Measurement of Barchan Dune Migration Rates in the Al-Huwamiliyah dune field, Udairi Range Complex, Kuwait

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ABSTRACT

The largest concentration of sand dunes in the State of Kuwait are in the Al-Huwamiliyah dune field, which extends from the Iraq border and the Udairi Range Complex (URC) in northwest Kuwait to the border with Saudi Arabia in the south (Figure 1). The URC covers 2,500 km^2 of land in northwest Kuwait and is the U.S. Army's premier training center within the U.S. Central Commands (CENTCOM) area of operations. This dune field contains 99% of the large dunes (>900 m^2) in Kuwait, with a majority of the large dunes being located in the URC. These Barchan dunes are perched on caliche pavement allowing them to migrate rapidly when driven by the prevailing northwesterly winds. In 1993 a study of 10 Barchan dunes found a migration rate of 23.3 m/year (Khalaf and Al-Ajmi 1993); a larger study of 86 dunes conducted in 2005 found a mean rate of 24 m/year (Al-Dousari and Pye 2005).

Economic development in this area has increased since the first Gulf War (1991). Structures and roads are now being constructed in the region with little regard to the negative economic impacts that will occur when these dunes migrate through newly built facilities (Khalaf and Al-Ajmi 1993). In this study a solitary large Barchan dune located within the URC's northern impact area and adjacent to several modernized range complexes (valued at $1 to 2 million (US) each) was surveyed using satellite imagery and two GPS ground surveys. The rate of migration for this dune was determined to be 18.78 m from April 25, 2019 to August 28, 2020 with movement to the southeast at 155°. The annual rate of migration was 14.08 m/year. Though lower than found in the two previous studies this rate still translates to 141 m per decade and highlights the need to consider the location and direction of movement of nearby Barchan dunes when selecting locations to construct permanent facilities within the URC.

Physical Geography of Kuwait

The State of Kuwait is located at the far northwestern corner of the Arabian Gulf. It borders Iraq to the north and west, Saudi Arabia to the south, and the Arabian Gulf to the east. Kuwait is 17,820 square kilometers in size, approximately the size of New Jersey. At its most distant points, it is about 200 km (120 mi) north to south, and 170 km (110 mi) east to west. Kuwait's area consists mostly of desert with some coastal wetlands in the northeast bordering Iraq and the Arabian Gulf. The country's highest point is an unnamed hill that peaks at 1,003 ft. (306 m) and its lowest point is at sea level.

Al-Huwamiliyah dune field is defined by longitudes 47°E and 47°30'E and the latitude 29°N and 29°50'N (Figure 1). The total area of this zone is about 5,000 km^2 and represents 28% of the total area of Kuwait. The fields topography is carved in caliche soils of Miocene-Pleistocene age, mostly covered by a thin blanket of aeolian deposits. Road development, military maneuvers, and increased human activities within the region, such as camel and goat herding, have contributed to denudation of the regions sparse vegetative cover and disturbance of the desert pavement. This has exposed additional loose sediments to wind action.

Climate

Kuwait has an arid climate with huge temperature differences. In summer, average high temperatures range from 108 to 118°F. The summers are punctuated by dramatic dust storms in March and April with wind speeds often exceeding 21 mph (9.7 m/s). At the end of October cooler winter weather sets in, dropping temperatures to as low as 21°F at night with daytime highs between 50–63 °F. During this time there are brief but strong thunderstorms. Precipitation occurs from October until April (mostly in November). Rainfall varies from 2.95-5.91 inches (75-150 mm) per year and can produce local flooding due to the lack of a well-developed drainage system.

For this study, the weather data from World Meteorological Organization (WMO) Station Mitribah (Figure 2) was taken as being representative for the URC. This station is located 23 km NE from the dune under study and is 3 km north the URC's northern boundary (Figure 1).

Soil Characteristics

Surface sediments within the URC consist predominantly of well-sorted quartz sand with a d_{50} of 0.23 mm. Course to medium sand makes up 90% of the total volume with the remainder being very coarse sand, silt and clay. When disturbed these sediments are readily transported by aeolian processes during the dry season (May-October). In situ sediments become cemented together over time to form caliche (Figure 3A). These cement like layers cause ponding of water in low lying areas during the wet season. Silt and clay are then deposited into them by run-off (Figure 3B). These low areas then serve as a source for wind-blown dust during the dry season (Figure 3C).

Wind & Barchan Dune Development

The Al-Huwamiliyah dune field receives a continues influx of aeolian sediment from Iraq allowing the formation of Barchan dunes. Barchan dunes are crescent shape dunes that form in arid regions were unidirectional winds blow on a firm substrate with a limited sand supply. The regions prevailing Westerly-Northwesterly winds, and general flat topography that drops over 70 km from an average elevation of 150 m at the URC North Impact Area (Figure 7, see Map) to sea level at the coast, enables the Barchan dunes to naturally migrating downwind and down slope to the southeast (Figure 4).

Mean sediment size for the barchan dunes in the region is characterized by a unimodal distribution, with an average grain size of 0.23 mm (Al-Awadhi and Misak 2000; Al-Dousari et al. 2013). Bedload transport of sand and saltation is observed in the dune field whenever wind speeds exceeded 5.5 m/s under dry conditions (Al-Awadhi et al. 2000). During the period of this study, daily average winds exceeded 12 mph (5.5 m/s) 23% (84 days) of the year.

ISBC Dune Measurements

In this study an individual medium sized Barchan dune located within the URC's modernized Infantry Squad Battle Course (ISBC) was analyzed base on satellite imagery taken on April 25, 2019 and two GPS ground surveys completed on May 23, 2020 and August 28, 2020. In April 2019 the centroid of the dune was located at 47° 8' 16"E, 29°44'21"N and positioned 100 m northwest of a newly constructed moving infantry target (MIT) and bunker-trench. As of August 28, 2020 the mid-point of the dune was 75 m away, with the left Horn of the dune being within 14 meters of the MIT. Currently, range maintenance

team uses heavy equipment to clear sand from in and around the MIT after each high wind event; if this was not done the left horn of the dune would overrun the MIT by August 2021.

Standard Barchans dune measurements were taken at the locations shown in Figure 5; resultant values are shown in Table 1. The height of the dune was estimated to +/- 0.5 m based on GPS measurements for 2020 and from the angle of repose for the slip face and length Ls for 2019. Based on Bourke and Goodie (2009) this dune is classified as a 'normal barchan dune'. The Horn-to-Horn width (W) vs. dune height (H) equation developed by Hesp and Hastings (1998) was applied to obtain a better estimate of the height (Hc) in meters.

$$Hc = \frac{W - 7.65}{8.82}$$

The calculated Hc for each time period was found to be in-line with and have the same trend as the measured height. Hc was taken as the height of the dune for the remainder of this study.

Table 1. Measurement in meters of dune morphology parameters for the ISBC Dune examined in this study.

Dune Parameters (m)	25-Apr-19	23-May-20	28-Aug-20
Length (L)	139	143	137 m
Back (Lo)	60	63	62 m
Slip face (Ls)	15	13	16 m
Front (Lb)	64	68	59 m
Slip Face Angle	31-35°	34°	35°
Horn to Horn Width (W)	77	66	81 m
Mean Horn Width	21	28	25 m
Height Measured (H)	9-10	9	11 m
Calculated Height (Hc)	7.9	6.6	8.3 m
Area (m^2)	7893	8023	8624 m^2
Volume (m^3)	42278	31498	50745 m^3

Human Activities

Beginning in 2009 the construction of extensive permanent roads and semi-permanent weapons range complexes in the URC began. As of 2020 there were 90 km of paved two-lane roads, 160 km of maintained "dirt" roads, and 40 weapon ranges in the URC -which include their own set of sand safety berms (~3 m tall), access trails, target pits, and towers. In addition, oil exploration continues in the region along with camel and goat herding (Figure 6). This has resulted in overgrazing and the construction of an additional ~200 km of temporary roads and sand berms in the URC. These temporary roads disturb the desert pavement and often block natural drainage routes. This results in ponding in

new locations during the wet season and increases the amount of sediment available for aeolian transport during the dry season.

Infrastructure on the URC

The URC is currently in a period of modernization with many of its weapon's ranges being upgraded from austere field expedient facilities to be on par with permanent ranges located within the United States. New ranges now include permanent range control towers and cement lined target pits equipped with automated targetry. Each tower costs an average of $250,000 to construct. A fully modernized small arms range cost $1.2 million (US) while the larger armored vehicle ranges cost about $2.5 million each.

The ISBC was constructed in 2019 and was damaged by a large windstorm with wind gust as high as 31 mph (13.8 m/sec) that occurred on May 6, 2020 (Figure 7). Targets pits were filled in by 0.5 to 1.0 m of sand and the ISBC range tower was undermined and toppled by winds that scouring sand from underneath the towers foundation.

ISBC Dune Morphology

The Barchan Dune selected for study is located within the newly constructed ISBC range and is located about 140 m northwest of one of the down range maintenance trails and immediately upwind of a moving infantry target (MIT). Survey of the dune was completed on May 23, 2020 and August 28, 2020. Imagery of the dune from April 25, 2019 was obtained from ESRI™ web services with a report positional accuracy of +/-0.5 m. The 'sandbag pile' shown in the photographs in Figure 8 provided a visual confirmation of dune migration.

It was noted that the dune was flatter, and the slip face less well defined after the May 6th high wind event. The storm had filled the slip face area with large amounts of fine sand and reduced the dune crest by 1.3 m. This sand was reworked by moderate wind events during the following summer and a well-defined slip face had redeveloped by August 28; at which time the crest height had increased by 1.7 m and the slip face had recovered to the classic 35^{o} angle of repose for sand with the slip face terminating cleanly at the desert pavement.

Aeolian and Wind Impacts

Active bedload transport of sand and saltation is observed in the dune field whenever wind speed exceeds 12 mph (5.5 m/s) under dry conditions (Al-Awadhi et al. 2000). A majority of sediment transport occurs during the dry season between May and October (see Figure 2). The predominant wind direction for the period of this study, April 2019 to August 2020, was found to be from the west, northwest (Figure 4) vs. from the northwest as reported in previous study's (Table 2). The rate of migration for the ISBC Dune is slower than found in the other two studies referenced because, on average, smaller (shorter L, smaller Hc) Barchan dunes migrate faster than larger dunes under the same environmental conditions (Engel et al. 2018). The future location of the ISBC Dune was projected to 2029 and shown in Figure 9; at which time it will cover the range access trail, the MIT, and the bunker.

Table 2. Direction of dune migration and velocity of movement for select Barchan Dunes within the Al-Huwamiliyah dune field. The ISBC Dune height shown is the mean height for the period based on Hesp and Hastings (1998) and from survey.

Study	Reported Annual Rate of Migration	Direction of Movement	Number of Dunes	Dune Height
Khalaf and Al-Ajmi 1993	23.3 m/year	SE	10	3.3 m Mean
Al-Dousari and Pye 2005	24 m/year	SE (139°)	86	3.1 m Mean
Daniels 2021 (This Study)	14 m/year	SE (155°)	1	6.6 to 8.3 m

Conclusion

The Udairi Range Complex is the U.S. Army's premier training center within the U.S. Central Commands (CENTCOM) area of operation. The URC is currently in the process of modernizing its weapons ranges. During the design phase for each Range complex the location of large dunes in the proposed range footprint should be identified and the expected rate and direction of migration considered when positioning range infrastructure. Taking this simple step will reduce the annual maintenance costs for these ranges by reducing the requirement to clear target pits of sand and repair infrastructure after high wind events.

Figures

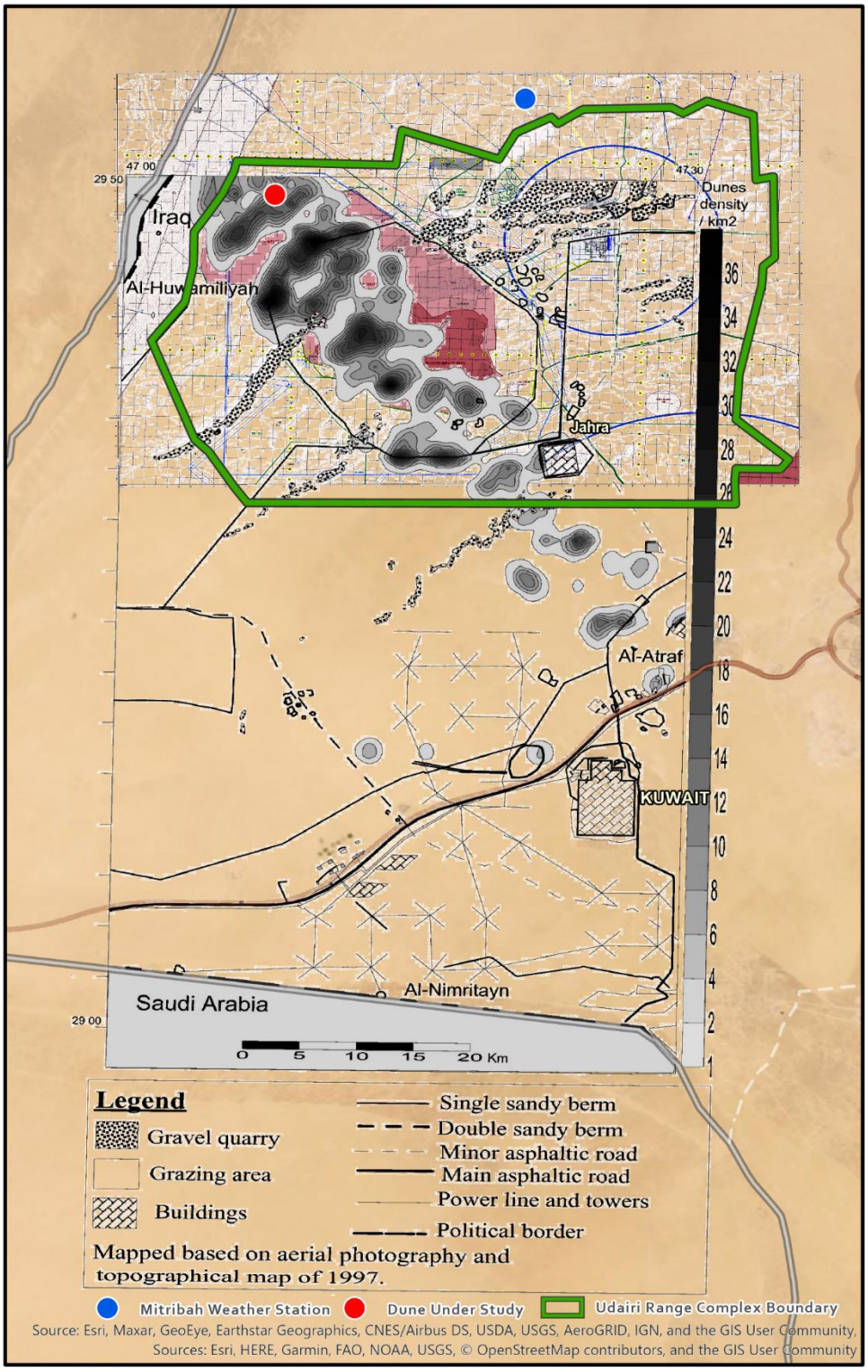

Figure 1. Extent of Al-Huwamiliyah dune field showing sand dune density per km^2 (After Al-Dousari and Pye 2005) along with key locations referenced in this study.

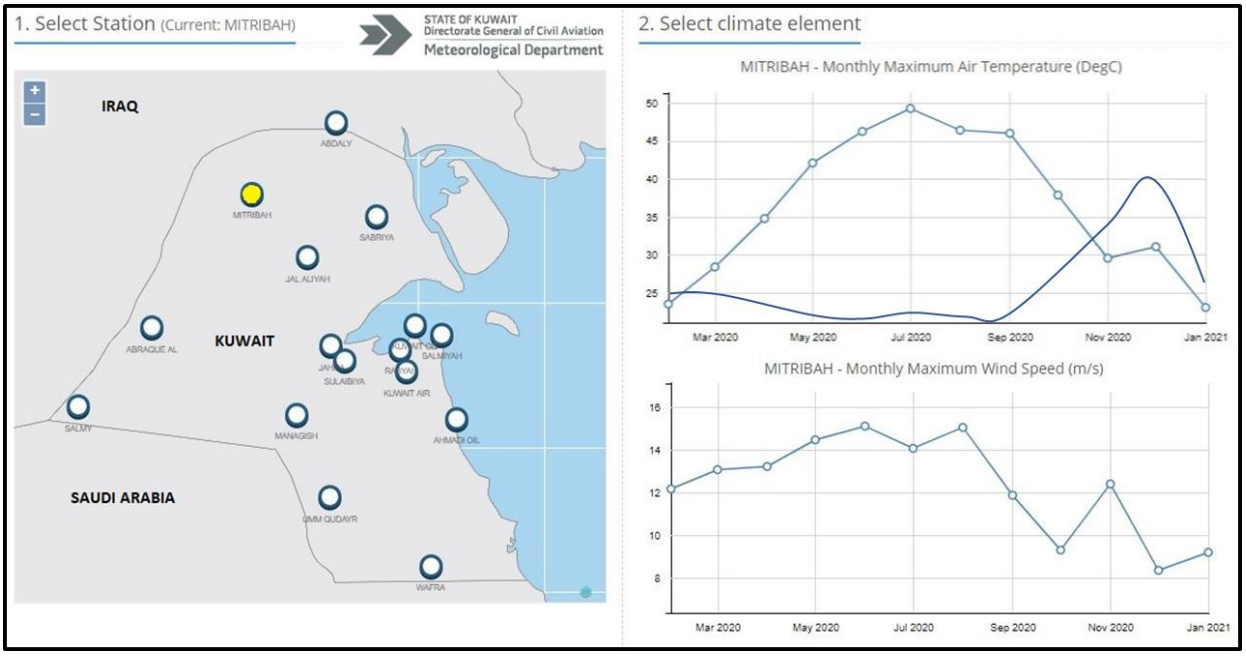

Figure 2. Climate Statistics for WMO Station Mitribah. The May-October dry season is a period of low humidity and high temperatures with wind speeds high enough to initiate sediment motion.

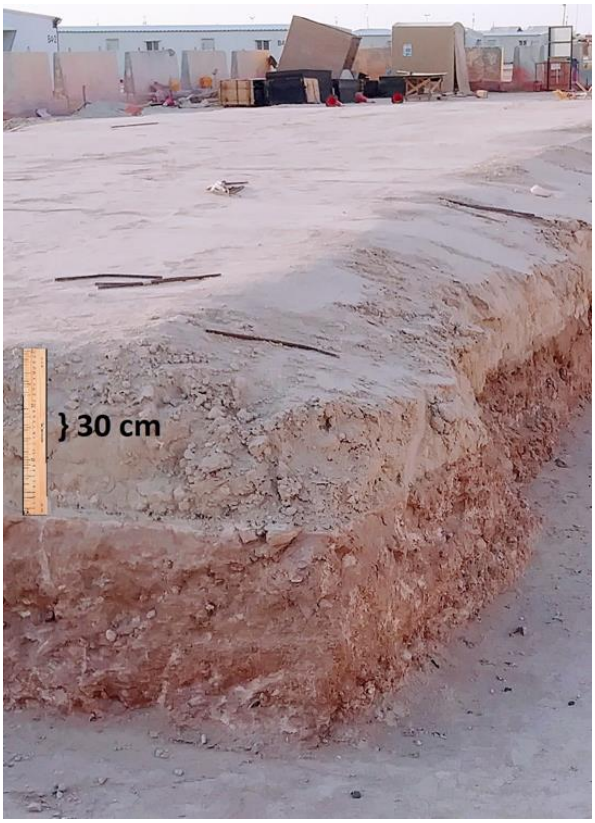

Figure 3A. Excavation site, 1m deep, showing a caliche layer and cemented sediment.

Figure 3B. Ponding and rapid vegetation growth during the wet season in a bermed low-lying area on the URC.

Figure 3C. Fine sand and silt deposit in an area subject to ponding during the wet season.

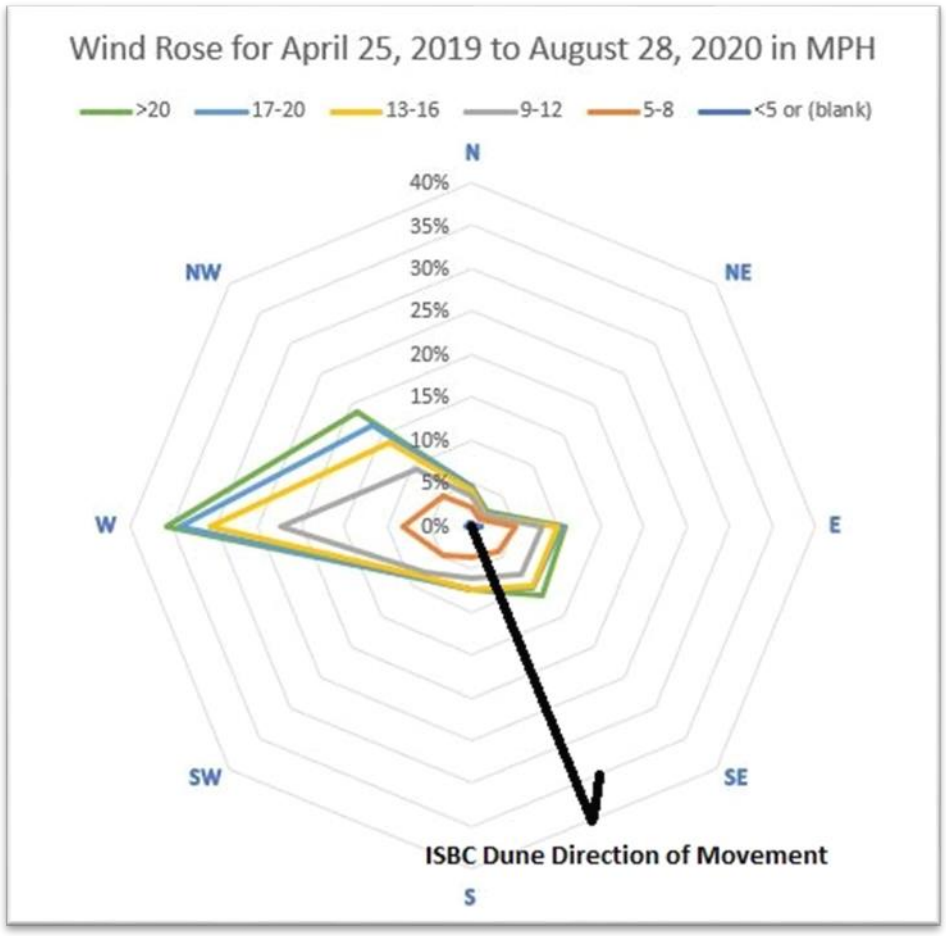

Figure 4. Wind rose for WMO Station Mitribah.

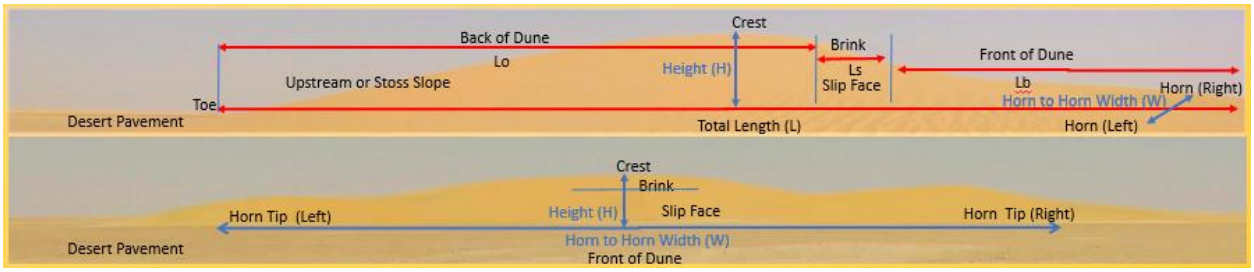

Figure 5. Barchan Dune Morphology Parameters.

Figure 6. The Al-Huwamiliyah dune field is seen as barren and undisturbed; but in reality, it is subject to a wide variety of ecological disturbance that serve to make large amounts of sand readily available for aeolian transport.

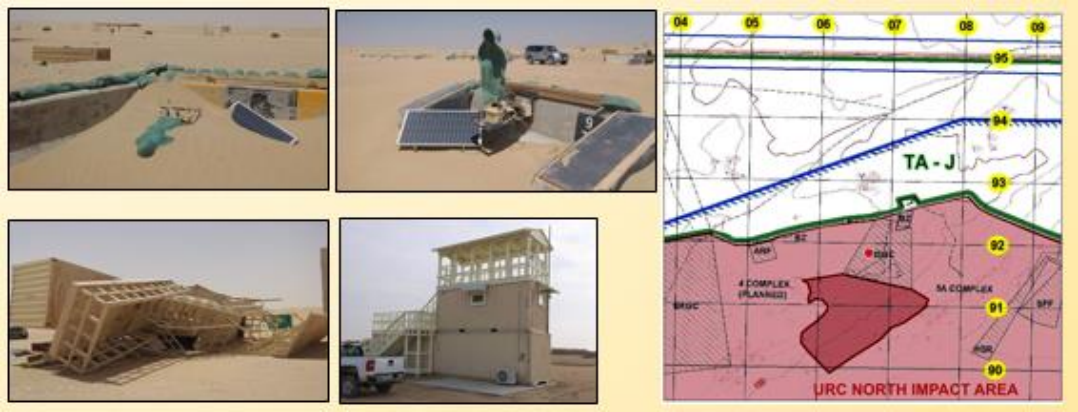

Figure 7. Sand drifting and structural damage caused by the May 6, 2020 wind storm. Photos show storm impacts on a stationary infantry target (SIT) and range tower (left) vs. after post storm clean-up (center). Map shows the location of the ISBC in relation to the ISBC Dune that was monitored for this study (show thus " **O** ").

Figure 8. Photographs showing ISBC Dune Morphology on May 23 and August 28, 2020

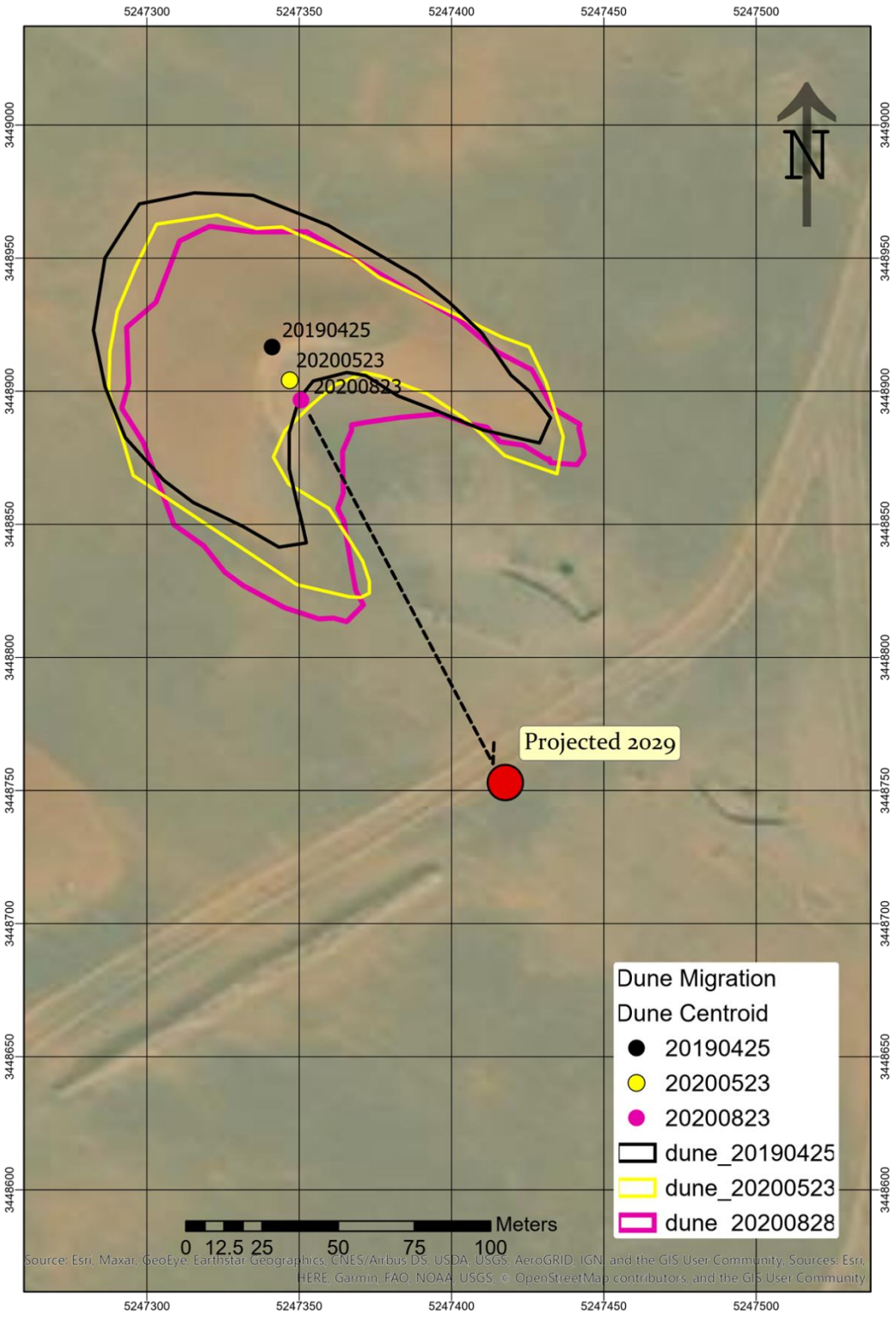

Figure 9. Projected future location of the ISBC Dune in 2029 based on the centroid of the dune, wind direction, and calculated annual rate of migration shown in Table 2.

References

Al-Awadhi, J.M, A.M Al-Dousari and R Misak. 2000. Barchan Dunes in Northern Kuwait. Arab Journal of Scientific Research 18(1):32-40.

Al-Awadhi, J.M and R Misak. 2000. Field assessment of aeolian sand processes and sand control measures in Kuwait. Kuwait Journal of Science and Engineering 27(1):159-175.

Al-Dousari, A.M. and K Pye. 2005. Mapping and monitoring dunes in northwest Kuwait. Kuwait Journal of Science and Engineering 32(2):119-134.

Al-Dousari, A.M. and A. Al-Hazza. 2013. Physical properties of aeolian sediments within major dune corridor in Kuwait. Arab Journal of Geosciences 6:519-527.

Bourke, M.C. and A.S. Goudie. 2009. Varieties of barchan form in the Namib Desert and on Mars. Aeolian Research 1:45 – 54.

Engel, M. Boesl, F. and H. Bruckner. 2018. Migration of barchan dunes in Qater – controls of the Shamal, teleconnections, sea-level changes and human impact. Geosciences 8: 240-254.

Hesp, P.A. and K. Hastings. 1998. Width, height and slope relationships and aerodynamic maintenance of barchans. Geomorphology 22:193-204.

Khalaf, F.I. and D. Al-Ajmi. 1993. Aeolian processes and sand encroachment problems in Kuwait. Geomorphology 6:111-134.