МРНТИ 20.23.27, 28.23.15

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COMBINATION OF GIS AND REMOTE SENSING AS A TOOL IN CIVIL ENGINEERING. A CASE OF MAIBALYK RESERVOIR, KAZAKHSTAN

AbstractThis study used the GIS and RS-based approach for a reservoir analysis, a case of the Maibalyk water reservoir in Nur-Sultan, the capital city of the Republic of Kazakhstan, to investigate the geomorphological characteristics of the reservoir and their potential to flood events. The reservoir is one of the potential recreational sites in Nur-Sultan. The Storage Capacity tool in conjunction with Digital Elevation Model (DEM) was used to compute water-surface elevations and corresponding storage capacities in the ArcGIS 10.5 software package. The input boundary polygon was extracted using Google Earth Pro images. The state of land use/land cover around the reservoir was also successfully derived from Landsat images. More low-lying areas (flood zones) were observed in the North and West of the reservoir compared to the South and East of the reservoir.
Keywords: Reservoir, GIS and RS, DEM, engineering structure, water storage.

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Аннотация. В данном исследовании для анализа водохранилища на примере Майбалыкского водохранилища в столице Республики Казахстан, Нур-Султане, был использован подход, основанный на ГИС и ДЗ, для исследования геоморфологических характеристик водохранилища и его потенциала к паводковым явлениям. Водохранилище является одним из потенциальных рекреационных объектов в г. Нур-Султане. Для расчета водно-поверхностных высот и соответствующих емкостей хранилищ в программном комплексе ArcGIS 10.5 был использован инструмент Storage Capacity совместно с Цифровой моделью рельефа (ЦМР). Входной граничный полигон был извлечен с помощью изображений Google Earth Pro. Состояние землепользования/почвенно-растительного покрова вокруг водохранилища также было успешно выведено из снимков Landsat. На севере и западе водохранилища наблюдалось больше низинных участков (зон затопления) по сравнению с югом и востоком водохранилища.
Ключевые слова: Резервуар, ГИС и ДЗ, ЦМР, инженерная структура, водохранилище.

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Түйіндеме. Осы зерттеуде Қазақстан Республикасының елордасындағы Майбалық су қоймасы мысалында су қоймасын талдау үшін Нұр-сұлтан су қоймасының геоморфологиялық сипаттамаларын және оның су тасқыны құ-

былыстарына әлеуетін зерттеу үшін ГАЖ және ҚЗ негізделген тәсіл қолданылды. Су қоймасы Нұр-Сұлтандағы әлеуетті рекреациялық нысандардың бірі болып табылады. ArcGIS 10.5 бағдарламалық кешенінде су-беттік биіктіктер мен сақтау қоймаларының тиісті сыйымдылықтарын есептеу үшін рельефтің сандық моделімен (РСМ) бірге Storage Capacity құралы пайдаланылды. Кіру шекара полигоны Google Earth Pro суреттерінің көмегімен алынды. Су қоймасы айналасындағы жер пайдалану/топырақ-өсімдік жамылғысының жағдайы да Landsat суреттерінен сәтті шығарылды. Су қоймасының солтүстігі мен батысында су қоймасының оңтүстігі мен шығысымен салыстырғанда төменгі учаскелер (су басу аймақтары) көп байқалды.
Түйінді сөздер: Резервуар, ГАЖ және ҚЗ, РСМ, инженерлік құрылым, су қоймасы.

Introduction. In the modern world, reservoirs have been important recreational sites, especially in cities. The whole process of transforming reservoirs into recreational sites requires an extensive assessment of the site. The planning and design processes are data-intensive posing a challenge to the field of Civil Engineering as part of the design teams. To transform a natural landscape into a modified recreational site, a systematic analysis is needed which must include the optimization of its structure and behavior [1]. Also, the reservoirs like Maibalyk may be highly vulnerable to flooding events if not properly managed. Therefore, in this era of massive data proliferation requirements from different sources, the priority is to develop efficient and effective methodologies or approaches geared towards optimizing data combinations as well as simultaneously solving increasingly complex application problems. A combination of GIS and RS utilizes the great potential that lies along the interface between GIS and RS for creating interoperable databases and simplifying information access and sharing [2]. The demand and use of GIS technology in the technical practice including Civil Engineering has been increasing [3].

In the preparatory phase of the construction, the problems of a spatial positioning (location) of the construction have to be solved jointly with the checking of the feasibility and purposefulness, the traffic projects are worked out, and the alternative. More detailed solutions to technical problems are designed. At project development there are used various forms of initial documents, results of the actual data gathering and surveys, map sheets, photographs, previous documents referring to the problems solved, and appropriate legal and technical standards [4]. In the recent past, apart from the recreational purposes, many studies have also been studying reservoirs for different other purposes such as simulating reservoir storage for a wind-hydro hybrid system, differences in the implementation of safe levels for reservoirs used for water supply and recreation, drought storage allocation rules for surface reservoir systems [5]. Also, land surface evaluation is an important aspect during the process of data compilation, interpretation, and conceptual ground modeling before undertaking engineering ground or site investigation work [6]. However, the morphological data for Maibalyk reservoir is still scarce. In this study, a GIS and RS-based approach for a reservoir analysis is used, a case of the Maibalyk water reservoir in Nur-Sultan, the capital city of the Republic of Kazakhstan. The study aimed to identify potential flood zones as influenced by morphological characteristics of the reservoir. With the help of the Storage Capacity tool (Spatial Analyst supplement tool) in conjunction with Digital Elevation Model (DEM), the computation of water-surface elevations and corresponding storage capacities in ArcGIS 10.5 software package was achieved. The geo-referenced input boundary polygon for demarcating the boundaries of the reservoir was extracted using Google Earth Pro images. Land use/land cover analysis around the reservoir territory was also accomplished in ArcGIS using Landsat images. The results derived from this study reveal the potential of incorporating GIS and RS especially in the preliminary stage of a site characterization, design as well as monitoring of an engineering structure.

Materials and methods. Maibalyk reservoir is located on the southern outskirts of Nur-Sultan, the capital city of Kazakhstan, a kilometer away from the Nur-Sultan Nazarbayev International Airport, between the Nura and Ishim rivers. The reservoir territories are characterized by low intensity developed areas (Figure 1). The total area of the reservoir with the adjacent territory is 73 km^2. Maibalyk Lake or reservoir is one of the planned public recreation areas for residents and guests in Nur-Sultan. In 2010 an international architectural competition for the sketch-idea of the project towards developing the reservoir into a recreational site took place.

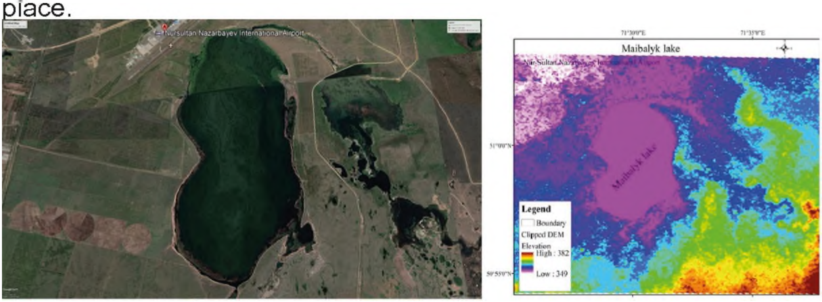


Figure 1 - Case study

The DEM with 30m resolution and Landsat images were retrieved from the official website of the United States Geological Survey (USGS). Maibalyk reservoir boundaries were extracted from Google maps. The high-resolution (4800 x 2718) Google Earth images were retrieved from the Google Earth Pro desktop version 7.3.2.5776 (64-bit). Depths of the reservoir from different locations were extracted from the DEM. In this study, a combination of terrain and land cover properties were used to explore the potential of GIS and RS for a reservoir analysis. The Maibalyk reservoir was analyzed in terms of depth, storage capacity as well as the land surface cover around the territory, providing essential information for further development of the reservoir. To investigate the depth of the reservoir at different locations, several cross-sections were drawn using the ArcGIS 3D-Analyst tool where maximum depths from each cross-section were extracted (Figure 2) and then plotted using Microsoft Excel 2019. The 14 cross-section points were named as point 1 to point 14 (PT1 to PT14).

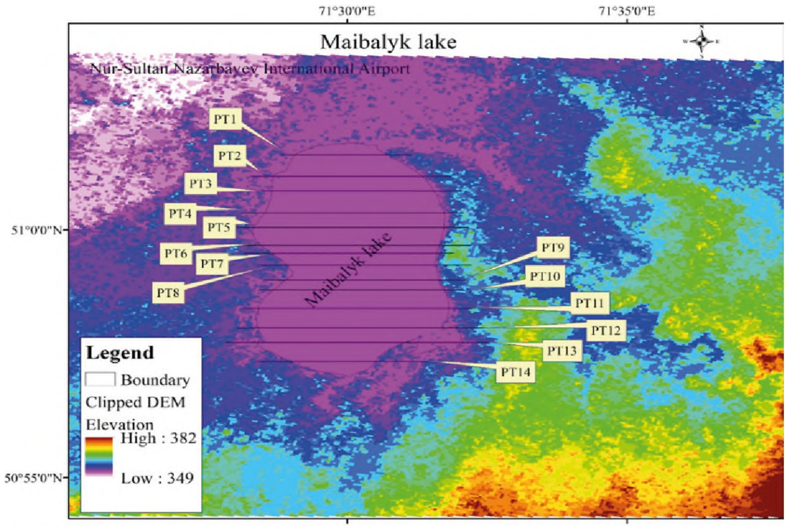


Figure 2 - Cross-section points on Maibalyk reservoir

The Storage Capacity tool which was imbedded in ArcGIS as a Spatial Analyst supplement tool in the Arc Toolbox in conjunction with Digital Elevation Model (DEM) was used to compute water-surface elevations and corresponding storage capacities in ArcGIS 10.5 software package. Storage capacity is determined as the net accumulated volume or surface area of the underlying region for a given water surface elevation (Equations 1 and2). The extraction of the reservoir boundaries was achieved by using the Polygon tool in Google Earth which was then saved as a Keyhole Markup language Zipped (kmz) file which is also known as kml in ArcGIS. For the kmz file to be used in ArcGIS had to be converted to layer using kml to layer conversion tool. The Storage Capacity tool requires the DEM to be in projected coordinates system. All the spatial datasets were projected to Universal Transverse Mercator (UTM) zone 40 North which is the projection zone of Kazakhstan.

$$V_a = water\ surface\ elevation \times underlying\ area \quad (1)$$

Where;

V_a refers to volume at each specific area

$$Total\ storage\ capacity = \sum_{a=1}^{a=n} V_a \quad (2)$$

The retrieved Landsat images were combined using the Composite Band tool in ArcGIS. Then the colors of the out from the combined bands were rearranged from 1, 2, 3 of red, green, and blue respectively to 5,4 and 2 for a better visualization. Interactive Supervised Classification approach in ArcGIS was used to analyze the land surface cover which is defined from the current use of the land, the classes were assigned according to the National Land Cover Database 2011 (NLCD2011) Legend [7]. For each class, more than 30 training samples were to improve the accuracy of the classification. The classified land uses were validated using Google Earth high-resolution images.

Results and discussion. Extraction of reservoir depths was accomplished and plotted. Figure 3, shows 14 cross-section points with the maximum depth at each point as selected in this study. Point 1 and 14 present the furthest points close to the either sides of the reservoir banks. It can be observed that the middle of the reservoir presents the highest depth. However, the trend of the depth in the reservoir is also observed to be non-uniform, some parts of the reservoir close to the middle are shallower than some parts close to the reservoir banks as observed from points 9, 10 and 11 in comparison to point 12. The shallowest parts of the reservoir are observed from points 1 and 14 which are close to the reservoir banks.

The complexity of the reservoir topography may have been influenced by several factors including sediment deposition, as well as erosion by ice movements. Debris that flows into a lake gradually settles to the bottom to add to the layers of sediment. Lake sediments are comprised mainly of clastic material (sediment of clay, silt, and sand sizes), organic debris, chemical precipitates [8]. The graphical presentation from Figure

3, provides a useful information about the nature of the reservoir in the preliminary assessment in the process of the site development for different purposes such as recreation, irrigation farming as well as fishing.

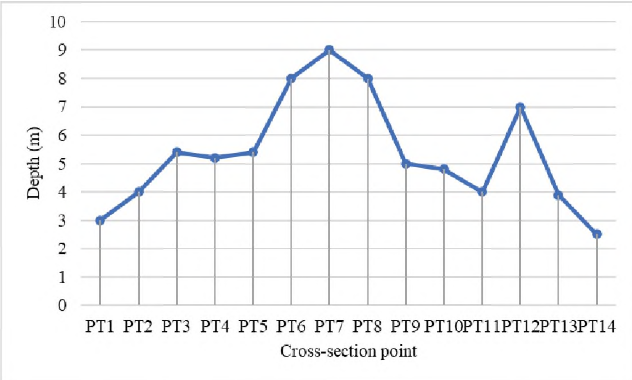


Figure 3 - Maximum depths from 14 cross-sections

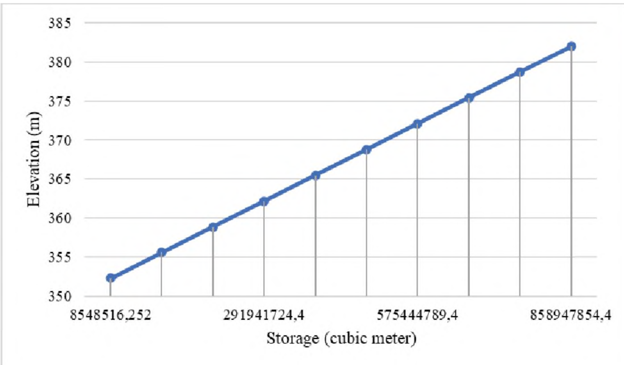


Figure 4 - Estimated storage from different water surface elevations

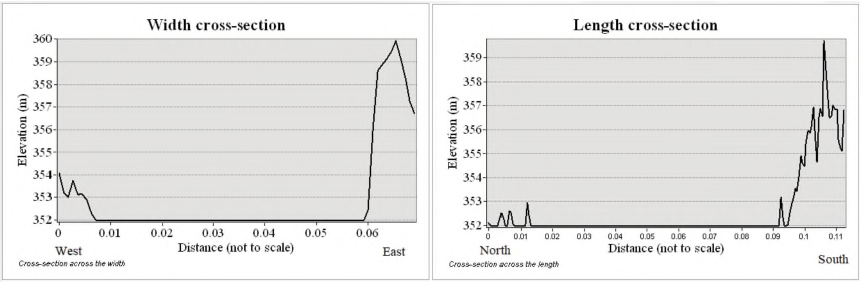
The computation of the reservoir storage capacity was achieved through the consideration of the surface area of the underlying region corresponding to a given water surface elevation. From Figure 4, it can be observed that the computed storage capacity increases with the increase in water surface elevation. An estimated reservoir perimeter of 26.2 km and a coverage area of 27.5 km^2 were extracted in this study. It is of primary importance to assess continuously all environmental effects of storage reservoirs and to provide monitoring facilities for measuring environmental factors both before and after construction. The Westside (cross the width) of the reservoir is characterized by low elevation areas compared to the East of the reservoir. Also, North of the reservoir is characterized by relatively low elevation areas compared to the South. The results reveal the presence of more flood zones around the North and West of the reservoir compared to the South and East of the reservoir (Tables 1 and 2 and, Figure 5).

Table 1 - Reservoir geomorphology across the width (West to East)

Point	West		East		Elevation difference (m)
	Elevation (m)	Depth (m)	Elevation (m)	Depth (m)	
1	353.5	1.5	354.9	2.9	1.4
2	352.5	0.5	356	4	3.5
3	352.9	0.9	357.4	5.4	4.5
4	353	1	357.2	5.2	4.2
5	354.8	2.8	357.9	5.9	3.1
6	354	2	360	8	6
7	354.4	2.4	360.9	8.9	6.5
8	354	2	360	8	6
9	353.6	1.6	356.7	4.7	3.1
10	353.3	1.3	356.8	4.8	3.5
11	353	1	355.8	3.8	2.8
12	355	3	358.9	6.9	3.9
13	353.7	1.7	355.8	3.8	2.1
14	355.9	3.9	362.2	10.2	6.3

Table 2 - Reservoir geomorphology across the length (North to South)

Point	North		South		Elevation difference (m)
	Elevation (m)	Depth (m)	Elevation (m)	Depth (m)	
1	352.6	0.6	355.8	3.8	3.2
2	353	1	357.8	5.8	4.8
3	353	1	359.9	7.9	6.9
4	354	2	358	6	4
5	353.5	1.5	356.9	4.9	3.4



(a) (b)

Figure 5 - Cross-sections (a) across the width, left (West), right (East), (b) across the length left (North), right (South)

The land use/land cover analysis around the Maibalyk reservoir was usefully achieved. The land use classes were categorized into three main groups, which are; water (including the Maibalyk reservoir itself), vegetation, developed low intensity and agriculture (cultivated land) as well as developed medium intensity (Figure 6). The developed low-intensity areas are characterized by a mixture of areas with barren land as well as cultivated crops. While developed, medium intensity is characterized by of constructed materials with impervious surfaces from 50% to 79% of the total cover. The developed, medium intensity class is observed more in areas around the airport where the surface is characterized by paved surfaces.

However, the biggest part of the around the reservoir is characterized by developed low intensity and agricultural activities. As the largest part of the reservoir territory is characterized by low-intensity development, then is likely that the surface is of high permeability. Due to the resolution issues from the Landsat images, some small streams discharging and withdrawing water from the reservoir were not properly captured. However, the general land use classification was of great success and impressive results were derived. Understanding the land surface cover around a reservoir territory is an important aspect in any geotechnical study related to reservoirs, it helps to predict potential factors during the slope stability analysis, as well as calculating the permeability and runoff flow factors around the reservoir.

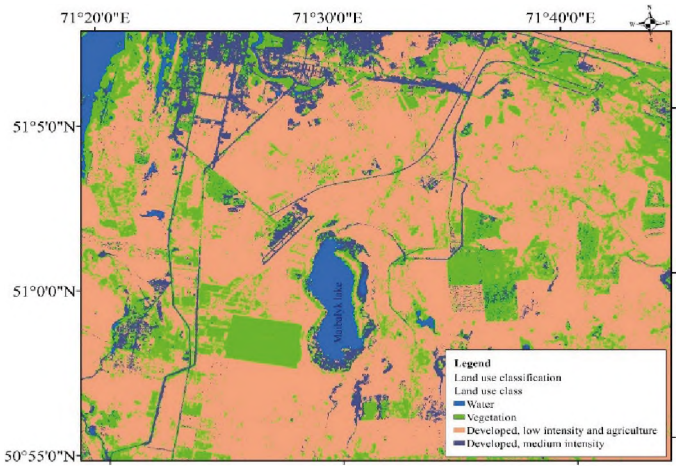


Figure 6 - Classified land uses

Conclusion. This study explored the potential of integrating GIS and RS into reservoir-related Civil Engineering studies. Maibalyk water reservoir in Nur-Sultan, the capital city of the Republic of Kazakhstan was used as a case study. With the help of ArcGIS 10.5 and DEM in conjunction with the Google Earth Pro desktop application, potential reservoir characteristics were successfully extracted. The state of land use/land cover around the reservoir was also successfully derived from Landsat images. From the derived results, the North and West sides of the reservoir are characterized by low-lying areas, that are more prone to flooding events compared to the South and East sides of the reservoir. Results from this study reveal the potential usefulness of combining GIS and RS into Civil Engineering studies as well as providing useful information on areas of emphasis towards the reservoir development.

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