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Evaluation of wind shear coefficient and surface roughness for selected cities in southwestern Libya

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Key words
Wind shear coefficient
Wind energy
Surface roughness
Power law
Turbine hub height
Extrapolation

Abstract
This paper aims to evaluate the wind shear coefficient for six selected sites in southwestern Libya, namely (Ghat, Murzuq, Qatrun, Sebha, Ubari and Trahgan) . Wind speeds from (1981 to 2022)at 10 m and 50 m above the ground surface were applied, which were obtained from NASA database were applied. The wind shear coefficient and surface roughness were calculated and the results were tabulated and curves presented too for each site by using the power law. By obtaining the wind shear coefficient and surface roughness, it became possible to use extrapolation of the wind speeds at the desired turbine hub height for any of the selected sites.

تقدير معامل قص الريح و خشونة السطح لمدن مختارة في جنوب غرب ليبيا

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قسم الطاقات المتجددة، كلية الهندسة، جامعة سبها

الكلمات المفتاحية:
معامل قص الريح
طاقة الريح
خشونة السطح
قانون القدرة
ارتفاع محور العنفة
الاستقراء

الملخص
تهدف هذه الورقة الي تقدير معامل قص الريح و خشونة السطح لستة مناطق في جنوب غرب ليبيا وهي (غات, مرزق, القطرون, سبها, اوباري و تراغن). أخذت قيم سرعات الريح لسنوات (1981-2022) عند ارتفاعات 10م و 50م فوق سطح الأرض من قاعد بيانات وكالة ناسا. تم حساب معامل قص الريح و خشونة السطح وعرضت النتائج من خلال الجداول و المنحنيات لكل موقع و ذلك باستخدام قانون القدرة . بالحصول على قيم معامل قص الريح و خشونة السطح يصبح بالإمكان استخدام قاعدة الاستقراء لسرعات الريح عند أي ارتفاع مطلوب لمحور عنفات الريح للمواقع الستة.

1. Introduction

Climate change drives risky events, sea rise, and resource disruptions worldwide. Hence, fossil fuel dependence is unsustainable, demanding a transition to renewable energy [1]. Whereas, all over the world, populations and human activities are increasing day by day. Consequently, the demand for energy is increasing. Fossil fuel-based energy production is both environmentally polluting and not sustainable.Libya is a major oil and gas producer, and is therefore no exception to the need to develop and find more economical alternatives to meet consumer demand [2]. Within global decarbonization efforts, fossil fuels face an ambiguous future [3]. Moreover, most countries, including Libya, are considering the use of sustainable, renewable, and environmentally friendly energy sources, especially solar and wind energy, which provide convenience to customers [4]. Consequently, these countries can alleviate Green house gases emissions and promote global climate change Prevention initiatives are planned [5]. Wind energy is the fastest booming renewable energy and is taking global attention due to technical advances in exploitation this energy as well as its production cost being competitive with traditional methods [6]. One of the basics of the economic evaluation of any site where a wind energy project is to be established is the availability of wind speeds and their characteristics at the layer adjacent to the Earth's surface. This information is obtained by meteorological towers that contain devices installed at a reference measuring point close to the Earth's surface. Then, the wind speeds are extrapolated to higher levels of the layer close to the Earth's surface, reaching the heights of the turbine hub or more. This is established by using a wind shear coefficient (WSC), the variation in speed of wind by considered of height, with two mathematical formulas of power law (PL) and Logarithmic Law (LL) used for extrapolation. (PL) extrapolation is the most utilized method for estimation of wind speeds at a higher height than what is measured and commonly uses a exponent of 1/7th (0.142); though, research indicates that this value is neither stable on a daily, weekly, or seasonal basis, nor accurate for all places due to varying surface roughness factors, atmospheric effects, and the point of measurement heights [7].

The power law equation [8-15].

$$v_2 = v_1 \left(\frac{h_2}{h_1}\right)^{\alpha} \qquad (1)$$

Where v_1 and v_2 wind speed at elevations *h_1 and h_2* respectively, α is the Hellman or fraction exponent also known an WSC.

The logarithmical law equation [9-11].

$$v_2 = v_1 \frac{ln(h_2/z_0)}{ln(h_1/z_0)} \qquad (2)$$

The logarithmical law based on z_o where z_o is surface roughness, it is valid only near the ground or relatively flat terrain [16].

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Wind shear is due to fraction of wind with ground roughness, it produces unstable stream and slow the wind speed to zero at ground level [17]. The wind shear exponent (α) gives the best fitting to wind speeds between two references hub heights with a single value to a given surface hence no tolerance for variation with height. The value of (α) increases with ground roughness (Zo) and decreases with enlarge of height and including of thermal effects on the vertical wind speed direction. As wind stream, it undergoes some changes. As a result, surface roughness and wind shear exponent factor also change depending on the topographic features of the ground, time of the day,wind direction, and the height level above the ground. These variations in wind speed and hence their estimation to higher hub heights should be considered. There is fast increase in wind speed over short time when surface roughness is lower. When surface roughness is large, there is slow and small increase in wind stream

profiles [18]. Sunanda Sinha et al. [13], studied 12 sites in the Indian state of Himachal Pradesh. The dataset spanned four years, from July 2011 to June 2013. Data for 11 sites were obtained from NASA at a height of 10 meters. Data for one site were measured at a height of 10 meters and were obtained from the Center for Engineering, Energy and Environment. They analyzed the wind speed data and obtained the monthly wind shear coefficient for each site. Okerie et al. [19], evaluated the wind shear coefficient and roughnesslength for two sites in southern Namibia. They used mean wind speeds measured every ten minutes for a year. For Korabib site, the speeds were measured at 20 and 50 m altitudes, and for the Warmbad site, the speeds were measured at 18.5 and 50.5 m altitudes. They used the power law and the logarithmic law in the calculations. Then obtained mean wind shear coefficients of 0.197 and 0.132 and roughness of 0.187 and 0.017 m for Korabib and Warmbad,

1.1 Data description

The data used in this paper obtained from NASA power data [20]. The data were analyzed using MATLAB and Excel programs.

1.2 Studying areas

Thestudied areas are located in southwestern Libya and the following table shows geographical location of each city.

Table (1) geographical location of studying areas [21]

city	Elevation (m)	Latitude	Longitude
Ghat	668	10° 10′ 41″ E	24° 57′ 52″ N
Murzuk	453	13° 54′ 0″ E	25° 54′ 0″ N
Qatrun	518	14° 34′ 33″ E	24° 55′ 44″ N
Sebha	420	14° 25′ 35″ E	27° 2′ 20″ N
Trahgan	420	14° 25′ 14″ E	25° 55′ 24″ N
Ubari	468	12° 46′ 0″ E	26° 35′ 0″ N

Fig (1) Areas studied in southwestern Libya

2. Methodology

Wind shear coefficient was calculated using the following equation [8, 10, 12, 14, 15, 22, 23].

$$\alpha = \frac{ln(v_2) - ln(v_1)}{ln(h_2) - ln(h_1)} \qquad (3)$$

Where $v_1$and$v_2$are wind speeds at heightsh_1 and h_2 respectively.

Also, wind shear coefficient can be calculated from the following equation [24].

$$\alpha = \frac{0{\cdot}37 - 0.088\, ln(v_{ref})}{1 - 0.088 Ln\left(\frac{H_{ref}}{10}\right)} \qquad (4)$$

Where v_{ref} wind speed at reference height H_{ref}.

Roughness length was calculated using the following equation [9, 10, 16, 25].

$$z_0 = exp\left[\frac{h_2^{\alpha}\, ln(h_1) - h_1^{\alpha}\, ln(h_2)}{h_2^{\alpha} - h_1^{\alpha}}\right] \qquad (5)$$

In this study equation (3) was applied to estimate the wind shear coefficient for all selected sites because the wind speed profiles at two different heights are known over a certain period [26].

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3. Results and discussion

Table (2)Annul wind shear coefficient(α)forselected cities in Southwestern Libya.

Year	Ghat	Murzuk	Qatrun	Sebha	Trahgan	Ubari
1981	0.2234	0.2395	0.2458	0.2253	0.2345	0.2302
1982	0.2202	0.2392	0.2446	0.2269	0.2335	0.2297
1983	0.2158	0.2375	0.2447	0.2219	0.2321	0.2268
1984	0.2199	0.2382	0.2455	0.2242	0.2332	0.2283
1985	0.2237	0.2414	0.2488	0.2269	0.2368	0.2313
1986	0.2208	0.2410	0.2454	0.2256	0.2358	0.2302
1987	0.2219	0.2434	0.2470	0.2279	0.2377	0.2333
1988	0.2233	0.2421	0.2491	0.2290	0.2389	0.2316
1989	0.2238	0.2408	0.2493	0.2258	0.2368	0.2311
1990	0.2200	0.2384	0.2435	0.2241	0.2316	0.2288
1991	0.2170	0.2380	0.2443	0.2226	0.2323	0.2276
1992	0.2208	0.2417	0.2468	0.2273	0.2356	0.2338
1993	0.2218	0.2401	0.2478	0.2253	0.2336	0.2303
1994	0.2173	0.2408	0.2442	0.2251	0.2331	0.2311
1995	0.2150	0.2357	0.2393	0.2203	0.2289	0.2267
1996	0.2186	0.2379	0.2441	0.2228	0.2311	0.2296
1997	0.2142	0.2376	0.2418	0.2217	0.2306	0.2286
1998	0.2125	0.2372	0.2408	0.2225	0.2303	0.2264
1999	0.2216	0.2419	0.2470	0.2285	0.2352	0.2331
2000	0.2232	0.2402	0.2486	0.2262	0.2357	0.2294
2001	0.2233	0.2393	0.2495	0.2283	0.2365	0.2318
2002	0.2209	0.2343	0.2419	0.2243	0.2310	0.2255
2003	0.2152	0.2401	0.2447	0.2247	0.2334	0.2304
2004	0.2237	0.2405	0.2459	0.2230	0.2336	0.2309
2005	0.2186	0.2415	0.2451	0.2251	0.2337	0.2318
2006	0.2168	0.2350	0.2437	0.2189	0.2305	0.2251
2007	0.2182	0.2420	0.2471	0.2278	0.2359	0.2316
2008	0.2205	0.2412	0.2480	0.2251	0.2343	0.2308
2009	0.2153	0.2437	0.2445	0.2290	0.2357	0.2351
2010	0.2163	0.2321	0.2331	0.2208	0.2222	0.2272
2011	0.2135	0.2366	0.2426	0.2239	0.2324	0.2264
2012	0.2177	0.2442	0.2517	0.2298	0.2379	0.2320
2013	0.2217	0.2393	0.2442	0.2241	0.2338	0.2296
2014	0.2158	0.2408	0.2461	0.2275	0.2363	0.2328
2015	0.2197	0.2422	0.2470	0.2272	0.2356	0.2330
2016	0.2258	0.2412	0.2458	0.2292	0.2362	0.2322
2017	0.2155	0.2350	0.2419	0.2221	0.2296	0.2263
2018	0.2162	0.2373	0.2450	0.2239	0.2319	0.2275
2019	0.2168	0.2427	0.2441	0.2265	0.2338	0.2323

2020	0.2206	0.2402	0.2495	0.2280	0.2365	0.2307
2021	0.2233	0.2415	0.2471	0.2270	0.2351	0.2312
2022	0.2210	0.2420	0.2441	0.2293	0.2345	0.2331

Table (3) Annul surface roughness (Zo)for selected cities in Southwestern Libya.

Year	Ghat	Murzuk	Qatrun	Sebha	Trahgan	Ubari
1981	0.2424	0.3264	0.3628	0.2516	0.2989	0.2763
1982	0.2273	0.3247	0.3557	0.2595	0.2935	0.2737
1983	0.2074	0.3152	0.3563	0.2352	0.2861	0.2591
1984	0.2259	0.3191	0.3610	0.2462	0.2919	0.2666
1985	0.2438	0.3371	0.3808	0.2595	0.3114	0.2820
1986	0.2300	0.3348	0.3604	0.2531	0.3059	0.2763
1987	0.2352	0.3486	0.3699	0.2645	0.3163	0.2925
1988	0.2419	0.3411	0.3826	0.2701	0.3230	0.2836
1989	0.2443	0.3337	0.3838	0.2541	0.3114	0.2809
1990	0.2263	0.3202	0.3493	0.2457	0.2835	0.2691
1991	0.2127	0.3180	0.3539	0.2385	0.2872	0.2631
1992	0.2300	0.3388	0.3687	0.2615	0.3048	0.2952
1993	0.2347	0.3297	0.3747	0.2516	0.2941	0.2768
1994	0.2141	0.3337	0.3534	0.2506	0.2914	0.2809
1995	0.2039	0.3053	0.3253	0.2277	0.2696	0.2586
1996	0.2199	0.3174	0.3528	0.2395	0.2809	0.2732
1997	0.2004	0.3158	0.3395	0.2343	0.2783	0.2681
1998	0.1931	0.3136	0.3337	0.2381	0.2768	0.2571
1999	0.2338	0.3400	0.3699	0.2675	0.3026	0.2914
2000	0.2415	0.3303	0.3796	0.2560	0.3054	0.2722
2001	0.2419	0.3252	0.3850	0.2665	0.3097	0.2846
2002	0.2306	0.2978	0.3400	0.2467	0.2804	0.2526
2003	0.2047	0.3297	0.3563	0.2487	0.2930	0.2773
2004	0.2438	0.3320	0.3634	0.2405	0.2941	0.2799
2005	0.2199	0.3377	0.3586	0.2506	0.2946	0.2846
2006	0.2118	0.3016	0.3504	0.2213	0.2778	0.2507
2007	0.2181	0.3406	0.3705	0.2640	0.3064	0.2836
2008	0.2287	0.3360	0.3759	0.2506	0.2978	0.2794
2009	0.2052	0.3504	0.3551	0.2701	0.3054	0.3021
2010	0.2096	0.2861	0.2914	0.2301	0.2366	0.2611
2011	0.1973	0.3103	0.3441	0.2448	0.2877	0.2571
2012	0.2158	0.3533	0.3986	0.2742	0.3174	0.2856
2013	0.2343	0.3252	0.3534	0.2457	0.2951	0.2732
2014	0.2074	0.3337	0.3646	0.2625	0.3086	0.2899
2015	0.2249	0.3417	0.3699	0.2610	0.3048	0.2909
2016	0.2540	0.3360	0.3628	0.2711	0.3081	0.2867
2017	0.2060	0.3016	0.3400	0.2362	0.2732	0.2566
2018	0.2091	0.3141	0.3581	0.2448	0.2851	0.2626
2019	0.2118	0.3446	0.3528	0.2575	0.2951	0.2872
2020	0.2291	0.3303	0.3850	0.2650	0.3097	0.2789
2021	0.2419	0.3377	0.3705	0.2600	0.3021	0.2815
2022	0.2310	0.3406	0.3528	0.2716	0.2989	0.2914

Table (4) average wind shear coefficient and surface roughness for selected cities in the southwestern Libya.

City	Wind shear coefficient (□)	Surface roughness (Zo)
Qatrun	0.2453	0.3598
Murzuk	0.2397	0.3274
Trahgan	0.2337	0.2952
Ubari	0.2301	0.2760
Sebha	0.2254	0.2522
Ghat	0.2193	0.2235

As shown in Figure (2), the maximum annual wind shear coefficient for Qatrun was 0.2517 in 2012 and the minimum value was 0.2331 in 2010. For Murzuk, the upper limit was 0.2424 in 2012 and the lower was 0.2321 in 2010. For Trahgan, the highest value was 0.2389 in 1998 and the lowest value was 0.2222 in 2010. For Ubari, the maximum result was 0.2338 in 1992 and the minimum was 0.2251 in 2006. For Sebha, the maximum (α) was 0.2298 in 2012 and the minimum was 0.2189 in 2006. For Ghat, the higher result was 0.2258 in 2016 and the lower was0.2125 in 1998.

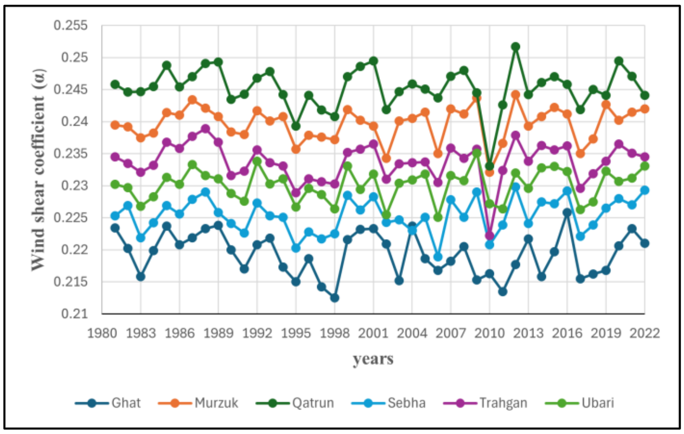

Fig (2) Average monthly wind shear coefficient for selected cities in southwestern Libya.

As shown in figure (3), for the city of Qatrun, the maximum annual value of surface roughness was 0.3985 in 2012 and the minimum value was 0.2914 in 2010. As for the city of Murzuk, its maximum shear coefficient was 0.3533 in 2012 and the minimum was 0.2861 in 2010. For the city of Trahgan, the highest coefficient was 0.3230 in 1988 and the lowest value was 0.2366 in 2010. For Ubari, the upper limit was 0.2952 in 1992 and the lowest limit was 0.2507 in 2010. For the city of Sabha, the highest value was 0.2742 in 2012 and the lowest value was 0.2213 in 2006. For the city of Ghat, the maximum result was 0.2540 in 2016. The smallest value was 0.1931 in 1998.

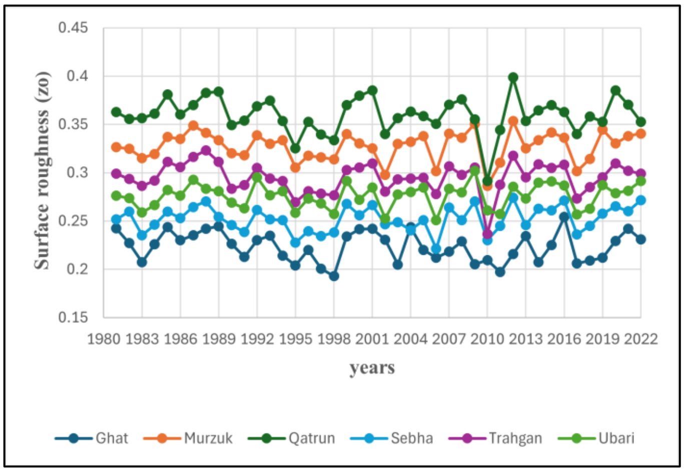

Fig (3) Average monthly surface roughness for selected cities in southwestern Libya.

As shown in figure (4) for the city of Qatrun, the maximum monthly average wind shear coefficient was 0.2662 in November and the minimum value was 0.2253 in May. For the city of Murzuk, the maximum shear coefficient was 0.2519 in February and the minimum was 0.2157 in June. For the city of Trahgan, the highest value was 0.2598 in February and the lowest was 0.1912 in June. For the city of Ubari, the upper limit was 0.2530 in January and the lower limit was 0.2035 in June. For the city of Sebha, the maximum shear coefficient was 0.2542 in January and the minimum was 0.1870 in June. For the city of Ghat, the maximum shear coefficient was 0.2395 in November and the minimum was 0.1912 in June.

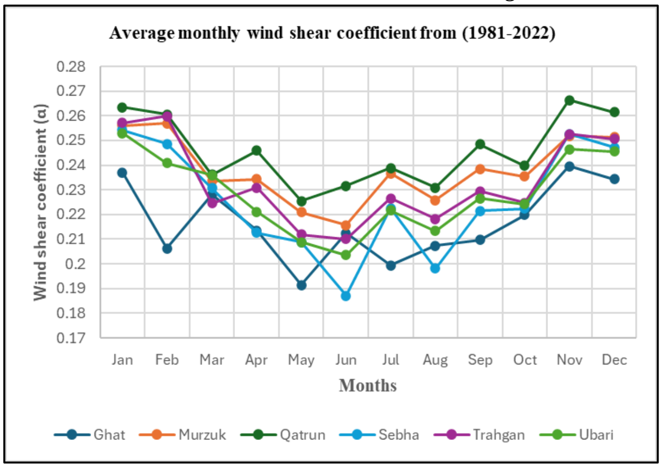

Fig (4) Average monthly wind shear coefficient for selected cities in southwestern Libya.

As shown in figure (5) for the city of Qatrun, the maximum monthly value of surface roughness was 0.4940 in November and the minimum value was 0.2519 in May. For the city of Murzuk, the maximum (α) was 0.4318 in February and the minimum was 0.2071 in June. For the city of Trahgan, the maximum result was 0.4503 in February and the minimum was 0.1833 in June. For the city of Ubari, the highest(α) was 0.4067 in January and the lowest value was 0.1573 in June. For the city of Sebha, the maximum was 0.4143 in January and the minimum was 0.1023 in June. For the city of Ghat, the maximum was 0.3266 in November and the minimum was 0.1155 in May.

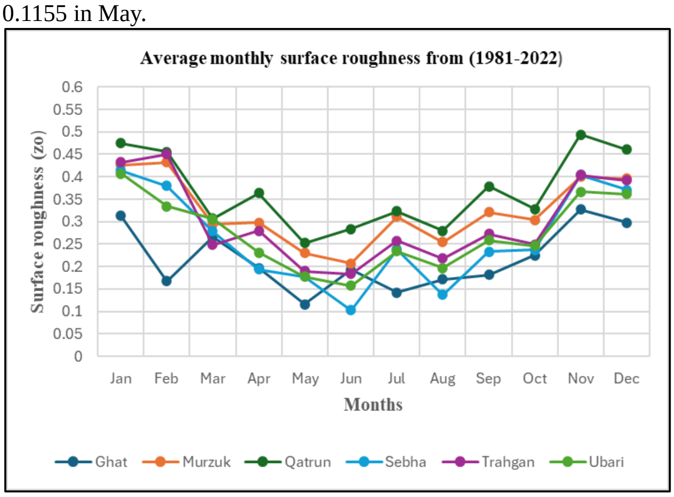

Fig (5) Average monthly surface roughness for selected cities in southwestern Libya.

4. Conclusion

After obtaining the average annual wind shear factor and annual surface roughness for the selected cities, which were Ghat (0.2193,0.2235), Murzuk (0.2397,0.3274), Qatrun (0.2453,0.3598), Sabha (0.2254,0.2522), Trahgan (0.2337,0.2952), and Ubari (0.2301,0.2760), respectively, it became possible to extrapolate wind speeds at different turbine hub heights. It also becamepossible toevaluate the wind energy capacity at different heights for any of the selected cities.

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