Statistical model and assessment of geo-ecological changes in Al-Hoviz alluvial marches in southeastern Iraq and further forecasting of the water level in them

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Abstract. This study included the developed statistical models, factor analysis was performed, and the dynamics of climatic-hydrological characteristics was predicted using the Holt-Winters method in the Minitab 18 and «Statistica» v. The statistical model is based on the analysis of the following data: characteristics of surface water - electrical conductivity (EC), total amount of dissolved solids (TDS), water temperature (t°C), water flow rate, m\textsuperscript{3}/s (Q), water surface area of Al-Hoviz AM, km\textsuperscript{2} (F), water volume of Al-Hoviz AM, km\textsuperscript{3} (W\textsubscript{AM}), water level of Al-Hoviz AM, m (H), normalized vegetation index (NDVI); climatic factors in Al-Hoviz AM for the period from 2010 to 2019 Based on the found interaction of factors and indicators, we build a model of the impact of indicators on NDVI, W\textsubscript{AM}, F and rank them according to the strength of the impact. Main effects plots for each of NDVI, W\textsubscript{AM}, F as independent variables. All these definitions of the interaction of indicators with each other determine the purpose of the model. From this visualization of the model, you can clearly highlight the factors that need to be monitored especially carefully, due to their strong impact on the study area. So, WAM and F are most strongly with a direct connection dependent on precipitation and Q of the Al-Musharrahh river (the main branch from the Tigris River), and with the strongest feedback - the temperature, somewhat less with a direct connection, they are influenced by the Q of the Al-Kahlaa river (the main branch from the Tigris River), and with feedback - the wind speed. Based on the identified relationships and interactions of climatic and hydrological factors, a forecast of changes in the water level of Al-Hoviz AM was made up to 2029. While maintaining the current situation, the tendency of the water level in AM will maintain a descending value.

1. Introduction
Mesopotamian alluvial marches (hereinafter - AM; wetlands; bog covered areas) of the Mesopotamian lowland (Mesopotamian or Iraqi alluvial marches) are wetlands of the region located in southeastern Iraq and partly in southwestern Iran. Al-Hoviz AM lie to the east of the Tigris River (Fig. 1), and some of them are located on the territory of Iran. The Iranian side of AM, known as Al-Azim AM, is fed by the Karha River, while the Tigris and its tributaries Musharah and Al-Kahlaa supply water to the AM of the Iraqi side, but with much less water than the Karha. During the spring flood, the water of the Tigris can also flow into the Al-Hoviz AM, which is drained by the Al-Kassar, a river that is of great importance in maintaining the Al-Hoviz AM as a flow system and thereby preventing salinization [1].
AM Iraqi were included in the UNESCO World Heritage List at the 40th session of the World Heritage Committee in Istanbul (17.07.2016). With their cultural and natural characteristics, wetlands played an important role in the development of the earliest cities and in the emergence of different peoples in southern Mesopotamia, called the cradle of civilization [2].

The Tigris and Euphrates basin has an alluvial plain surface (Alluvial plain), where the Euphrates river has a slope of 4 cm / km at 300 km, and the Tigris slope is 8 cm / km [3]. As a result of the lack of slope of the land, two rivers deviate from their path and form curved and twisted paths (Meandering and sinuous loops), and, finally, to the branches are formed over a large area of the delta.

Iraqi AM represent both economic and social value as a force of its rich biodiversity - it is home to a large variety of animals, birds and fish, as well as many plant species. The biogeochemical cycle of this vast region is in its natural state, fulfilling two important functions: improving water quality along the Tigris and Euphrates rivers in southern Iraq, contributing to sediment retention and control of pollutants. These areas act as a natural sponge that accumulates water during high river flows and releases water during low flows. As for Al-Hoviz AM, the water quality is strongly influenced by the water flow, which is annually supplied by three rivers - Karkha, Tib and Dovayrech, originating in Iran and flowing into Al-Hoviz AM [4].

The natural environment of AM has changed as a result of anthropogenic and natural factors, including a decrease in the discharge of water flows from the Iranian side (due to the construction of dams or the diversion of most of the water to Iran) and a decrease in the inflow of water from the Tigris River, due to its low level due to 42 dams built on the territory of Iraq and beyond, during the hostilities during the Iran-Iraq war of 1980-1988. [5]. Drainage of AM in 1992 became a real natural disaster!

![Figure 1. Map of Al-Hoviz alluvial marches](image-url)
Climate is the most important factor in soil formation; it has a direct effect on physical and chemical weathering. The most important climate elements that leave their mark on the environment are temperature, wind, rain, humidity and evaporation. With less than 200 mm of annual rainfall, the wetland climate is arid subtropical, the climate of the study area is characterized by hot summers (with an average maximum temperature of about 43 °C, the average annual temperature reaches 33 °C), the average annual temperature exceeds 18 °C, reaching 25 °C. Humidity is low, and evaporation from the water surface is high, as a result of which the loss of water due to evaporation is ten times higher than precipitation in the study area [6, 7]. Average annual rainfall is low, and the rainy season is from November to early March and averages 24 mm.

2. Materials and research methods
Based on the studied factors (Table 1), statistical models were developed, and factor analysis was performed in the software "Statistica" v.10, and Minitab 18, and it is possible to predict the development of indicators using the Holt-Winters method in the Minitab 18 program. This method is used because , which considers the seasonality of changes in the analyzed data.

### Table 1. Physical and geographical factors of the statistical model

| Year | Water volume Al-Hoviz AM km³ | Water surface area F Al-Hoviz AM in km² | Average annual air temperature, °C | Average annual precipitation, (mm/year) | Water flow rate Al-Kahlaa river Q m³/s | Water flow rate Al-Musharrah river Q m³/s | Average annual relative humidity % | Average annual wind speed (m/s) | Water temperature t °C | NDVI vegetation km² | EC dS/m | TDS ppm |
|------|-----------------------------|----------------------------------------|-----------------------------------|-----------------------------------------|----------------------------------------|----------------------------------------|----------------------------------|----------------------------------|-------------------|-------------------|--------|--------|
| 2010 | 0.198                       | 880                                    | 27                                | 10.41                                   | 15                                     | 9                                      | 2.85                             | 43                               | 3                 | 24.6              | 756.30 | 2.85   |
| 2011 | 0.222                       | 993                                    | 24                                | 9.16                                    | 22                                     | 8                                      | 3.7                              | 40                               | 3.5               | 23.4              | 823.05 | 2.31   |
| 2012 | 0.193                       | 867                                    | 24                                | 18.26                                   | 23                                     | 12                                     | 3.6                              | 42                               | 3.3               | 24                | 725.82 | 2.08   |
| 2013 | 0.265                       | 1180                                   | 24                                | 15.83                                   | 50                                     | 12                                     | 4                                | 46                               | 3.2               | 25.6              | 834.22 | 2.30   |
| 2014 | 0.272                       | 1213                                   | 24                                | 13.75                                   | 38                                     | 9                                      | 3.5                              | 55                               | 1.43              | 23.6              | 869.72 | 2.58   |
| 2015 | 0.260                       | 1157                                   | 25                                | 9.08                                    | 22                                     | 8                                      | 3                                | 50                               | 1.75              | 23.4              | 909.63 | 2.22   |
| 2016 | 0.248                       | 1108                                   | 24                                | 10.47                                   | 34                                     | 9                                      | 3                                | 51                               | 1.55              | 23.5              | 809.71 | 3.14   |
| 2017 | 0.151                       | 1419                                   | 25.41                             | 3.35                                    | 28                                     | 9                                      | 2.5                              | 75                               | 1.41              | 24.7              | 840.19 | 3.11   |
| 2018 | 0.262                       | 1167                                   | 25.75                             | 24.45                                   | 21                                     | 10                                     | 2                                | 80                               | 1.37              | 26                | 515.61 | 2.90   |
| 2019 | 2                          | 1846                                   | 25.66                             | 79.28'                                  | 46                                     | 28                                     | 5.20                             | 58.5                             | 1.72              | 26.8              | 452.14 | 2.90   |

The indicators collected in the general table (Table 1) are heterogeneous in units of measurement, which complicates further calculations, so the next step is to standardize the data. In this case, we use the «maximum-minimum» standardization method, where the minimum value in the initial population is assigned the value 0, and the maximum value -1 (Table 2). According to this table, the ranked years by points are distributed from the best by state (rank 1) to the worst (rank 10) (Fig. 2). Figure 2 shows that some indicators interact with each other - they simultaneously decrease or increase, which indicates a direct relationship between them, and there are also indicators that decrease with an increase in other indicators, and, in turn, increase with a decrease.
Table 2. Standardization of indicators (table 1)

| Year | Water volume W, km³ | Water surface area F, km² | Average annual air temperature, °C | Average annual precipitation, (mm / year) | Water flow rate Al-Kahla river Q, m³ / s | Water flow rate Al-Musharah river Q, m³ / s | Water level H, AM (m) |
|------|---------------------|--------------------------|-----------------------------------|------------------------------------------|------------------------------------------|------------------------------------------|---------------------|
| 2010 | 0.025419            | 0.013279                 | 1                                 | 0.09298                                  | 0                                        | 0.228571                                | 0.265625            |
| 2011 | 0.038399            | 0.128703                 | 0                                 | 0.076518                                  | 0.2                                       | 0                                        | 0.53125             |
| 2012 | 0.022715            | 0                        | 0                                 | 0.196365                                  | 0.228571                                 | 0.2                                      | 0.5                 |
| 2013 | 0.061655            | 0.319714                 | 0                                 | 0.164362                                  | 1                                         | 0.2                                      | 0.625               |
| 2014 | 0.065441            | 0.353422                 | 0                                 | 0.136968                                  | 0.657143                                 | 0.05                                     | 0.46875             |
| 2015 | 0.058951            | 0.296221                 | 0.333333                          | 0.075464                                  | 0                                         | 0                                        | 0.3125              |
| 2016 | 0.052461            | 0.24617                  | 0                                 | 0.093771                                  | 0.542857                                 | 0.05                                     | 0.3125              |
| 2017 | 0                   | 0.563841                 | 0.47                              | 0                                         | 0.371429                                 | 0.05                                     | 0.15625             |
| 2018 | 0.060032            | 0.306435                 | 0.583333                          | 0.278888                                  | 0.171429                                 | 0.1                                      | 0                   |
| 2019 | 1                   | 1                        | 0.553333                          | 1                                         | 0.885714                                 | 1                                        | 1                   |

Table 2. Continuation

| Year | Average annual relative humidity% | Average annual wind speed (m / s) | Water temperature t – o C | NDVI vegetation kg / m² | EC dS/m⁻¹ | TDS ppm | Score | Rank |
|------|----------------------------------|----------------------------------|--------------------------|-------------------------|------------|---------|-------|------|
| 2010 | 0.075                            | 0.765258                         | 0.352941                 | 0.664845                | 0.726415   | 1       | 5.031763 | 5    |
| 2011 | 0                                | 1                                | 0.352941                 | 0.81075                 | 0.216981   | 0.792945 | 3.795546 | 8    |
| 2012 | 0.05                             | 0.906103                         | 0.176471                 | 0.598221                | 0.216981   | 0.792945 | 3.795546 | 8    |
| 2013 | 0.15                             | 0.859155                         | 0.647059                 | 0.835166                | 0.207547   | 0.113497 | 5.183155 | 3    |
| 2014 | 0.375                            | 0.028169                         | 0.058824                 | 0.912763                | 0.471698   | 0.631902 | 4.210079 | 6    |
| 2015 | 0.25                             | 0.178404                         | 0                       | 0                       | 0.132075   | 0.641104 | 3.478053 | 9    |
| 2016 | 0.275                            | 0.084507                         | 0.029412                 | 0.781591                | 0.132075   | 0.641104 | 3.478053 | 9    |
| 2017 | 0.875                            | 0.018779                         | 0.382353                 | 0.848215                | 0.971698   | 0.777607 | 5.485172 | 2    |
| 2018 | 1                                | 0                                | 0.764706                 | 0.138735                | 0.733585   | 0.946319 | 5.122462 | 4    |
| 2019 | 0.471318                         | 0.168746                         | 1                       | 0                       | 0.733585   | 0.946319 | 9.799016 | 1    |
Table 3. Correlations of indicators (Part 1)

| Water volume W_{AM} Al-Hoviz AM in km² | Water surface area F Al-Hoviz AM in km² | Average annual precipitation, (mm/year) | Average annual temperature, °C | Average annual wind speed, (m/s) | Average annual relative humidity% | Water flow rate Al-Kahlaa river Q m³/s | Water flow rate Al-Musharrah river Q m³/s | Water level H Al-Hoviz AMa (m) |
|----------------------------------------|----------------------------------------|----------------------------------------|---------------------------------|---------------------------------|---------------------------------|----------------------------------------|----------------------------------------|---------------------------------|
| 1.0000000                             | 0.817648                               | 0.235422                               | 0.970834                        | 0.510316                        | 0.969230                        | 0.745480                               | 0.479583                               | -0.261833                      |
| 0.817648                               | 1.000000                               | 0.173787                               | 0.744140                        | 0.623818                        | 0.769135                        | 0.479583                               | 0.479583                               | 0.479583                      |
| 0.235422                               | 0.173787                               | 1.000000                               | 0.232889                        | -0.398505                       | 0.195010                        | -0.261833                              | 0.479583                               | -0.261833                      |
| 0.970834                               | 0.744140                               | 1.000000                               | 0.480321                        | 0.974455                        | 0.698645                        | 0.745480                               | 0.479583                               | 0.745480                      |
| 0.510316                               | 0.623818                               | -0.398505                              | 1.000000                        | 0.665672                        | 0.559500                        | 0.665672                               | 0.665672                               | 0.665672                      |
| 0.969230                               | 0.769135                               | 0.195010                               | 0.974455                        | 0.768571                        | 0.665672                        | 0.768571                               | 0.768571                               | 0.768571                      |
| 0.745480                               | 0.479583                               | -0.261833                              | 0.665672                        | 1.000000                        | 0.479583                        | 1.000000                               | 1.000000                               | 1.000000                      |
| 0.117113                               | 0.509948                               | 0.348712                               | 0.160335                        | 0.628642                        | 0.291423                        | 0.291423                               | 0.291423                               | 0.291423                      |
| -0.206599                              | -0.558183                              | -0.188206                              | -0.170990                       | -0.145293                       | -0.100691                       | 0.302533                               | -0.447070                              | 0.302533                      |
| 0.684222                               | 0.629530                               | 0.468233                               | 0.732206                        | 0.728642                        | 0.291423                        | 0.291423                               | 0.291423                               | 0.291423                      |
| -0.695896                              | -0.476761                              | -0.436851                              | -0.817030                       | -0.108991                       | -0.734357                       | -0.245683                              | -0.245683                              | -0.245683                      |
| 0.219299                               | 0.427910                               | 0.477351                               | 0.168312                        | 0.155399                        | -0.285145                       | 0.220654                               | -0.220654                              | -0.220654                      |
| 0.298381                               | 0.336678                               | 0.685359                               | 0.228607                        | -0.301178                       | 0.119428                        | -0.220654                              | -0.220654                              | -0.220654                      |

Table 3. Correlations of indicators (Part 2)

| Water volume W_{AM} Al-Hoviz AM in km² | Average annual wind speed (m/s) | Average annual relative humidity% | Average annual temperature t – °C | NDVI veget km² | EC ds/m² | TDS–ppm |
|----------------------------------------|---------------------------------|---------------------------------|---------------------------------|----------------|-----------|----------|
| 0.117113                               | -0.206599                       | -0.695896                       | 0.219299                        | 0.298381        |
| 0.509948                               | -0.558183                       | 0.629530                        | 0.477351                        | 0.336678        |
| 0.348712                               | -0.188206                       | 0.468233                        | 0.168312                        | 0.228607        |
| 0.160335                               | -0.170990                       | 0.732206                        | 0.155399                        | -0.220654       |
| 0.021365                               | -0.145293                       | 0.419286                        | 0.108991                        | -0.301178       |
| 0.100107                               | -0.100691                       | 0.728642                        | 0.155399                        | 0.428857        |
| 0.447070                               | 0.302533                        | 0.291423                        | -0.245683                       | -0.220654       |
| 1.000000                               | -0.771889                       | 0.483121                        | -0.416933                       | 0.428857        |
| -0.771889                              | 1.000000                        | -0.148792                       | 0.176536                        | -0.457694       |
| 0.483121                               | -0.148792                       | 1.000000                        | -0.806478                       | 0.208321        |
| -0.416933                              | 0.176536                        | -0.806478                       | 1.000000                        | -0.355465       |
| 0.618655                               | -0.638470                       | 0.326196                        | -0.333973                       | 0.667692        |
| 0.428857                               | -0.457694                       | 0.208321                        | -0.355465                       | 1.000000        |
Correlation of indicators was made by Spearman's method to determine the interaction of indicators with each other (Table 3).

3. Results

Thus, based on the analysis of the constructed model of the interaction of factors, it can be noted that several of them are most important for monitoring the state of marches - these are average annual precipitation, (mm/year) (factor weight 5.4), water flow rate of the Al-Musharrah River Q m$^3$/s (factor weight 5.5) and water temperature t°C (factor weight 4.97).

The main effects plot is used to study the difference between the average levels of one or several factors. The main effect is that different levels of a factor react differently to the influence of factors. The main effects plot displays the average response value for each factor level connected by a line. When the line is horizontal (parallel to the x-axis), there is no main effect. Each factor level affects the response in the same way, and the average response is the same for all factor levels. When the line is not horizontal, the main effect occurs. Different levels of the factor affect the response in different ways. The steeper the slope of the line, the greater the magnitude of the main effect.

Based on the found interaction of factors and indicators, we build a model of the impact of indicators on NDVI, W$_{AM}$, F and rank them according to the strength of the impact. The main effects plots for each of NDVI, W$_{AM}$, F, as independent variables, are shown in Figure 3.a, where we see the degree of influence of precipitation, H and Q on W$_{AM}$ - at the beginning of the diagram - the line is horizontal and almost parallel to the x-axis, which means that there is no significant effect, but at the end there is a steeper slope of the line, which means an increase in the impact over the last year (2019).
Figure 3. a. Water volume model $W_{AM}$

In Figure 3.b, it is obvious that the indicators affect $F$, where at the beginning of the diagram the line is not horizontal and not parallel to the x axis, but at the end of the diagram there is a steeper slope of the line and especially for precipitation indicators, $H$ and $Q$ compared to others. indicators, which means an increase in impact over the last year (2019).

Figure 3.b. Water surface area model $F$

In Figure 3.c, it is noticeable that the indicators affect the NDVI, where at the beginning of the diagram the line is not horizontal and not parallel to the x axis, but at the end of the diagram there is a steeper slope of the line and especially for indicators of precipitation, air temperature, $H$, $Q$ and TDS compared to other metrics, which means increased exposure over the last year (2019).

Based on this, in Figure 4, we can note the type of relationship and its strength between the factors and the presented indicators (WAM, NDVI, $F$), arrows from factors to indicators indicate a direct relationship, and from indicators to factors - an inverse, black arrows indicate a weak relationship, blue arrows indicate medium bond and red arrows indicate strong bond. It was noted that all factors have a direct relationship with WAM and $F$, but the differential force, except for the wind speed, is inversely associated with a weak and medium relationship, respectively. And the factors have an inverse
relationship with the NDVI, but the differential force, except for wind speed, has a weak direct relationship.

Figure 3.c. Vegetation area model NDVI

Figure 4. Visualization of the model of interaction of factors and indicators
From this visualization of the model, you can clearly highlight the factors that need to be monitored especially carefully, due to their strong impact on the study area. For example, $W_{AM}$ and $F$ are most strongly dependent on the precipitation and $Q$ of the Al-Musharrah river with a feedforward, and the temperature with the strongest feedback, somewhat less with a feedforward, they are influenced by the $Q$ of the Al-Kahlaa river, and with feedback, by the speed wind.

In the presented graph, the actual observation data are shown in blue (Fig. 5), and the most probable forecast data are shown in green. Thus, it is possible to compile a table of predicted values (Table 4), where Forecast are the most probable predicted values (probability up to 95%), and Lower and Upper are, respectively, the less probable lowest and highest values of indicators in the forecasted years.

![Figure 5. Forecast of water level up to 2029](image)

| Table 4. Forecast values of water level (m) until 2029 |
|-----------------|-----------------|-----------------|-----------------|
| Period       | Forecast        | Lower           | Upper           |
| 2020         | 3.01494         | 1.33240         | 4.69747         |
| 2021         | 2.91823         | 1.20933         | 4.62712         |
| 2022         | 2.82128         | 1.08299         | 4.55956         |
| 2023         | 3.46799         | 1.69744         | 5.23855         |
| 2024         | 2.88614         | 1.08059         | 4.69170         |
| 2025         | 2.79221         | 0.94909         | 4.63534         |
| 2026         | 2.69812         | 0.81501         | 4.58123         |
| 2027         | 3.31494         | 1.38958         | 5.24030         |
| 2028         | 2.75734         | 0.78761         | 4.72708         |
| 2029         | 2.66620         | 0.65011         | 4.68229         |

Using the data obtained, it is possible to draw up a general trend of changes in the water level of Al-Hoviz AM (Fig. 6).
In this graph, we can see that while maintaining the current situation, the trend of the water level in the AM will maintain a downward value. Thus, we can predict that, if one does not intervene in the situation, it is quite possible that AM will be drained in the future.

4. Conclusion

The climate of the study area is characterized by hot summers, evaporation from the water surface is high, and the average annual precipitation is low, only in the rainy season from November to early March, which leads to salinization of Al-Hoviz AM.

Based on statistical models, it was noted that all factors have a direct relationship with \(W_{AM}\) and \(F\), but the differential force, except for wind speed, is inversely related to weak and medium relationships, respectively. And the factors have an inverse relationship with the NDVI, but the differential force, except for wind speed, has a direct weak relationship, we see the degree of influence of precipitation, \(H\) and \(Q\) on \(W_{AM}\) and \(F\), which are increased over the last year (2019), and it is noted that in the same year, precipitation, air temperature, \(H\), \(Q\) and TDS had an impact on the NDVI compared to other indicators. All these definitions of the interaction of indicators with each other determine the purpose of the model. In such a situation, the trend of the water level in the AM will maintain a downward value. Thus, one can predict that, if one does not intervene in this situation, it is quite possible that AM will dry out in the future.

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