accepted as a proven, robust system for food safety assurance. According to the Food Standards Agency (2017), HACCP is a proactive system that provides an effective approach to identify and control food safety hazards in order to provide safe products for consumers and protect public health.

Therefore, the food industry implements various types of measures and systems to assure food safety from harvest to consumption. The paramount goal underlying these systems is preventing problems from occurring in the first instance. They are designed to reduce and eliminate risks of safety hazards in food through identifying hazards associated with food processing, handling, and controlling the points critical to food safety. Under such systems, when a deviation is indicated, appropriate steps will be taken promptly to re-establish control and avert any possible health issues by assuring that hazardous products do not reach the end consumer.



What Actions Can You Take to Protect Yourself Against Foodborne Illnesses?

There are several measures that you can take to protect yourself and your family against foodborne illnesses:

Safe transportation of Food Items

Safe purchasing and transportation of food is your first step to protect yourself against foodborne illnesses. Practice the following to ensure food you purchase is safe to eat at the source:

- Purchase food items and raw ingredients from well-known, trustworthy and reliable food providers.
- Make sure to check the temperature and condition of food items prior to purchasing.
- Ensure the proper transportation of chilled and frozen food items from the store to your home. Chilled food items need to be kept at (5ºC) or below while frozen food items need to be kept at (-18ºC) or below.

Proper Storage of Food Items

Chilling food properly helps to strop harmful bacteria from growing.

Practice the following to ensure proper storage conditions:

- Check chilled food on delivery to make sure it meets minimum temperature requirements.
- Put food that needs to be kept chilled in the refrigerator straight away.
- Cool cooked food as quickly as possible and then put in the refrigerator.
- Keep chilled food out of the refrigerator for the shortest time possible during preparation.
- Check regularly that your refrigerator is 5ºC or below.

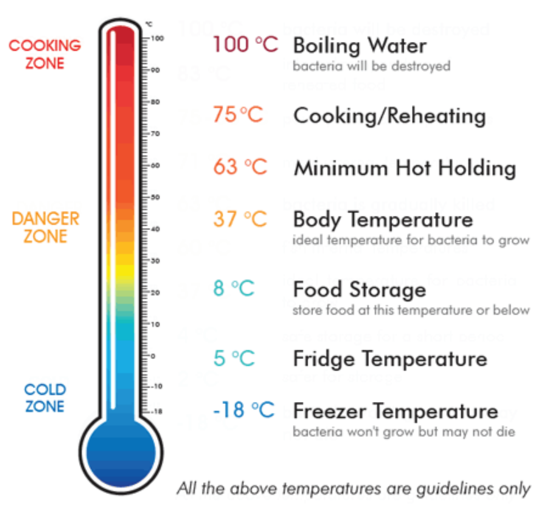


Figure 7: Food temperature guidelines.

Figure 8: Proper storage of food items and stock rotation.

Proper Processing of Food Items

Proper processing prevents cross-contamination of food items. Cross-contamination is when bacteria are spread between food, surfaces or equipment, leading to foodborne illnesses. Practice the following to protect yourself against cross-contamination:

- Clean work surfaces, chopping boards and equipment thoroughly before you start preparing food and after you have used them to prepare raw food.
- Use different chopping boards and knives for raw and ready-to-eat food.
- Keep raw food separate from ready-to-eat food at all times.
- Cook food thoroughly to kill bacteria with a minimum cooking temperature of 75°C.

Proper Hygienic Practices

Effective cleaning removes bacteria on hands, equipment or surfaces, which helps to stop harmful bacteria from spreading onto food. Practice the following to ensure high levels of cleanliness:

- Wash your hands thoroughly before preparing food items.
- Clean food areas and equipment between different tasks, especially after touching raw food.
- Clear and clean as you go. For instance, clear away used equipment or spilled food as you work and clean and sanitize work surfaces thoroughly.

Figure 9: Food preparation areas clean, tidy, and disinfected.

Figure 10: Different boards for cutting produce and meat to prevent cross-contamination.

Figure 11: Proper hygienic practices.

References

1. Department of Health (2010) 8 Food poisoning and contamination [online] Available at: http://www.health.gov.au/internet/publications/publishing.nsf/Content/ohp-enhealth-manual-atsi-cnt-l~ohp-enhealth-manual-atsi-cnt-l-ch3~ohp-enhealth-manual-atsi-cnt-l-ch3.8

2. Food Standards Agency (2009) The Food Safety Act 1990 – A Guide for Food Businesses [online] Available at: https://www.food.gov.uk/sites/default/files/media/document/fsactguide.pdf

3. Food Standards Agency (FSA) (2017) Hazard Analysis and Critical Control Point system in meat plants [online] Available at: https://www.food.gov.uk/business-guidance/hazard-analysis-and-critical-control-point-system-in-meat-plants

4. Mayo Clinic (2017) Food poisoning [online] Available at: https://www.mayoclinic.org/diseases-conditions/food-poisoning/symptoms-causes/syc-20356230

5. National Health Service (NHS) (2018) Food poisoning [online] Available at: https://www.nhs.uk/conditions/food-poisoning/

6. Overbosch, P. and Blanchard, S (2014) Principles and Systems for Quality and Food Safety Management-Chapter 22. In Food Safety Management (pp. 537-558). Available at: https://www.sciencedirect.com/science/article/pii/B9780123815040000226

7. Saudi Food & Drug Authority (SFDA) (2020) Food Hygiene Requirements [online] Available at: https://www.sfda.gov.sa/sites/default/files/2020-12/FoodHygieneRequirementsEn.pdf

8. Sprenger, R. (2017) Hygiene for Management [online] 19th ed. Highfield. Available at: https://www.highfieldproducts.com/x/previews/?p=45#features/

9. Tucker, C., Larkin, S. and Akers, T. (2011) Food Safety Informatics: A Public Health Imperative. Online Journal of Public Health Informatics [online], 3(2), Online Journal of Public Health Informatics, 2011, Vol.3(2) Available at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3615782/

10. World Health Organization (WHO) (2002) WHO global strategy for food safety: safer food for better health [online] Available at: http://apps.who.int/iris/handle/10665/42559?locale-attribute=en&

11. World Health Organization (WHO) (2015) WHO estimates of the global burden of foodborne diseases [online] Available at: PRINT-1347-OMS-FOS-FERGreport-20160408.indd (who.int)