ENVIRONMENTAL IMPACT FROM THE CONSTRUCTION AND OPERATION OF APOSELEMIS DAM AND TUNNEL, IN NORTHERN-EASTERN CRETE

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ABSTRACT

The study investigates the current environmental impact observed at the natural and urban environment, due to the construction and operation of the Aposelemis dam and tunnel project, aqueduct of the Heraklion city, NE Crete. The study mainly concerns the recent two years of the project's operation, and focuses at four affected areas, namely (i) the Lasithi Plateau upland area, (ii) the narrow dam's region, (iii) the Aposelemis river estuary and wetland, and also (iv) the wider Heraklion urban area. Apart from extensive bibliographic research, the study was based on many ground truth visits, while a crucial aspect consists of a Gallup Poll, conducted through four different questionnaires posed to the population of the four affected areas. The recorded consequences on natural and human environment were characterized as positive or negative and evaluated according to their size and importance, estimated for the current period and also for the future. The current investigation indicates the project's initial environmental impact and it is clear that further research must be conducted in the future.

KEYWORDS

Aposelemis dam; Aposelemis wetland; Crete; Environmental impact; Lasithi Plateau tunnel

1. INTRODUCTION

Dams, through disruption of physiochemical and biological processes, have water and associated environmental impacts that have far reaching social and economic consequences [6]. Dam construction should be considered in order to meet future water demands, however strongly considering the reduction of their negative impacts [1]. The impact of each dam is unique, depending not only on the dam structure and the attributes of local biota but also climatic and geomorphic conditions [6].

The present study concerns Aposelemis water supply project, which was implemented to reinforce the water supply in the cities of Heraklion, Agios Nikolaos and additional areas important for tourism in NE Crete, Greece [3]. Various opinions and criticism were reported on the implementation of the Aposelemis project during its long-term planning and construction period [2]. The project became fully operational in early 2019, when the Lasithi Plateau diversion tunnel was put into operation, in order to reinforce the reservoir's potential with plateau's flood water.

The study investigates the initial environmental impact observed due to the full operation of the project (2019 and forward), and focuses on the four affected areas; (i) the Lasithi Plateau

upland area, (ii) the narrow dam's region, (iii) the Aposelemis river estuary and wetland, and (iv) cities of dam's water supply.

Figure 1. Study areas (Google Earth Map, 2019).

2. METHODOLOGY

The study was based on extensive bibliographic research, many ground truth visits and also a Gallup Poll.

The bibliographic research included various technical studies of the Aposelemis project, scientific articles concerning the project and the characteristics of the surrounding area, and also international references concerning environmental impact from dams worldwide. Contemporary official press releases were also taken into account.

In addition, during the study many site visits took place, in order to observe the environment of the affected areas and obtain site information focused on the environmental impact.

Bibliographic research and observatory site visits resulted in the design of four different detailed questionnaires, administered to the population of the four corresponding areas (Lasithi Plateau, dam's region, river estuary and cities of Heraklion, Agios Nikolaos and Hersonissos). In total, ninety (90) questionnaires were collected. The research was greatly affected by the distancing and transport restrictions applied by the Greek government during the spring of 2020, as prevention measures against COVID19 pandemic.

3. RESULTS AND DISCUSSION

3.1 Bibliographic research results

3.1.1 Aposelemis water supply project

The total Aposelemis project includes the Aposelemis dam, reservoir and associated constructions, new alignment section of the road Heraklion – Lasithi Plateau, lakeside alignment, protective embankment of Agios Constantinos byzantine church, water treatment plant, pipe networks, water tanks and pumping stations [7]. A special component of the project is the Lasithi Plateau diversion works, with emphasis on the diversion tunnel which leads plateau's flood water and surface runoff into Aposelemis reservoir [7].

3.1.2 Study area

A complex hydrogeological regime occurs within the wider area of the project. Various scientific investigations conclude that a certain amount of Lasithi Plateau's surface runoff (Chavgas stream), which drains through Chonos sinkhole, after a complex underground route, is discharged through Kastamonitsa springs and therefore contributes to Aposelemis river streamflow[5-8]. Downstream of Potamies village, Aposelemis streamflow infiltrates into karstic formations and recharges the karst aquifer systems significantly [8].

Regions of great ecological importance are located in the project's wider area. The Lasithi Plateau region constitutes part of the ecologically protected network Natura 2000 [3]. Moreover, the important character of Gonies Gorge's bird area, led to the underground diversion tunnel construction (of approximately 3.4 km length), as a significant modification of the project's initial design [3]. River Aposelemis estuary consists an important wetland, which accommodates various flora and fauna species, and is characterized as a Permanent Wild Life Shelter Area [3,9].

3.2 Environmental observation results

3.2.1 Lasithi Plateau area

The Lasithi Plateau's diversion works are located at the NW part, causing only partial landscape disturbance. Aposelemis project –

with emphasis on the diversion tunnel – is used for the plateau's flood water drainage. The tunnel's operation takes place during certain periods of time and year, in association with the weather conditions and reservoir water level. Water discharge into Chonos sinkhole may be either banned or allowed [3].

From mid-spring to mid-autumn, intense agricultural activities take place at Lasithi Plateau. Agricultural pollution affects soil and water resources, both on surface and underground [3]. Irrigation needs are primarily covered by groundwater pumping of wells, which cease providing water during the mid-summer period, due to the over- pumping of the alluvial aquifer. Two artificial reservoirs have been constructed to cover the irrigation needs, as Aposelemis project's compensation measure [3].

3.2.2 Aposelemis dam area

The former landscape of the narrow dam's region has been widely altered by the project. Where once there were Aposelemis riverbed, cultivated land with olive trees, the road section of Heraklion – Lasithi Plateau and Sfendyli village, today lies the lake of the dam (Figure 2). Sfendyli's former inhabitants, although economically compensated, have been scattered [2].

A new wetland has been created, attracting species that previously did not exist in the area. The lake's large water volume, leads to higher humidity levels, and consequently to the formation of a new microclimate in the lakeside area.

Figure 2. Aposelemis reservoir, under full capacity conditions (photo taken by author, 23- 01-2020).

The main characteristic during the two recent winters (years 2019 and 2020), concerns the rapid reservoir filling and the subsequent procedures of controlled dam's overflow, for security reasons (Figure 3).

Figure 3. Aposelemis dam overflow, during recent controlled procedure (photo taken by author, 11-01-2020).

During recent summer periods, the reservoir maintains sufficient water volume, despite certain amounts' extracted for water supply purposes, and additional lost amounts due to the high evaporation rates in the area [7]. Under fine weather conditions, few recreational activities may take place at the lakeside area.

3.2.3 Aposelemis estuary and wetland

Aposelemis estuary is located at a distance of approximately 11.5 km NNW of Aposelemis dam. The area is investigated due to the upstream dam construction, and also due to the great ecological importance of Aposelemis wetland. It must be noted that the project's design includes flow of unrefined reservoir water (15 l/s) straight into Aposelemis wetland at the estuary [3].

The landscape observation depends greatly on the season and weather conditions in the area. The river at the surface may be observed as disconnected by the sea (Figure 4), with brackish characteristics, while occasionally surface sea inflow can be detected.

Figure 4. Surface flow discontinuity between the

river and the sea, at Aposelemis estuary (photo taken by author, 09-02-2020).

Posterior to intense rainfall events, flood conditions within the riverbed and outflow to the sea, may be observed. Streamflow at the estuary was observed in great width and volume during the recent procedures of the dam's controlled overflow (Figure 5).

Figure 5. Aposelemis estuary outflow, during recent procedure of dam's controlled overflow (photo taken by author, 11-01-2020).

Concerning the groundwater resources, it must be noted that the alluvial and karstic aquifers of the wider area, suffer from sea water intrusion [4].

The dry hydrological period coincides with the region's tourist season. Various accommodation complexes exist on both sides of the Aposelemis river estuary, while occasional constructions have affected the coastal area. In addition, uncontrolled tourist activities often disturb and degrade the natural environment (sand dunes vehicle disturbance, solid waste pollution etc). Because of intense human activities and constructions within the estuary's wider area, as well as due to the upstream flow infiltration into karstic formations, the project's impact cannot be easily detected.

3.3 Gallup poll results

3.3.1 Lasithi Plateau area

The public opinion at Lasithi Plateau concludes faster plateau's flood water drainage due to the tunnel operation. During the recent agricultural period (year 2019), certain percentage of the public opinion observed quantity differentiation in plateau's groundwater resources, expressed as lower water level observed in certain wells in the area, and also as estimated diminished pumping duration period (in certain wells) than the previous years.

3.3.2 Aposelemis dam area

The public opinion of the lakeside region, observes intense alteration of the former daily activities. It is concluded that living near the dam increases insecurity among the residents. During the case of emergency leading to the dam's controlled overflow, residents feel anxious, stressed and afraid. Lakeside region's population is concerned about the lake's water quality, due to potential agricultural pollution, as well as because of the dead fish incident in August of 2019. Nevertheless, the latter does not indicate pollution according to the corresponding study [7]. Within the immediate downstream area, quantity degradation of groundwater resources is observed, referring to lower groundwater level and cases of completely dry wells.

3.3.3 Aposelemis estuary and wetland

Since the construction of the dam upstream, a certain percentage of public opinion observes reduced streamflow, wetland's flora and fauna alteration and relatively reduced coast width at the estuary. Within the wider downstream region, quality and quantity degradation of groundwater resources occur for the last six years, expressed by observations of increased brackish characteristics and lower water level in wells. However, groundwater quality and quantity characteristics were observed to be relatively improved during the two recent years (2019 and 2020).

3.3.4 Cities of water supply

The research conducted in the cities of Heraklion and Hersonissos, concludes that during the past years (up to year 2018), both regions suffered from intense water supply quantity problems, while interruption events of water supply were not infrequent. In addition, poor water quality characteristics, mainly due to the city network's conditions, lead to extensive use of bottled water. The quantity and quality of water supply during the two recent years (2019 and 2020), both appear to have improved. Public opinion estimates that

the Aposelemis water supply project poses a positive influence on the cities' activities.

The research conducted in the city of Agios Nikolaos, concludes scarcity in water supply problems over time, in general.

3.4 Observed environmental impact

Co-evaluation of all collected data led to the detection of the environmental impact observed today at natural and human environment, due to the Aposelemis water supply project. Environmental impacts are characterized as positive or negative, and are evaluated according to their size and importance, estimated for the current period and also for the future (Tables 1 & 2). Current environmental impact is directly correlated with the high precipitation rates over the recent reported years (2019 – 2020).

3.4.1 Positive environmental impacts

The project succeeded in a) obtaining water supply for several urban areas, b) draining the flood water from the Lasithi Plateau, c) establishing new landscape and wetland at the narrow dam site, d) reducing the groundwater pumping and e) increasing recreational activities around the lake. Additional positive consequences are the improvement of flood security in Lasithi Plateau and the facilitation of certain agricultural activities. Moreover, lake's landscape affects positively the mental health of visitors. Furthermore, the upcoming improvement of the water supply network in the city of Heraklion, will lead to the reduction of the bottled water consumption; saving household resources, improving citizens' health and urban landscape, and also reducing municipal solid waste (of plastic bottles).

3.4.2 Negative environmental impacts

The main negative environmental impact of the Aposelemis project can be listed as follows: a) reduction of the surface runoff downstream, b) disturbance of the aquifers recharge, c) agricultural pollution of the lake and d) microclimate alteration. Additional negative effects are the loss of cultivated land, the displacement of the former inhabitants, the increasing anxiety of lakeside residents, new slope stability issues in the surrounding areas of the project and flood occurrence at the NW part of Plateau. Moreover, negative consequences are the downstream sedimentation disturbance, the alteration of the former ecosystem in the dam region, the disturbance of certain agricultural activities downstream (due to diminished water resources) and the landscape alteration of the new work sites.

Table 1. Observed environmental impacts of Aposelemis water supply project, on Natural environment variables.

Natural Parameters	Impact's Description	Reference Area	Positive (+) Negative (-)	Current		Future	
				Size	Importance	Size	Importance
Surface Water	Lasithi Plateau's flood water drainage	Plateau	+	↑	↑	↑	↑
	Flood conditions at NW part of Lasithi Plateau	Plateau	-	↓	↓	↓	↓
	Agricultural pollution transport into the reservoir	Dam	-	↔	↔	↔	↔
	Reduction of the surface runoff downstream	Down stream	-	↔	↔ to ↑	↔	↑
Ground Water	Disturbance of groundwater supply downstream	Down stream	-	↔ to ↑	↔	↑	↑
	Disturbance of upland karstic aquifers' supply (due to sinkhole isolation work)	Upland	-	↓	↓ to ↔	↑	↑
	Disturbance of Lasithi Plateau's alluvial aquifers' recharge	Plateau	-	↓	↓	↔	↔
	Reduction of groundwater pumping (due to dam's water efficiency)	General	+	↓	↓	↑	↑
	Reduction of karstic aquifers pumping (used for bottled water extraction)	General	+	↓	↓	↓	↓
Soil Resources	Disturbance of sedimentation downstream	Down stream	-	↓	↓	↑	↑
	New alignment's slope stability issues	Dam	-	↓	↓	↓	↓
	Lakeside area's slope stability issues	Dam	-	↓*	↓*	↓*	↓*
	Disturbance of underground karstic cave	Upland	-	↓*	↓*	↓*	↓*
Landscape	New landscape of dam's lake	Dam	+	↑	↑	↑	↑
	Landscape disturbance at technical works' area	Plateau & Dam	-	↓	↓	↓	↓
	Improvement of city landscape (storage tanks' removal from building tops)	Cities	+	↓*	↓*	↔	↓ to ↔
Climate	Alteration of lakeside area's microclimate (high humidity levels)	Dam	-	↔	↔	↔	↔
Ecosystem	Wetland's supply disturbance	Estuary	-	↓	↓	↔ to ↑	↔ to ↑
	Formation of new wetland at dam's lake	Dam	+	↑	↑	↑	↑
	Alteration of dam's area former habitat	Dam	-	↑	↓	↑	↓
General	Municipal solid waste reduction (due to reduced bottled water consuption)	General	+	↓	↓	↑	↑

Legend: (↑) High, (↔) Medium, (↓) Small,
(*) Not currently observed. Reference due to potential future impact.

Table 2. Observed environmental impacts of Aposelemis water supply project, on Human environment variables.

Human Parameters	Impact's Description	Reference Area	Positive (+) Negative (-)	Current		Future	
				Size	Importance	Size	Importance
Socio- Economic Parameters	Water supply for several urban areas	Cities	+	↑	↑	↑	↑
	Improvement of the water supply network in the city of Heraklion	Cities	+	↓	↓	↑	↑
	Household resources saving for Heraklion citizens	Cities	+	↓	↓	↓ to ↔	↓ to ↔
	Tourist activities facilitation	Cities	+	↓	↓	↑	↑
	Sfendyli former habitants' scattering	Dam	-	↓	↓	↓	↓
	Improved flood security in Lasithi Plateau	Plateau	+	↑	↔	↑	↔
Mental health	Increasing insecurity, anxiety and fear of lakeside residents	Dam	-	↑	↓	↔ to ↑	↓
	Lake's landscape affects positively the mental health of visitors	Dam	+	↓	↓	↓	↓
	Sadness of former owners' loss	Dam	-	↓	↓	↓	↓
Physical health	Lakeside residents' health disturbance, due to new microclimate characteristics (humidity, insects etc)	Dam	-	↔	↓	↔	↓
	Improvement of citizens' health, related to water-network quality	Cities	+	↓	↓	↓	↓
Land use	New lakeside activities	Dam	+	↔	↓	↔ to ↑	↔ to ↑
	Cultivated area loss	Dam	-	↑	↓	↓	↓
	Agricultural activities in downstream areas	Down stream	-	↔	↓	↔	↓
	Agricultural activities in Lasithi Plateau area (due to imroved flood drainage)	Plateau	+	↓	↓	↓	↓

Legend: (↑) High, (↔) Medium, (↓) Small

3.5 Proposed measures and good practices

Based on scientific references, the study further suggests implementation of mitigation measures and good practices concerning the four affected areas. Regarding the Lasithi Plateau upland area, the study suggests implementation of groundwater observation programs on both the alluvial and karstic aquifers, and sustainable agricultural techniques. Concerning the narrow dam's region, implementation of controlled ecotourism near the lake is suggested, and also the application of sustainable energy projects, wastewater treatment, and slope stability measures. For the wide downstream area of Aposelemis estuary and wetland, the study suggests the establishment of the pending protection law framework for the wetland, implementation of groundwater observation programs, and application of water management plan combined with artificial recharge techniques. Finally, concerning the cities of water supply, apart from the upcoming network improvement in the city of Heraklion, a water resources management plan combined with an education program for the consumers-citizens is suggested.

4. CONCLUSIONS

The above listed environmental impact is directly correlated with the high precipitation rates over the last two years (2019 – 2020). In case of future changes, the environmental impact should be reevaluated.

Certain environmental effects are not fully observed, and the current reference period may be premature for the full evaluation. The current investigation indicates the project's initial environmental impact and it is clear that further research must be conducted in the future.

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