Assessing climate stability and greenhouse gas emissions in Issyk-Kul basin of Kyrgyzstan: A Focus on the tourist season

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Abstract. The dataset of this study is derived from measurements of greenhouse gases and particulate matter (PM2.5, PM10) collected with portable gas analyzers using the in situ measurement method in the Issyk-Kul basin of Kyrgyzstan. Data were collected from July, 2023 to September, 2023 to assess atmospheric conditions and air quality in towns and villages surrounding Lake Issyk-Kul. Various factors contribute to the deterioration of air quality, including increased automobile traffic and fires. In addition, calm air conditions, which can be caused by anticyclones, temperature inversions or low wind speeds, can lead to the accumulation of pollutants. This stagnation leads to increased concentrations of pollutants and facilitates chemical reactions between them, often resulting in smog.

1 Introduction

The Issyk-Kul basin is facing serious challenges due to climate change, which adversely affects human health, agricultural GDP, residents' income, and their general welfare. This study emphasizes the importance of forecasting and monitoring climatic variability in the region [1]. A major concern is how climate change affects food and water security. Additionally, the infrastructure and artificial environment are increasingly vulnerable to climatic changes, which threaten the biosphere of Lake Issyk-Kul and disrupt its ecosystem [2]. To enhance the welfare of the population in this resort area, expanding ecosystem services throughout the Issyk-Kul Basin is critical. A key aspect of our project involves seasonal monitoring of greenhouse gas (GHG) emissions from economic activities, state facilities, and settlements around Lake Issyk-Kul, assessing their impact on the lake's biosphere.

Rosenstock et al. [3] found that the world emits about 50 billion tons of carbon dioxide equivalent GHGs every year. The future forecasting of GHG emissions in the Issyk-Kul region will primarily rely on data from modern, high-precision measuring instruments, complemented by the use of neural networks known for their high predictive accuracy [4]. Preliminary analyses indicate that the data on GHS emissions and pollutants in the Issyk-Kul biosphere are multifaceted. Notably, there is a direct link between wastewater from melting glaciers and the adjacent agricultural

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lands along the Lake Issyk-Kul. This region experiences significant GHG emissions, originating from agricultural activities, industrial processes, domestic waste, and recreational facilities in the coastal zone of the lake. Together, these sources constitute a complex and substantial category of GHG formation, characterized by both anthropogenic and agricultural emissions. Therefore, to address the formation of GHGs and air pollution in the Issyk-Kul basin and its lake, we propose the adoption of low-carbon and green technologies for river water treatment. These technologies, including constructed wetlands (often referred to as Wetland Biofiltration Units or WBUs), are already effectively employed in both developed and developing countries. Their implementation along the Issyk-Kul basin could provide a sustainable solution to mitigate environmental impacts while aligning with global ecological standards.

As the summer of 2023 commenced, there was a noticeable increase in the influx of tourists to the resorts along Lake Issyk-Kul. The primary tourist zone typically spans from the village of Kosh-Kul to Korumdu. However, due to the elevated air temperatures recorded in July and August of 2023, holidaymakers have been diversifying their destinations, extending their travels to various villages within the Issyk-Kul district (see Fig. 1. below).

This shift in tourist patterns can be attributed to several factors. Primarily, the limited capacity of guest houses in the traditional tourist zones and the high cost of beachfront flats, which usually offer better infrastructure and catering facilities, seem to be driving this change.

Fig. 1. Villages on the sunny side of Issyk-Kul and the town of Cholpon-Ata.

2 Materials and methods

The Earth's atmosphere comprises a complex mixture of gases, along with solid and liquid aerosols intricately 'suspended' within its system. These particles, collectively termed Dispersed Systems (DS), exhibit unique properties necessitating the consideration of the physical and chemical processes occurring at each particle's surface. A dispersed system is characterized as a composition of two or more substances, wherein one substance exists as finely dispersed particles within the medium of the other. By examining the classification of these disperse systems, their nomenclature can be understood based on their numerical size, as delineated in Table 1.

<table>
<thead>
<tr>
<th>Aggregate state in the dispersed phase</th>
<th>Aggregate state in a dispersed medium</th>
<th>System name</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gas</td>
<td>Gas</td>
<td>Aerosols</td>
<td>Earth's atmosphere</td>
</tr>
</tbody>
</table>

Table 1.
According to the data presented in the Table 1, the atmospheric air system contains several thousand tonnes of fine particles and gases. In addition to these naturally occurring substances, the atmosphere is also burdened with a range of anthropogenic pollutants. These include chemical compounds, gases, and smoke emissions from vehicular engines, as well as liquid and solid particulates resulting from human activities. Furthermore, burning of firewood and solid fuels contributes significantly to air pollution. Notably, the presence of minute solid metal particles poses a global threat to the biosphere, adversely impacting the quality of air. These findings underscore the critical need for comprehensive environmental monitoring and management strategies to mitigate the detrimental effects of such pollutants on the air we breathe.

The study of dispersed systems presents a multifaceted challenge, encompassing the examination of their kinetic and optical properties, among others. The complexity of these systems necessitates advanced approaches in modeling and forecasting their impacts on climate and ecology. Importantly, the study considers the significant environmental impacts caused by human activities. In this context, the application of artificial intelligence (AI) emerges as an indispensable tool for assessing environmental balance. The research undertaken by the AI Research Centre at Kyrgyz National University named after J. Balasagyn addresses this pressing contemporary issue. Their work highlights the crucial role of AI in advancing our understanding of environmental dynamics and in developing effective strategies for ecological management.

2.1. Study of the composition of micro-sized particles in the atmospheric air near motorways and near Lake Issyk-Kul

In this study, we present the results of instrumental measurements of the mass concentration of fine particulate matter (PM2.5, PM10) and the total suspended particles (TSP) in the atmospheric air of villages located between Sary-Kamysh and Orto-Uryuk, as well as in Cholpon-Ata city (see Fig. 1). These measurements were conducted thrice daily—at morning, noon, and evening—near motorways and lake shores. We employed gas analyzers designed for continuous automatic monitoring of PM2.5, PM10, and total dust content in the air.

Throughout the study period, no exceedances of the established maximum permissible concentrations (MAC) for fine particles in the PM2.5 and PM10 fractions were recorded near the roadways. However, we observed a sharp, albeit temporary, increase in particle mass concentration at locations with high vehicle congestion. In the early morning, the mass concentrations of suspended particles along the road were as follows: PM2.5 ranged between 6 and 14 µg/m³, PM10 between 8 and 12 µg/m³, and TSP between 5 and 10 µg/m³. Notably, the mass concentration of suspended particles near the lakeshore was observed to be approximately at similar levels.

The data obtained from this study are instrumental in calculating health risks to the population from exposure to transport-related gases, assessing the composition of PM2.5 and PM10 near motorways, and planning further air quality monitoring studies in the district's villages and settlements, including Cholpon-Ata city. We anticipate that these findings will facilitate the development of computerised forecasting models and the application of the Air Quality Index (AQI) for more effective environmental management.
2.2 Carbon dioxide study

Carbon dioxide (CO$_2$) is a chemical compound comprised of one carbon atom and two oxygen atoms. Also known as carbonic acid or carbon dioxide gas, it is a prominent greenhouse gas. CO$_2$ plays a crucial role in the Earth's environmental systems, including the atmosphere, lithosphere, biosphere, and hydrosphere, facilitating the carbon exchange among these spheres [3].

As a GHG, CO$_2$'s concentration in the atmosphere is a key determinant of the planet's climate [3]. Its ability to absorb and trap infrared radiation creates the GHG, which is essential for maintaining the Earth's temperature. Without this effect, the planet's average temperature would be approximately 30 degrees Celsius lower [3].

However, the increasing concentration of CO$_2$ in the atmosphere, primarily due to industrial activities, poses significant environmental challenges. Increased levels of CO$_2$...
enhance the greenhouse effect, which leads to global warming—a rise in Earth’s average temperature. This warming has far-reaching consequences, including rising sea levels due to melting glaciers, increased frequency of natural disasters, desertification, ocean acidification, and extreme climate changes. These changes pose a threat not only to human health but also to the entire biosphere.

In addition to its environmental impact, CO₂ finds extensive use in various industries, ranging from food production to medicine. This highlights its integral role in diverse biological, climatic, and chemical processes. The challenge facing humanity today is the effective management and control of CO₂ concentrations, tasks that are of global importance.

2.3 In situ measurement of carbon dioxide

In early August 2023, we conducted a field measurement experiment within the Issyk-Kul district villages and the town of Cholpon-Ata. Measurements were taken three times daily over a 10-day period using two types of portable gas analyzers. During that month, the climatic weather parameters were as follows (applicable to all measurements): temperature ranged from 22 to 28°C, humidity varied between 34% and 52%, wind speeds reached up to 7 m/s, and atmospheric pressure was recorded between 625 and 636 mm Hg.

The concentration of CO₂ gas in the area spanning from the villages of Sary Kamysh to Orto-Uryuktu and the city of Cholpon-Ata showed significant fluctuations, ranging from 264 to 580 µg/m³. The highest concentration of CO₂ was recorded in Cholpon-Ata. In Cholpon-Ata city and the nearby village of Bosteri, the CO₂ emissions were predominantly anthropogenic in nature. This is attributed to the high volume of vehicular traffic, with more than 20,000 vehicles estimated to pass through daily. For context, observations made in April revealed that the concentration of carbon dioxide in the same area was approximately 230 to 370 µg/m³, indicating a notable increase in subsequent months.

In our study, measurements were taken from the shore of the lake as well as from altitudes above it. This approach was adopted in response to the observation of numerous scooters on the lake, which are a popular recreational activity where many people gather. Given that a single scooter is estimated to consume approximately 150-180 liters of fuel per day, quantifying the exact amount of CO₂ emissions over the lake proved challenging. However, our instruments recorded CO₂ concentrations ranging from 400 to 620 µg/m³ above the lake surface.

These measurements were conducted in the village of Ananyevo, encompassing various locations: from the mountain base, along the lakeshore, and at altitudes of 700 to 1000 meters above the lake. The CO₂ values exhibited notable variations: approximately 340-360 µg/m³ at the mountain’s foot, 400-420 µg/m³ in garden areas, 400-420 µg/m³ at the junction of the village with the highway, 380-430 µg/m³ along the lakeshore, and 425 µg/m³ consistently at heights of 3 to 5 meters above the lake. It is important to note that there were no motorboats present on this particular beach during the time of measurement.

In order to identify the moving average trend of carbon dioxide concentrations from 2011 to 2023, an integrated ARIMA model was utilized (see Fig. 4a and b). The graphs reveal distinct trends: from 2011 to 2016, no significant change in CO₂ concentrations was observed; however, from 2016 to 2020, a slight increase occurred. Remarkably, in 2020, a sharp decline in CO₂ concentrations from 480 µg/m³ to 280 µg/m³ was clearly observed, coinciding with the global COVID-19 pandemic. This decline is supported by scientific sources, which note that CO₂ emissions were reduced by approximately 7% in 2020 alone, equivalent to a reduction of about 2.4 billion tons from the previous year’s total of approximately 34 billion tons. This significant fluctuation in CO₂ emissions underscores the necessity for the global community to engage with the Paris Agreement on Climate Change.
Protection [19], which aims to limit global warming to a temperature increase of no more than 2°C compared to pre-industrial levels (1750-1850) by 2030.

Fig. 4. Changes in the CO₂ trend.

Changes in the CO₂ trend over a 10-day period (see Fig. 4) exhibited a complex oscillatory character, marked by sharp increases and abnormally low concentrations. Overall, the average trend indicates a slight increase in CO₂ concentrations. Furthermore, our measurements focusing on methane (CH₄), a potent greenhouse gas, indicated concentrations ranging from 0.01 to 0.06 µg/m³ in areas densely populated with poplar trees. Concurrently, levels of carbon monoxide (CO) and oxygen (O₂) were observed to be within normal ranges, with oxygen content in some tree-rich areas registering between 20% and 22%.

Coinciding with the end of July and the beginning of August, a period marked by increased solar activity, we observed the effects of neutral particles carried by the solar wind impacting the Earth's surface. Our gamma radiometer recorded measurements in the range of 0.16 to 0.24 µg/h during this period. Additionally, on the mornings of these days, we noted the occurrence of snowfall on the peaks of the Kungai Ala-Too mountain range. It shows that, even during the summer period, the region experiences abnormal days. Nevertheless, these abnormal weather conditions do not impact the resort season at Issyk-Kul, where approximately 200 resorts and recreation centers of various ownership types continue to receive vacationers and tourists [9]. From an analytical standpoint, it can be asserted that during the summer seasons, the primary sources of atmospheric pollutant emissions in the...
Table 2. Emissions of pollutants into the atmospheric air from fuel consumed by motor vehicles, in thousand tons.

<table>
<thead>
<tr>
<th>Emissions</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon monoxide</td>
<td>207,634</td>
<td>379,904</td>
<td>306,897</td>
<td>306,258</td>
</tr>
<tr>
<td>Hydrocarbons</td>
<td>22,741</td>
<td>41,609</td>
<td>33,613</td>
<td>33,542</td>
</tr>
<tr>
<td>Sulphur dioxide</td>
<td>0,742</td>
<td>1,357</td>
<td>1,096</td>
<td>1,093</td>
</tr>
<tr>
<td>Nitrogen oxides</td>
<td>13,348</td>
<td>24,422</td>
<td>19,729</td>
<td>19,688</td>
</tr>
<tr>
<td>Soot</td>
<td>0,544</td>
<td>0,995</td>
<td>0,803</td>
<td>0,802</td>
</tr>
<tr>
<td><strong>Total emissions</strong></td>
<td>256,909</td>
<td>479,174</td>
<td>395,535</td>
<td>400,270</td>
</tr>
</tbody>
</table>

3 Results and discussion

It is apparent that the wetland along the shore of Lake Issyk-Kul holds significant ecological potential. If restored to its original natural state, as depicted in Fig. 5-6, this area could become a vital habitat for migratory birds, leading to the formation of a rich wetland ecosystem [6]. This restoration is an important task that needs to be undertaken in the near future. The rehabilitation of the wetland is a critical task that must be addressed in the near future to enable the storage of carbon-containing gases and the subsequent reduction of GHG emissions.
The observed increase in hydrogen sulphide content in the coastal atmosphere is likely indicative of an H2S source in the vicinity. Considering this, Ananyevo village has the potential to develop into a resort area featuring natural springs. Hydrogen sulfide springs are recognized for their therapeutic properties, which include the improvement of muscle and joint metabolism, reduction of blood cholesterol levels, and stimulation of the thyroid, sex glands, and adrenal glands. This necessitates long-term monitoring of the site [3]. Consequently, field measurements of suspended particulate matter and greenhouse gases conducted during the summer period in the Issyk-Kul Basin yielded the following average values, as shown in Table 3.

### Table 3. In-situ measurements of suspended particulate matter and greenhouse gas in the summer period at the Issyk-Kul Basin.

<table>
<thead>
<tr>
<th>No</th>
<th>Towns and villages</th>
<th>Distances, km</th>
<th>CO2</th>
<th>CH4</th>
<th>PM2.5</th>
<th>PM10</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Bishkek</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Balykchy</td>
<td>164</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Tamchy</td>
<td>219</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Baet</td>
<td>245</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Cholpon-Ata</td>
<td>255</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Temirov</td>
<td>280</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>7</td>
<td>Ananyevo</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Orukty</td>
<td>345</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Karakol</td>
<td>400</td>
<td></td>
<td></td>
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</tbody>
</table>
4 Conclusion

In this study, we have identified key factors contributing to the increase in GHG emissions, particularly during the summer months. Notably, this rise is predominantly anthropogenic, closely linked to the surge in tourist activity in river regions. The increase in leisure activities, especially the use of motor vehicles, plays a significant role in augmenting these emissions.

Agriculture is another critical sector impacting GHG levels. Our observations reveal that farmers' reliance on various fertilizers for enhancing crop yields inadvertently contributes to the escalation of GHGs. This agricultural practice, although essential for food production, exacerbates climate change challenges.

Moreover, our study has observed environmental changes along the lake shores, including a marked decline in sea buckthorn bushes and the near disappearance of wetlands. These changes are primarily due to the expansion of agricultural land and the alteration of groundwater levels. This situation underscores the complex interplay between agricultural expansion and the preservation of natural ecosystems.

Overall, our findings highlight the urgent need for balanced environmental strategies that address the rising GHG emissions, while considering the imperatives of agricultural productivity and ecological conservation.

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