Current climate conditions within semi-arid rangelands of the Caspian lowland desert

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Abstract. The Caspian lowland desert is a plain slightly inclined to the Caspian Sea, which covers an area of 2,148,648 hectares and is divided into northern, more arid, with semi-desert landscapes (Nogai Steppe) and middle that covers the deltas of the Terek and the Sulak. These territories are routinely used for animal husbandry with a forage base to be attributed to climate conditions. In recent decades, there has been a widespread rise in air temperature with different trends in precipitation. These trends are estimated based on the datasets from the Makhachkala and Lagan meteorological stations for 1960–2018. Despite the current climate changes, the conditions for heat and moisture availability to support the vegetation period estimated by the hydrothermal coefficient generally remain quite stable and sometimes even more enabling for a sustainable forage base to be formed in the region.

1. Introduction
The Caspian lowland desert is a plain slightly inclined to the Caspian Sea. It stretches for 500 km from north to south, for 700 km from west to east, and covers an area of 2,148,648 hectares. It has altitudes varying between 149 m above sea level in the northern regions, and 28 m below sea level in the southern regions. In the north-west of the lowland there is a site called Black Lands. It is a semi-arid area that is not covered with snow even in winter due to strong winds. The land’s name derives from dark brown soils and Artemisia nova. The territory consists of several powerful tectonic structures – the Caspian Depression, the Ergeninsky Upland, the Tersky and Nogai Depressions.

In historical times, the plain was exposed to numerous transgressions and regressions. That gave rise to the formation of loams in the north, and sand deposits with aeolian topography in the south. The ecoregion is characterized by warm and dry climate, since in summer the Atlantic air gives off moisture on the western slopes of the Staropolsk Upland, and in winter, due to air-mass transport from Asia, the cold surface of the Caspian Sea does not saturate air masses with moisture. Moreover, there is never much snow in that area, and it does not stay on due to significant winds. Such conditions are favourable for semi-desert vegetation characterised by patchiness and complexity. The latter is associated with heterogeneity of soil and ground conditions (mainly water and salt regimes of soils) that primarily depend on the terrain. As a result, steppe and semi-desert features are combined in the
groundcover. Steppe semi-arid habitats are dominated by turfgrains, deserts – sagebrush, saltwort, and other species of grey forbs. They are the ones that form a forage base for animal husbandry.

According to the Caspian Institute of Biological Resources, DSC RAS, 52 % of the total land available in Dagestan is subject to water and wind erosion, while 38 % are saline to varying degrees. Salt marshes alone occupy 542.5 thousand ha, wind-borne free-moving and loosely fixed sands and sandy soils – 450.1 thousand ha. Of the total area of arable land, just 24.2 % of the fields are suitable for tillage, 47.7 % are relatively suitable, and the rest of the area is deemed to be useless and rather useless land [1, 2, 3, 8].

2. Materials and methods
The paper aims to provide a number of proposals elaborated to address the effective use of agricultural land of the ecoregion located in the Republic of Dagestan, based on a retrospective analysis. It also provides a comprehensive assessment of the current climate status typical of this region. A series of datasets were provided by the Makhachkala weather station located in the extreme south, and the Lagan weather station that monitors a northern range of the target area for 1960–2018.

The results indicate a pronounced tendency towards a rise in temperature, with ambiguous rainfall fluctuations in the southern part of the target area. In this regard, there is a need to assess current climate conditions for the entire territory. Source data for assessing climate change are publicly available on meteo.ru. Statistical methods were used to process them.

3. Current climate conditions in the plains of Dagestan
The authors studied a lowland zone that constitutes the ecoregion and is divided into northern, more arid, with semi-desert landscapes (Nogai Steppe) and middle covering the deltas of the Terek and the Sulak. The region is peculiar for being a winter cattle-breeding base in Dagestan. Thus, up to 60 % of winter Dagestan rangelands is concentrated on the area of Kizlyar pastures, where about 2 million heads of sheep and hundreds of thousands of cattle spend winter time (Fig. 1).

![Figure 1. Lowland Dagestan: Ia – Terek-Kuma Lowland; Ib – Terek-Sulak Lowland](image)
There are seven districts in the target area, but the altitudes of up to 100 m are mainly concentrated in Kizlyar, Nogai and Tarumovsky municipal districts. In other districts, including Babayurt, Khasavyurt, Kizilyurt and Kumtorkalinsky, the altitudes of up to 1000 m and above can be present in the west, but there are just a few. Therefore, having explored this region, the authors provided the main climatic calculations for the flat part, although the Makhachkala weather station is located in the south of this region (Table 1). A total of 7 districts within lowland Dagestan occupy an area of 2.15 million hectares or 42.74 %, while a share of agricultural land reaches 46.45 %, or nearly every second agricultural hectare is in this zone [4–6, 11].

**Table 1. Distribution of lands by regions in the north of lowland Dagestan as of January 1, 2019, ha**

| Municipal districts | Total land area | Agricultural land | Residential area | Land for industrial, transport and other use | Specially protected areas | Forest land | Water land | Land reserve |
|---------------------|-----------------|-------------------|------------------|--------------------------------------------|-------------------------|------------|-----------|-------------|
| Nogai               | 887113          | 867972            | 1821             | 1362                                       | -                       | 14173      | 1785      | -           |
| Tarumovsky          | 310902          | 271862            | 1757             | 14249                                      | 18485                   | 1594       | 2955      | -           |
| Kizlyar             | 304744          | 292014            | 3803             | 1034                                       | 3                       | 2296       | 5594      | -           |
| Babayurt            | 325522          | 310879            | 3059             | 1116                                       | 5                       | 5949       | 4514      | -           |
| Khasavyurt          | 142358          | 118248            | 7032             | 1530                                       | 36                      | 14562      | 950       | -           |
| Kizilyurt           | 52401           | 43141             | 3148             | 1120                                       | -                       | 4354       | 361       | 277         |
| Kumtorkalinsky      | 125608          | 114081            | 1483             | 1043                                       | 393                     | 7841       | 767       | -           |
| **Total for the target area** | **2148648** | **2018197** | **22103** | **21454** | **18922** | **50769** | **16926** | **277** |
| % of RD             | 42.74           | 46.45             | 13.76            | 49.76                                      | 65.99                   | 12.04      | 63.61     | 16.11       |

For successful agricultural production, not its location alone, but the climate conditions are also important. The latter are characterized by rather considerable temporal variability. In the environment, it leads to a change in the annual vegetation used by the fauna that resides natural landscapes. If they are used as pastures, a change in the live vegetation affects a potential number of livestock and, if it increases, may lead to their anthropogenic degradation.

The traditional indices providing the basis for climate assessments include air temperature (monthly, seasonal and annual) and corresponding precipitation. An integral indicator reflecting vegetation conditions and widely accepted in agroclimatology and agroclimatic zoning is the hydrothermal coefficient (HTC) of Selyaninov. It is the ratio of the total precipitation in the growing season to the sum of the average daily temperature during this period. Thus, an HTC value higher than 1.6 characterizes an excessively wet zone, 1.6–1.3 – a forest wet zone, 1.3–1.0 – a forest-steppe (insufficient moisture), 1.0–0.7 – a steppe (arid zone), 0.7–0.4 – dry steppe (very arid zone), 0.4 and less – semi-desert and desert. The annual temperature fluctuations according to the Makhachkala and Lagan weather stations for 1960-2018 is shown in Fig. 2.
Figure 2. Annual temperature fluctuations according to Makhachkala (a) and Lagan (b) weather stations for 1960–2018. Hereinafter: the dashed line is a linear trend, the solid line is a moving average for a 10-year period

Based on the statistical data, in the southern part of the ecoregion, the average annual temperature over this period was +12.4 °C, varying from +10.0 °C in 1993 to 13.9 °C in 2010 and 14.1 °C in 1966. A linear trend illustrates a well-defined rise in air temperature, while a moving average justifies the frequency of this process. Thus, the first lowest temperature was recorded in the mid-1970s, followed by a warmer spell. The second minimum occurred in the 1990s and early 2000s, followed by a steady rise in the average annual temperature. Moreover, in 2003 and 2009 alone it fell below a long-term average, while staying above it in other years. In recent years, warming is proved to be caused by a rise in temperature in all seasons of the year.

In the northern part of the ecoregion, the average annual temperature for this period was 10.9 °C, varying from +8.9 °C in 1969 to +12.7 °C in 2010. A linear trend also illustrates a well-defined rise in temperature, with the rate of increase to be even higher than in the southern part of the target area. Around the early 1990s, quite significant interannual variations in air temperature were recorded, which were weakly expressed at a given averaging step. A steady well-defined rise in temperature began in the late 1990s, when annual temperature above normal began to prevail. Like the southern part, there was a decrease in interannual temperature range, especially in the last decade [7–10].

In general, despite some temporary discrepancies, there is a proximity of temperature changes in both the southern and northern parts of the ecoregion. They can be seen in the fact that if the first highest temperature was recorded in the southern part in 1993, and the second – in 1969, then in the northern part, on the contrary, the first lowest temperature fell on 1969, and the second – on 1993. In 2010 the maximum was the same, but the highest temperature in the southern part was attained in 1966. The annual rainfall fluctuations according to the Makhachkala and Lagan weather stations for 1960–2018 is shown in Fig. 3.

Figure 3. Annual rainfall fluctuations according to Makhachkala (a) and Lagan (b) weather stations for 1960–2018
Statistical analysis shows that the average annual rainfall in the southern part of the ecoregion was 357 mm, whereas its minimum could be below 250 mm (1965 – 229 mm, 1975 – 232 mm, 1986 – 212 mm). As for the maximum, it was not until 1990 (650 mm) and 2009 (611 mm) that they significantly exceeded the indicated norm. A linear trend illustrates that a rise in precipitation level during the target period was the same. As with air temperature, it had a certain temporal component. It was in the form of time intervals when the amount of precipitation was above or below their average value. Thus, until the mid-1980s, the range of precipitation fluctuations was relatively small (from 250 to 400 mm), and from the second half of the 1970s, there was a reduction in precipitation, as evidenced by the trend constructed through the averaging method for a 10-year period. There was a rise in precipitation in the late 1980s with a maximum in 1990. It was even heavier than in the previous period, and the minimum rarely dropped below 300 mm. The common peaks of 1990 and 2009 is due to the fact that for only two months the amount exceeded the norm by 2.3–4.0 times.

The average rainfall in the northern part of the target area was 221 mm. The lowest precipitation of 76 mm was recorded in 1972, and it was slightly higher than 100 mm in 1962 (113 mm), in 1986 (114 mm) and 2018 (112 mm). The maximum precipitation exceeded 350 mm and was recorded in 1997 (364 mm) and 2011 (384 mm). A linear trend illustrates heavier precipitation from beginning to end of the series in question. However, like the southern part, the northern part experienced both decline and rise in the amount of precipitation during this time. Thus, at the very beginning of the series under review, the amount was mainly above the norm, but gradually decreased, and from 1975 to 1985 it was declining. Since the mid-1990s, there was a rise in precipitation, which reached a maximum by 2010. Recently, there has been a period of precipitation decline.

Despite the fact that there is no complete synchronization of the annual precipitation, the southern and northern parts of the ecoregion have some common climatic trends. Thus, precipitation decreased to varying degrees in the 1970s, when desertification processes reached their peak not only in the target area, but throughout the Caspian region. In both cases, there was a rise in precipitation in the late 1990s and early 2000s and a decline in recent years. The difference in climatic parameters may partly be due to the position of the weather stations. The climate in the southern part of the lowland (near Makhachkala) is affected by its proximity to the Greater Caucasus, while the northern part (Lagan) do not have such orographic barriers, which creates more favorable conditions for the air mass transport.

An integral index characterizing the vegetation conditions, and, accordingly, the production of phytomass is the above mentioned hydrothermal coefficient. Figure 4 illustrates a change in the southern and northern parts of the ecoregion for 1960–2018.

![Figure 4. HTC fluctuations according to Makhachkala (a) and Lagan (b) weather stations for 1960–2018](image)

The average HTC in the southern part for 1960–2018 amounted to 0.52, which corresponds to dry steppes. However, the index significantly fluctuated from year to year. Thus, its minimum value quite often approached 0.3, which is typical of semi-deserts. What is more, quite often, especially in the
second half of the target time period, its value exceeded 0.7, thereby corresponding to the values typical of steppes. A linear trend indicates rather stable conditions for heat and moisture availability during the effective vegetation period that lasted longer, as evidenced by the analysis of temperature variations. The tendency, based on the sampling for decades, suggests that until the beginning of the 1990s, the conditions were more typical of dry steppes. That was followed by more frequent humidification conditions close to steppe ones.

The average HTC in the northern part of the ecoregion for 1960–2018 amounted to 0.35, which corresponds to semi-deserts and deserts. However, a spread in humidification conditions varies significantly from year to year. Thus, the minimum HTC values made up 0.05 in 1975, and the maximum reached 0.79 in 1979. A linear trend indicates a change in the vegetation conditions from semi-desert to dry-desert. Like in the southern part this trend began from the mid-1990s, although in 2018 the HTC again fell below 0.1.

4. Conclusion

The hydrothermal coefficient is a complex index characterizing the climate conditions of rangelands formed within the semi-deserts of the Caspian lowland desert. Unlike temperature and precipitation changes, the HTC is characterized by greater stability. In the southern part of the ecoregion, its value remains almost unchanged, while in the northern part it indicates a slight improvement in the conditions of moisture availability during the effective vegetation period. Nevertheless, significant interannual variability of climate conditions, and, accordingly, of the hydrothermal coefficient, does not lead to a change in the native, mainly dry-steppe vegetation. In relatively dry years, when the conditions for desertification are formed, dry steppes become less effective, and likewise the forage base for animal husbandry. This situation was recorded in the 70s of the 20th century, when there was a cold and dry phase. At present, there is a warm and wet phase in the ecoregion, accompanied by the conditions appropriate for the expansion of steppe features, and, consequently, the improved forage base for transhumance and pasture livestock [5, 7, 9].

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