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Consideration of Water Uses for Its Sustainable Management, the Case of Issyk-Kul Lake, Kyrgyzstan

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Abstract: Water is an essential element for life, and development would not be possible without its availability. This study identified the main water consumers and their likely impact on water lake level for the case of Issyk-Kul Lake Basin, Kyrgyzstan. Data on precipitation, lake level, irrigation, household and industrial water consumption from 1980 to 2014 were provided by the Department of Water Resources and Irrigation, Ministry of Agriculture and Land Reclamation of the Kyrgyz Republic. The input data was analyzed with OriginPro 8.5 for Statistical Analysis. The results indicated a decreasing irrigation water consumption from 2029.42 to 461.76 million$\cdot$m^3 in 1980 and 2014, respectively. Likewise, households consumed 27.02 million$\cdot$m^3 in 1980 falling to 16.55 million$\cdot$m^3 in 2014, similar to the manufacture's water consumption. However, it was noted that agriculture is a high water consumer, whose water demand for irrigation rises from April to August, the period during which the precipitation also increases. Nevertheless, manufactures and household water consumption do not have timed limits of use like in agriculture, which in turn affects the lake water level. Therefore, as the rainfall increases by April to August, we suggest to harvest and only use the rainfall water during its abundance period. This would help in restoring the lake's water level during the time of rainwater uses, and leads to water consumption balance, flood management and lake biodiversity conservation as well.

Keywords: agriculture; Issyk-Kul lake basin; household; manufacture; water consumption

1. Introduction

Agricultural irrigation practices, rapid urbanization and climate change increase pressure on water resources. The world population is projected to be 9.7 billion by 2050, an increase of about 2 billion from today (7 billion); this world population may increase its pressure on both water quality and quantity [1,2]. Worldwide water utilities experience seasonal fluctuations in their aggregate consumption levels and these variations generally cause specialized maintenance and administrative schedules to develop individual utilities as a mean of optimizing the natural resources [3]. Water from rivers, lakes and aquifers is mostly used for irrigation, bathing, washing and other human needs. Increasing exploitation of natural resources, inappropriate land-use practices, and uncoordinated sectoral policies and development activities in lake basins impair various

important functions of water. Therefore, appropriate approaches for water management are urgently needed [4–6].

Natural forces and human activities have been reported to damage water resources. Despite increasing public awareness on the role of water in human health and development, water scarcity and pollution is experienced due to lack of consistency and consensus of economic and political willingness on water resources management [7,8]. Water plays an important role in the productive process, since this natural resource can become either a limiting factor for development or the driving force behind economic growth. Therefore, it is necessary to know the situation regarding water resources and its relationship with the regional productive process [9]. Water size and salinity fluctuate whenever the balance between hydrological inputs (precipitation, surface runoff and groundwater inflows) and outputs (evaporation and seepage losses) changes due to seasonal and climatic variation or anthropogenic activities [10,11]. While the impact of water diversions for irrigated agriculture and urban consumption on several large salt lakes (Aral Sea, Dead Sea, Mono Lake) has been widely publicized, the global extent and rapidity with which saline lakes are being impacted throughout the world has yet to be fully appreciated [12,13].

Kyrgyzstan is a Central Asian country with the advantage of having water resources fully formed in its own territory. Kyrgyzstan has significant resources of underground and surface waters, stocks of which are in the rivers, glaciers and eternal snow arrays. The country has more than 3500 rivers and streams, which belong to the main pools; the Syr-Darya river, the Amu Darya, Chu, Talas, Tarim and Lake Issyk-Kul [14–16]. On its territory is the the Issyk-Kul basin formed by a plurality of streams, of which about 123 are used for irrigation purposes. Surface water is characterized by sediment, salts and fine sediments transported by the lake surrounding rivers. Mineralization of surface waters in general is less than 1 g/L, which makes it suitable for irrigation [17,18]. The Lake Issyk-Kul has been subject to changes in its water level, increasing sediments and other anthropogenic activities which changed its physical-chemical properties [19]. Previous studies conducted at Lake Issyk-Kul [18,20,21] have identified its main problems related to water pollution and its increasing water demand, which in turn, threaten sustainable use of the lake, fisheries, glacial retreat, agriculture, water diversions, biodiversity, tourism and its biosphere reserve. This shows that Issyk-Kul Lake Basin is under increasing pressure which needs accurate and sustainable management for its continuous use. Therefore, the objectives of this study are to (1) consider historical water consumption and its main users and (2) provide suggestions, based on the results, regarding how the lake water can be sustainably productive and usable.

2. Materials and Methods

2.1. Description of the Study Area

Issyk-Kul lake basin is a closed mountain lake, located at about 77° E and 42°30′ N, in the northern part of the Tian-Shan mountain belt in the Kyrgyz Republic (Central Asia). It is situated at an altitude of 1607 m above sea level and surrounded by high mountain ranges: the Kungey Ala-Too Range in the north with the highest peaks reaching 4770 m, and the Teskey Ala-Too Range in the south with peaks exceeding 5200 m [22–24], see in Figure 1. The total area equals approximately 22,080 km^2, of which the lake occupies 6236 km^2, the coastal zone called zone dissipation runoff occupies 3092 km^2, and other part of the basin (12,752 km^2) is occupied by mountain areas.

Moreover, about 118 rivers enter the lake and are predominantly fed by melt-water from snow and glaciers, which occupy about 509 km^2 of this drainage basin, at altitudes of 3000 m and above [25–27]. Currently, 17 hydrological stations are in use around the lake. The main local lake's climate formation factors are a huge mass of water and the chain mountainous ridges that protect the basin from the scorching breath of the Central Asian deserts. The climate of Issyk-Kul basin is moderately warm, favorable for grain, crops and gardening [28,29].

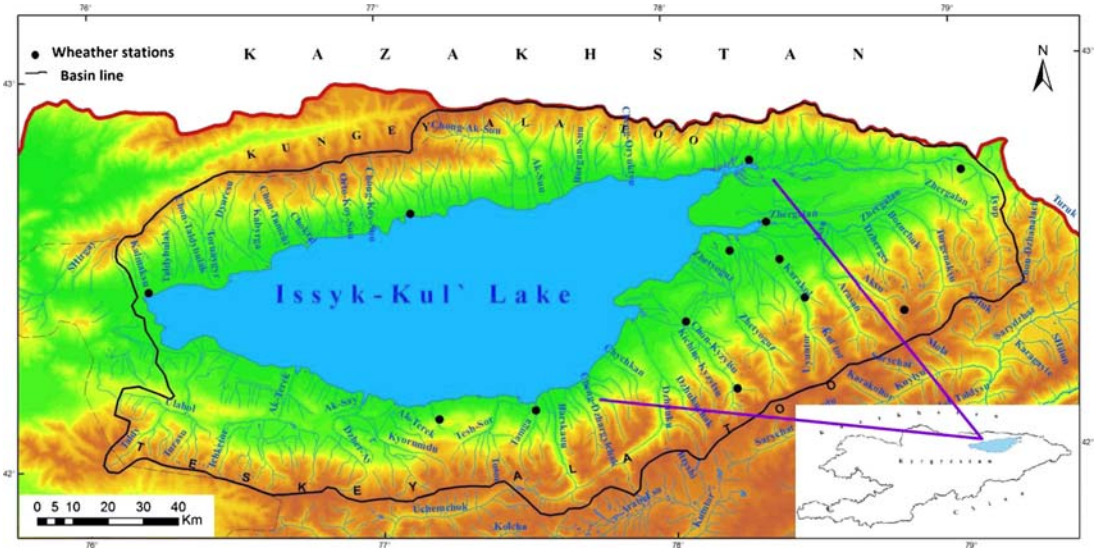

Figure 1. Map of Issyk-Kul Basin Lake.

2.2. Data Collection and Analysis

This study used data on irrigation, household and manufactures water consumption and lake water level provided by the Department of Water Resources and Irrigation, Ministry of Agriculture and Land Reclamation of the Kyrgyz Republic, from 1980 to 2013. Data on precipitation was provided by the Meteorological stations (Cholpon-Ata, Balykchy, Kyzyl-Suu and Karakol) located around the Issyk-Kul Lake Basin. The input data was analyzed with OriginPro 8.5 for Statistical analysis. In addition, this study adopted the literature methodology to facilitate the analysis and discussion of the results.

3. Results

3.1. Issyk-Kul Lake Water Level and Supply

Issyk-Kul Lake has been subject to several water consumers, including but not limited to construction, irrigation and recreation. These water uses led to variation in the lake's water level being headed by agricultural irrigation water demand, which was 43% in 1998 of the total lake tributaries [19], against today's increase, which is more than 70% compared to other lake's water consumers.

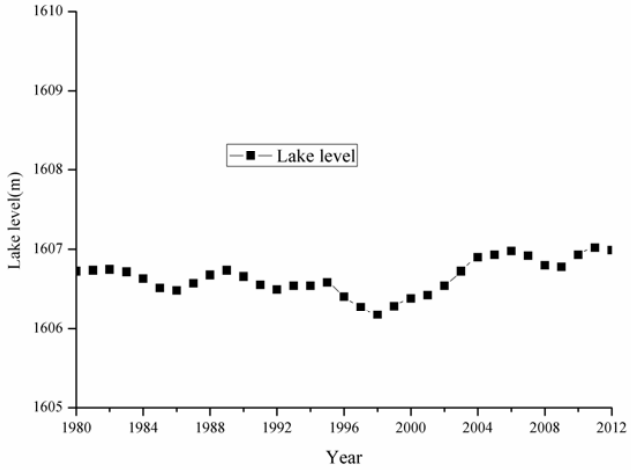

Figure 2. Issyk-Kul Lake water level.

As indicated in Figure 2, the lake registered little seasonal variation of water levels from 1606.73 m in 1980 to 1606.29 m in 1999, while from 2000, the water level slightly increased until 2011 (1607.02 m) and ended in 2012 with small decreasing numbers (1606.99 m). These alterations of water level can result from the lake water uses and the system under which the water is used and/or climate change, which is reported to affect water resources.

3.2. Annual Precipitation Variation

The Issyk-Kul lake water is subject to changes in the runoff and distribution of its sources, mainly the rainfall, snowmelt water, glaciers and other tributaries. However, as indicated in Figure 3 below, some years feature heavy precipitation compared to others, which in turn affects the lake water level. The precipitation was marked by increasing and decreasing records. The high value was registered in 1993 (35 mm) and the lowest was 12.3 mm in 1997, while the years of 2007 up to 2013 recorded decreasing rainfall from about 29.9 to 25 mm, respectively.

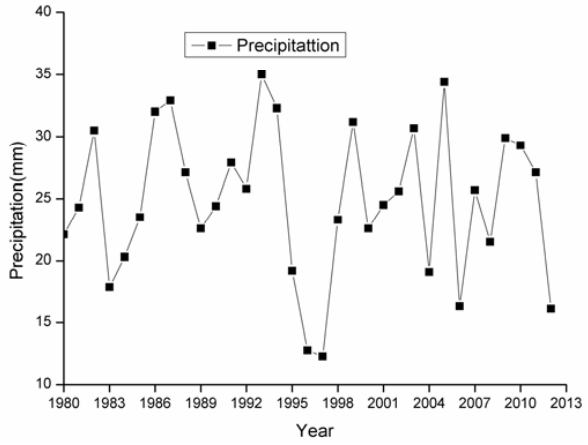

Figure 3. Averaged annual precipitation from 1980 to 2013 precipitation as one of the lake's water sources, can affect the water level due to its annual fluctuations.

3.3. Main Issyk-Kul Lake Water Consumers

The results (Table 1) on the lake's water consumers considered (agricultural irrigation, manufacture and household) from 1980 to 2014 reveal decreasing water consumption numbers. This reduction in water consumption could be a result of the collapse of the Soviet Union in 1989–1992, where water users decreased and the remaining were deployed in different places, meaning that they used other water sources [29,30]. However, as the population around the lake grows, its water demand rises, and leads to a water level decrease, which was detected and controlled by government policies through using other lakes and basins, managing the lake's streams, soil erosion control measures, rainwater harvesting, etc. [17,19,26,31].

Table 1. Lake water consumers from 1980 to 2014.

Time (Years)	Agriculture	Manufacture	Household
1980–1989	2029.42	17.74	27.02
1990–1999	981	9.46	18.06
2000–2014	461.76	8.74	16.55

Note: Table 1 reveals decreasing water consumption (million·m^3) for all considered consumers; however, despite the reduction in water demand; agriculture is still the lake's highest water consumer compared to manufacture and household water consumption accounts.

Although agriculture water demand showed decreasing numbers (Table 1), its water demand has been reported [8,32] to change over time with great likelihood of increasing water demand depending

on the type of crops grown. In addition, the types of irrigation like flooding or sprinkler cause high volume water consumption, because they are associated with environmental effects like water salinization, while, drip irrigation is suggested for both quantity and quality of water management, as it does not consume much water but helps to reach crops with minimum total water use [33,34]. Therefore, it is good to consider the best irrigation practices which favor water management at Issyk-Kul Lake Basin.

4. Discussion

4.1. Water Resources and Increasing Demand

Issyk-Kul has been subject to changes in its water level, increasing sediments and other anthropogenic activities such as expansion of agricultural irrigated lands and rise of recreational, household and industrial water demand [18,20,21]. These threaten the lake fisheries, glacial, water quality, biodiversity, biosphere and other socio-economic and environmental services and call for appropriate measures for its sustainable management and use.

Water demand at Issyk-Kul Basin Lake (Table 1), reveals decreasing numbers, which could be a result of the region's background and the lake water management measures adopted [29,30]. However, as the basin is used for many other purposes, such as ecological or socio-economic [20,31]. This exposes the lake to natural and anthropogenic forces, meaning that whatever measures are taken for its management, there is great need to consider each and every demand and/or use to sustainably manage the lake water due to its role in the sustainable socio-economic development of the region.

4.2. Climate Change and Water

Climate change puts pressure on the quantity and quality of water resources. This pressure has been previously reported to lead to precipitation fluctuations in Asian countries [8,35,36] and these shifts on the hydrological budget are expected to increase with effect on water resources.

The findings, illustrated in Figure 4 below, are in agreement with previous findings [37,38] that highlighted how variation in precipitation is among reasons of water shortage, and suggested using rainfall harvest as an alternative and involving local community, who the most affected by water deficit, in decision making regarding water resources management. This enhances durable access to safe and clean water and its management, and ensures that everyone involved will consider the right way of sustainably using water [39].

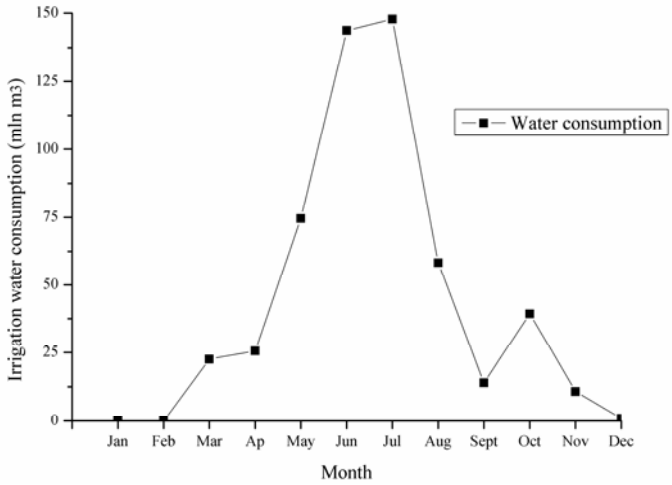

Figure 4. Issyk-Kul Lake Monthly Agricultural water consumption, there is gradual water demand within the months of February to July, while from July to September the demand decreases then rises again in October. This variation in agricultural water demand calls for great consideration of monthly precipitation and other water sources for the lake to be well managed under its varying demand and uses.

In addition, precipitation increases from April to July/August, then keeps on decreasing up to the end of the year (Figure 5), while in October, agricultural water demand rises again (Figure 4), under decreasing precipitation. This shows that the time of high volume of water demand is not proportional with its availability (Figure 4 against Figure 5), which can be seen in previous studies [33,40] which reported that agriculture is among the world's most significant water consumers and its water consumption is projected to keep increasing as long as the human population grows, where adaptive policies are to be regarded. Moreover, the population located near Issyk-Kul Lake grew from 441.3 to 458.5 thousand in 2010 and 2014, respectively [41]. This expresses increasing food demand, household and other development activities which require availability and access to water. For the problem to be dealt with, it is proposed to interchangeably use the lake and rainfall water [42,43].

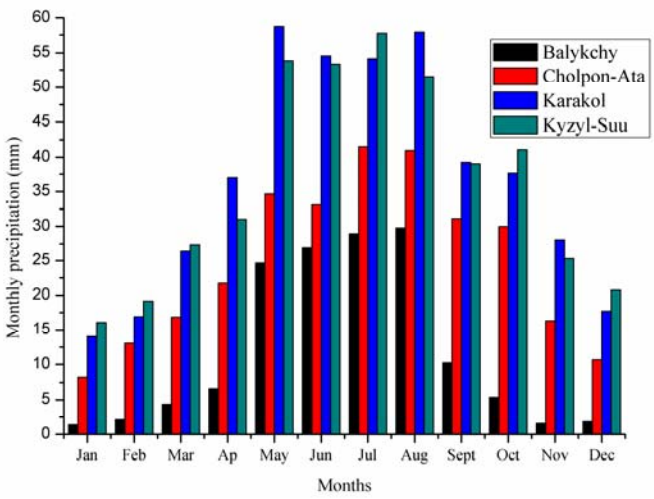

Figure 5. Averaged monthly precipitation from 1980 to 2013 per station, meteorological stations reveal gradual increase of precipitation from January to April being followed by remarkable increase from May to July/August, with high marks at both the Karakol and Kyzyl-suu meteorological stations, while from September to December the intensity of precipitation decreases.

Despite the fact that integrated water resources management action is being taken, it is still mandatory to consider climate change, global population growth and other increasing water demands for its sustainable management [44]. Furthermore, even though the results of this study revealed decreasing water demand (Table 1), to mitigate and adapt to the impact of climate change on water resources, particularly at Issyk-Kull basin, it is good to consider the hydrological weather related changes that are appearing (Figures 3 and 5) and adapt accordingly.

4.3. Water and Sustainability

Sustainable development, socio-economic development, healthy ecosystem and human survival are rooted in water availability. Water helps in hosting and preserving development activities upon which human depend in daily life. It also serves as the link between the climate system, environment and human society [45,46]. Water, if efficiently and equitably managed, can help to achieve sustainable development. However, it has been reported that water scarcity is among the most significant development challenges worldwide, and access to water is not equal [47,48].

The United Nation's (UN) overarching goal is to secure sustainable water for all, due to the role of water in ensuring people's health, prosperity, resilient communities, equitable societies and protected ecosystems, which in turn are the basis of sustainable development [49]. Nevertheless, this cannot be realized without universal access to water, its sustainable management and effective governance [50]. Water management is also a serious problem in Eastern Asia, where a number of problems, compounding the issue include but not limited to floods, increased salinization and a loss of

fresh water reserves due to agriculture along with pollution from sewage and industry have severely damaged the water supply with dangerous effects on the health of local people [51].

For sustainable management of Issyk-Kul Basin Lake, whose water is used for many purposes, there is great need to take into consideration: variation of water resources (Figure 2); the changing climate which causes fluctuations in intensity and frequency of precipitation (Figures 3 and 5), one of the sources of the lake's water; managing the changes (increase/decrease) in the demand and uses of the lake water (Figure 4 and Table 1) along with decision makers and common community understanding on the use, conservation and protection of the lake.

5. Conclusions

This study considered the Issyk-Kul Lake to determine the change in its water consumption and suggest future water management practices. The results indicated that agriculture was the main water consumer for irrigation practices along with household and manufacture water consumption. The identified lake water consumers revealed decreasing numbers; however, meteorological stations and annual average precipitation indicated timely variation in rainfall, one of the lake water sources. Precipitation increases from May to July and/or August, the period in which agricultural water demand (seasonal) was increasing. This can lead to drought if consumers use lake water and/or flooding due to heavy rain which is not managed. Based on the findings for water management at Issyk-Kull lake, we suggest to (1) consider maximum rainfall harvest for the lake water and biodiversity conservation; (2) irrigate with the rainfall water during its falling time and reserve the lake water for manufacture and households whose water demand does not have a time limit; and finally (3) integrate decision makers and the local community (water users) into water resources management policy making.

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Author Contributions: Burul Alymkulova and Jilili Abuduwaili designed the study; Gulnur Issanova statistically computed the input data; Burul Alymkulova and Lamek Nahayo wrote the manuscript. Finally, all authors contributed to the final version of manuscript by proofreading.

Conflicts of Interest: The authors declare no conflict of interest.

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