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ENVIRONMENTAL IMPACT OF APOSELEMIS DAM AND TUNNEL WATER SUPPLY PROJECT IN NE CRETE, GREECE

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Abstract

The current investigation concerns the impact observed at natural and human environment, due to the implementation of the Aposelemis water supply project, as additional aqueduct of Heraklion and Agios Nikolaos cities, as well as other important tourist areas, in NE Crete, Greece. Aposelemis project is differentiated from standard water supply dam projects, through a special component of an underground tunnel that diverts uphill surface water from Lasithi Plateau into the reservoir. The study concerns the first years of project's operation, and focuses at four affected areas, namely the Lasithi Plateau upland area, dam's region, river estuary and water supplied cities. The investigation was based on various site visits, while a significant aspect involves local stakeholders' observation, opinion and perception on the environmental impact of the project in everyday life, through four detailed questionnaires posed to the affected areas' population. The recorded consequences were characterized as positive or negative and evaluated according to their size and importance, estimated for the current period and also for the future. Among the main positive effects are urban areas' drinking water supply and improved upland plateau's flood water drainage, while among the negative consequences appear multiple water resources' impacts and feelings of downstream lakeside residents. The investigation indicates the initial environmental impact and sets the basis for further future research towards sustainability.

Keywords: *Aposelemis dam, Aposelemis tunnel, Environmental impact, Crete*

Περίληψη

Η παρούσα έρευνα αφορά τις υφιστάμενες περιβαλλοντικές επιπτώσεις, που καταγράφονται στο φυσικό και ανθρωπογενές περιβάλλον, μετά την ολοκλήρωση του έργου ύδρευσης Αποσελέμη ως ενίσχυση της υδροδότησης των πόλεων Ηρακλείου, Αγίου Νικολάου και επιπλέον τουριστικών περιοχών, στη βορειοανατολική Κρήτη. Το έργο ύδρευσης Αποσελέμη διαφοροποιείται από τα τυπικά έργα ύδρευσης φραγμάτων, εξαιτίας της υδραυλικής σήραγγας μέσω της οποίας επιφανειακό νερό από το Οροπέδιο Λασιθίου διοχετεύεται στον ταμιευτήρα. Η διερεύνηση αφορά κυρίως στα πρόσφατα έτη λειτουργίας του συνόλου του έργου (2019 και έπειτα), και επικεντρώνεται στις τρεις άμεσα επηρεαζόμενες περιοχές: το Οροπέδιο Λασιθίου, την περιοχή του φράγματος και τις εκβολές Αποσελέμη. Επιπρόσθετα, επιπλέον διερεύνηση πραγματοποιείται για τις περιοχές η υδροδότηση των οποίων σήμερα ενισχύεται από το φράγμα και οι οποίες επηρεάζονται έμμεσα από το έργο, με έμφαση στην πόλη του Ηρακλείου. Η διερεύνηση βασίστηκε σε πλήθος επί τόπου επισκέψεων παρατήρησης του περιβάλλοντος των εξεταζόμενων περιοχών. Σημαντικότατη συνεισφορά αποτέλεσε η διερεύνηση της κοινής γνώμης, μέσω τεσσάρων διαφορετικών ερωτηματολογίων, ειδικά σχεδιασμένων για κάθε περιοχή μελέτης, τα οποία απευθύνθηκαν σε κατοίκους ή/και δραστηριοποιούμενους των περιοχών αυτών. Οι περιβαλλοντικές επιπτώσεις που καταγράφηκαν, χαρακτηρίστηκαν ως θετικές ή αρνητικές και αξιολογήθηκαν ως προς το μέγεθος και τη σημασία τους, τόσο κατά την υφιστάμενη περίοδο όσο και ως μία εκτίμηση για το μέλλον.

Ως κύριες παρατηρούμενες θετικές περιβαλλοντικές επιπτώσεις εντοπίσθηκαν η ενίσχυση της υδροδότησης σημαντικών αστικών περιοχών, η ταχύτερη αποστράγγιση των πλημμυρικών υδάτων του Οροπεδίου Λασιθίου και το νέο τοπίο - υγροβιότοπος της λίμνης του φράγματος. Μικρότερου μεγέθους θετικές επιπτώσεις αφορούν σε μείωση απολήψεων υπόγειου νερού, σε παραλίμνιες δραστηριότητες και σε βελτίωση της ψυχικής υγείας των επισκεπτών. Θετική επίπτωση μεγάλης εκτιμώμενης μελλοντικής σημασίας, αφορά την επικείμενη αναβάθμιση των υποδομών του υφιστάμενου δικτύου ύδρευσης της πόλης Ηρακλείου, με συσχετιζόμενες δυνητικές επιπτώσεις περί μείωσης κατανάλωσης εμφιαλωμένου νερού, εξοικονόμησης πόρων των νοικοκυριών, βελτιώσεις θεμάτων υγείας και τοπίου, έως μείωσης όγκου αστικών στερεών αποβλήτων υπό την έννοια απορριπτόμενων πλαστικών φιαλών. Στον αντίποδα, ως οι κύριες παρατηρούμενες

αρνητικές περιβαλλοντικές επιπτώσεις του έργου, εντοπίστηκαν η μείωση της κατάντη επιφανειακής απορροής, η διαταραχή τροφοδοσίας κατάντη υπόγειων υδροφορέων, η δυνητική ρύπανση εντός του ταμιευτήρα και η αλλοίωση του παραλίμνιου μικροκλίματος. Επιπλέον υφιστάμενες αρνητικές επιπτώσεις αφορούν σε θέματα ψυχικής υγείας των κατοίκων του κατάντη οικισμού, στην απώλεια εύφορων εκτάσεων και στο διασκορπισμό των πρώην κατοίκων της περιοχής της λεκάνης κατάκλυσης, σε αστοχίες πρανών της νέας οδού, σε διαταραχή αναπλήρωσης ανάντη καρστικών και προσχωματικών υδροφόρων Οροπεδίου, στις πλημμυρικές συνθήκες του μικρού βορειοδυτικού τμήματος Οροπεδίου και σε δυνητικές επιπτώσεις στον υγροβιότοπο στις εκβολές.

Ως πιθανές καλές πρακτικές, προτείνονται: (α) η υλοποίηση προγραμμάτων παρακολούθησης του υπόγειου υδατικού δυναμικού σε διάφορες θέσεις (κατάντη πορώδεις και καρστικοί υδροφορείς, πορώδεις υδροφορείς Οροπεδίου Λασιθίου και ανάντη καρστικά συστήματα), (β) πρακτικές βιώσιμης γεωργίας τόσο για την περιοχή του φράγματος όσο και για το Οροπέδιο Λασιθίου, (γ) ελεγχόμενες δραστηριότητες αναψυχής και οικοτουρισμού με κοινωνικά και οικονομικά προνόμια για τον τοπικό πληθυσμό, (δ) μέριμνα για την παραλίμνια περιοχή, (ε) εφαρμογή ΑΠΕ σε εγκαταστάσεις του έργου, (στ) κατάρτιση θεσμικού πλαισίου προστασίας του υγροβιότοπου Αποσελέμη και υλοποίηση προγράμματος παρακολούθησης, (ζ) εφαρμογή τεχνικών τεχνητού εμπλουτισμού των κατάντη υφάλμυρων υπόγειων υδροφόρων και (η) κατάρτιση και εφαρμογή ικανού σχεδίου διαχείρισης υδατικών πόρων με έμφαση στην εκπαίδευση του καταναλωτικού κοινού ώστε να κατανοεί την αξία των υδατικών πόρων και να μην οδηγείται σε κατάχρηση του περιβαλλοντικού αγαθού.

Λέξεις-Κλειδιά: *Φράγμα Αποσελέμη, Σήραγγα Αποσελέμη, Περιβαλλοντικές Επιπτώσεις, Κρήτη*

1. INTRODUCTION

Extensive environmental and social impacts have been reported from the construction and operation of large dams worldwide (Bird and Wallace, 2001). Dam structures often disrupt various physiochemical and biological processes, and cause water and associated environmental impacts that have far reaching social and economic consequences (McCartney, 2009). Different regions are often disproportionally

affected, which engenders water allocation conflicts (Fung et al., 2019) and a potential source of social and political instability (Karami and Karami, 2020). Civil society and environmental groups are often mobilized by dam development's associated environmental and social impacts (Gerlak et al., 2020). According to McCartney (2009) the impact of each dam is unique, depending not only on the structure and the attributes of local biota but also on climatic and geomorphic conditions.

Dam structures affect both abiotic and biotic environmental variables. As "one of the most significant human interventions in the hydrological cycle" (McCartney, 2009), dams affect water resources quantity and quality (Akbarzadeh et al., 2019; Gierszewski et al., 2020) and also land systems (Rufin et al., 2019) and soil resources, with emphasis on sedimentation (Ji et al., 2020; Lyu et al., 2020) and impacts on riverbed (Gierszewski et al., 2020) and coastal environment (Ji et al., 2020). Dam constructions often disturb various components of river biodiversity (Albert et al., 2021), with reported impacts on primary production (McCartney, 2009) and fish species (Alho et al., 2015; Fung et al., 2019; Santos et al., 2020). Alteration of river vegetation communities may subsequently affect a wide range of mammal and bird species that depend on them (McCartney, 2009). In certain cases, the lack of respect towards environment's components and procedures led to catastrophic impacts and negative criticism. During the recent decades, the global scientific society was considerably concerned about dam projects (Bird and Wallance, 2001; Beck et al., 2012; Keskinen et al., 2012; Hodbod et al., 2019; Karami and Karami, 2020). Dam removal and river restoration were investigated in order to reverse the environmental impacts (Lejon et al., 2009; Beck et al., 2012; Buckner et al., 2018; Birnie-Gauvin et al., 2020). Sustainability assessment, optimum construction and management of dams and reservoirs became crucial concepts (Beck et al., 2012; Chen et al., 2016; Ho and Goethals, 2019; Karami and Karami, 2020; Wilk-Woźniak et al., 2021).

Dam construction should be considered in order to meet future water demands, however strongly considering the reduction of their negative impacts (Chen et al., 2016). Availability of water resources is expected to become vital in the future (Damkjaer and Taylor, 2017), due to climate change (Mimikou et al., 2000; Ludwig et al., 2011; Amanambu et al., 2020) and population growth (McDonald et al., 2011; Chen et al., 2016), in combination with the modern society living.

Investigations of climate change within the Mediterranean region indicate "*an increasing general shortage of water resources and consequent threats to water availability*" (Ludwig et al., 2011). Focusing on the island of Crete, the quantitative impact of climate change is expected to be substantial on future water resources status (Koutroulis et al., 2013). Koutroulis et al. (2013), through the investigation of 24 different climate scenarios for Crete Island, indicated an expected decline in average water availability from 93% during the period 2000–2050 to a "*devastating*" 70% for the next fifty-year period. Therefore, "water resources management should consider infrastructure and adaptation strategies to mitigate risks of the forecasted deficit" (Koutroulis et al., 2013). Gikas and Angelakis (2009) investigate potential use of non-conventional sources in Crete, such as seawater desalination and reclaimed wastewater reuse. Water supply for Heraklion city remained a vital issue throughout time (Chalkiadakis, 2012). Water demands are increasing due to rapid population growth and increasing trend of tourist interest – in 2017, Heraklion city was declared as the fastest growing tourist destination of Europe (Chifos et al., 2019).

The present study concerns the Aposelemis project, which was implemented to reinforce the drinking water supply in the cities of Heraklion, Agios Nikolaos and additional areas important for tourism in NE Crete (Papagrigoriou et al., 2018). The first proposals for the construction of Aposelemis dam, as an attempt to address Heraklion city's water supply issues, are dated back in 1959 (Chalkiadakis, 2012). Preliminary exploratory studies were conducted in 1972, while the investigation, design and implementation of the Aposelemis project lasted since 2018 (Chifos et al., 2019). During the long-term planning and construction period, the initial design of certain parts was significantly modified, often due to environmental obstacles (Papagrigoriou et al., 2018). The total Aposelemis project encountered various technical challenges and difficulties (Kollios and Migirou, 2010; Gütter and Rudigier, 2016; Papagrigoriou et al., 2018) as well as strong opposition, objections and criticism from the local communities, that in year 2001 reached an appeal to the European Commission concerning the project's environmental impact assessment (Chifos et al., 2019). The philosophy of the project's design is based on the transportation of flood and surface water from Lasithi Plateau, straight into the Aposelemis reservoir through an underground work (diversion tunnel). Aposelemis project commenced in supplying the cities in late 2015 (Chifos et al., 2019), while the diversion tunnel was still under

construction. The project became fully operational in early 2019, when the tunnel began diverting water into the reservoir.

During the writing of the present, no study covering the recent full operation of the project (tunnel's operation and subsequent reservoir filling) has been found, as far as we are aware. Therefore, the present study aims to cover this literature gap, by investigating the initially observed environmental impacts of project's full operation. The research focused on the four mainly affected areas; Lasithi Plateau, dam's region, river estuary and supplied cities. The issue was approached through four carefully designed questionnaires (different for each area) addressed to local stakeholders – residents or professionals. Survey topics aimed to record local observation, opinion and perception on the environmental impact of the project.

2. MATERIALS AND METHODS

2.1 Study area

The Aposelemis project is located in the central-east northern part of the island of Crete in southern Greece, at Heraklion and Lasithi districts. The Aposelemis dam is located at approximately 25 km southeast of Heraklion city, in Hersonissos municipality, in vicinity with the villages Potamies, Sfendyli and Avdou (Fig.1). The Aposelemis River has a total length of 23 km, flows in a direction SE-NW and discharges into the Cretan Sea (Voudouris et al., 2007). At a distance of approximately 10 km southeast of the dam (Chifos et al., 2019), at an elevation of approximately 850 m above msl, lies the Lasithi Plateau. A complex hydrogeological regime occurs within the wider area. Various studies conclude that a certain amount of Plateau's surface runoff (Chavgas stream), which drains through Chonos sinkhole into karstic formations, after a complex underground route, is discharged through Kastamonitsa springs, contributing to Aposelemis river streamflow (Koutsoyiannis et al., 2003; Voudouris et al., 2007). Downstream of the dam, Aposelemis streamflow infiltrates into karstic formations and contributes significantly to the recharge of aquifer systems (Voudouris et al., 2007).

Regions of great ecological importance are located in the project's wider area. Lasithi Plateau constitutes a protected area Natura 2000 (Papagrigoriou et al., 2018). The important character of Gonies Gorge's bird area, led to the underground diversion

tunnel construction, as a significant modification of project's initial design (Papagrigoriou et al., 2018). River Aposelemis estuary consists an important wetland, which accommodates various flora and fauna species, and is characterized as a Permanent Wildlife Shelter Area (WWF Hellas, 2008). During the two recent years of observation (2019-2020), high precipitation rates were recorded at the area of eastern Crete. In contrast, the previous winters (2016-2017) were unusually dry (Chifos et al., 2019).

2.2. Aposelemis water supply project

The Aposelemis dam has a maximum height of 61 m and consists of a reservoir's impounding of approximately 25.3 million m^3 (Papagrigoriou et al., 2018). A special component of the project is the complex of Lasithi Plateau diversion works, with emphasis on the tunnel of approximately 3.4 km length (Papagrigoriou et al., 2018) and an inclination of approximately 15% (Gütter and Rudigier, 2016). The total Aposelemis project also includes a new road section, a protective embankment of a byzantine church, a lakeside road, a complete water treatment plant, and also various pipe networks, tanks and pumping stations, forming two major aqueducts (Papagrigoriou et al., 2018) (Fig.1).

Since the first operation of the diversion tunnel in early 2019, the reservoir fills rapidly during certain winter periods, due to the large amounts of plateau's flood water impounded. For security reasons, when the reservoir reaches the upper limit, controlled procedures of dam's overflow take place, and certain amounts of water are led to the immediate downstream riverbed area.

2.3 Data Collection

During the study, many site visits took place, in order to observe the environment and obtain information based on random interviews with local citizens, focused on the environmental impact.

Collected data and field information resulted in the design of four different detailed questionnaires, administered to the population of the four corresponding areas.

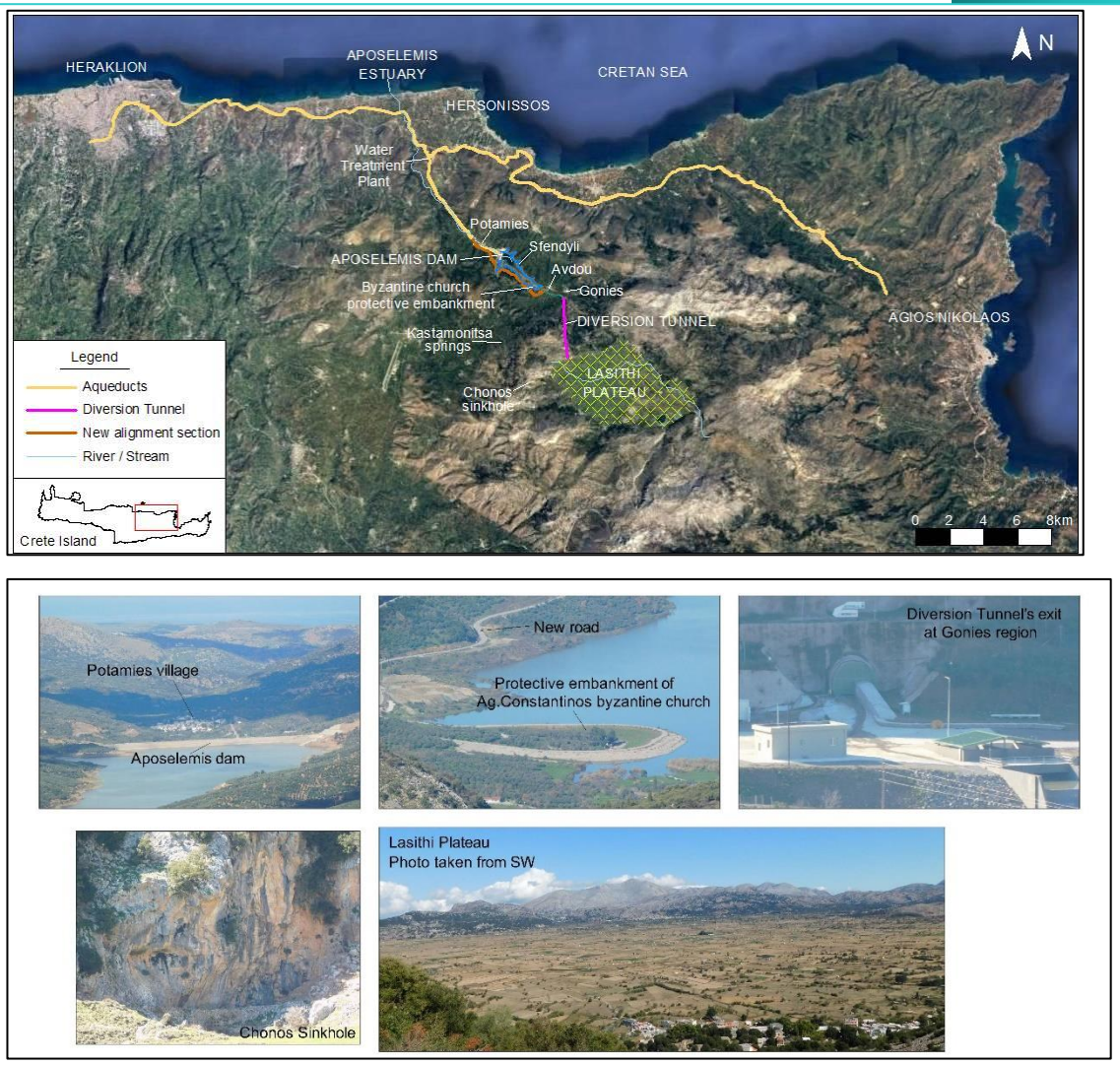

Fig. 1: The Aposelemis water supply project, within the wide area of central-east northern part of Crete. Base map *Source* Google Earth Pro (2020). The figure illustrates the Aposelemis dam and reservoir, the diversion tunnel, and also the extensive network of the project's aqueducts. Informative photographs of the area and the project are also presented.

Considering the great differentiation in project's implications among the four areas, the design of the questionnaires was not a straightforward procedure. As Root-Bernstein et al. (2020) noted, "*questionnaires are difficult to write so that questions are unambiguous and are always understood in the way intended*". The questionnaires consist of a two-page multiple choice format of an average of 30 questions each and are available as Electronic Supplementary Material, in English. The multiple-choice format was chosen in order to quantify the results and facilitate data analysis. Multiple choice potential answers were based on information, opinions and phrases derived from locals

during the initial site research. The four questionnaires were differentiated according to each area's special characteristics, implications, perceptions and requirements. Given the various oppositions on project's implementation from local communities in the past (Chifos et al., 2019), past opinion and today perceptions were crucial. Questionnaires' matrix framework is presented in Fig. 2.

The main selection criterion for the sample participants was having experienced the study areas since before the project's implementation. The sample collected aimed to cover both genders, and also a range of ages, educational and professional levels. All participants were informed that the survey was voluntary and anonymous.

The survey was conducted during the spring of 2020 and was greatly affected by the distancing and transport restrictions applied by the Greek government, as prevention measures against COVID19 pandemic. The scheduled procedure of collecting questionnaires in situ was evidently replaced by indirect methods (telephone interviews, emails etc.) and the "snowball approach" was implemented. Within the majority of the cases, questionnaire completion took the form of a semi-structured interview. In total, ninety (90) questionnaires were collected. Other methods, such as the Delphi method (Manoliadis et al., 2006), which uses questionnaires only for a group of experts, could not be applied at the study area due to the fact that experts with knowledge about the newly developed post construction conditions at the four different investigated areas could not be identified.

The difficult conditions of social distancing measures coupled with study's time constraints led to the moderate coverage of 90 participants. Regarding the interview character of many questionnaire acquirements, in addition to the preliminary qualitative data obtained through random interviews during the first survey period, it is estimated that the investigated issue has been satisfactorily assessed. According to Guest et al. (2006) thematic saturation is possible to occur within the first twelve interviews, while Boyer et al. (2019) noted that "a sample of 8–12 interviews of a homogeneous group is all that is needed to reach saturation".

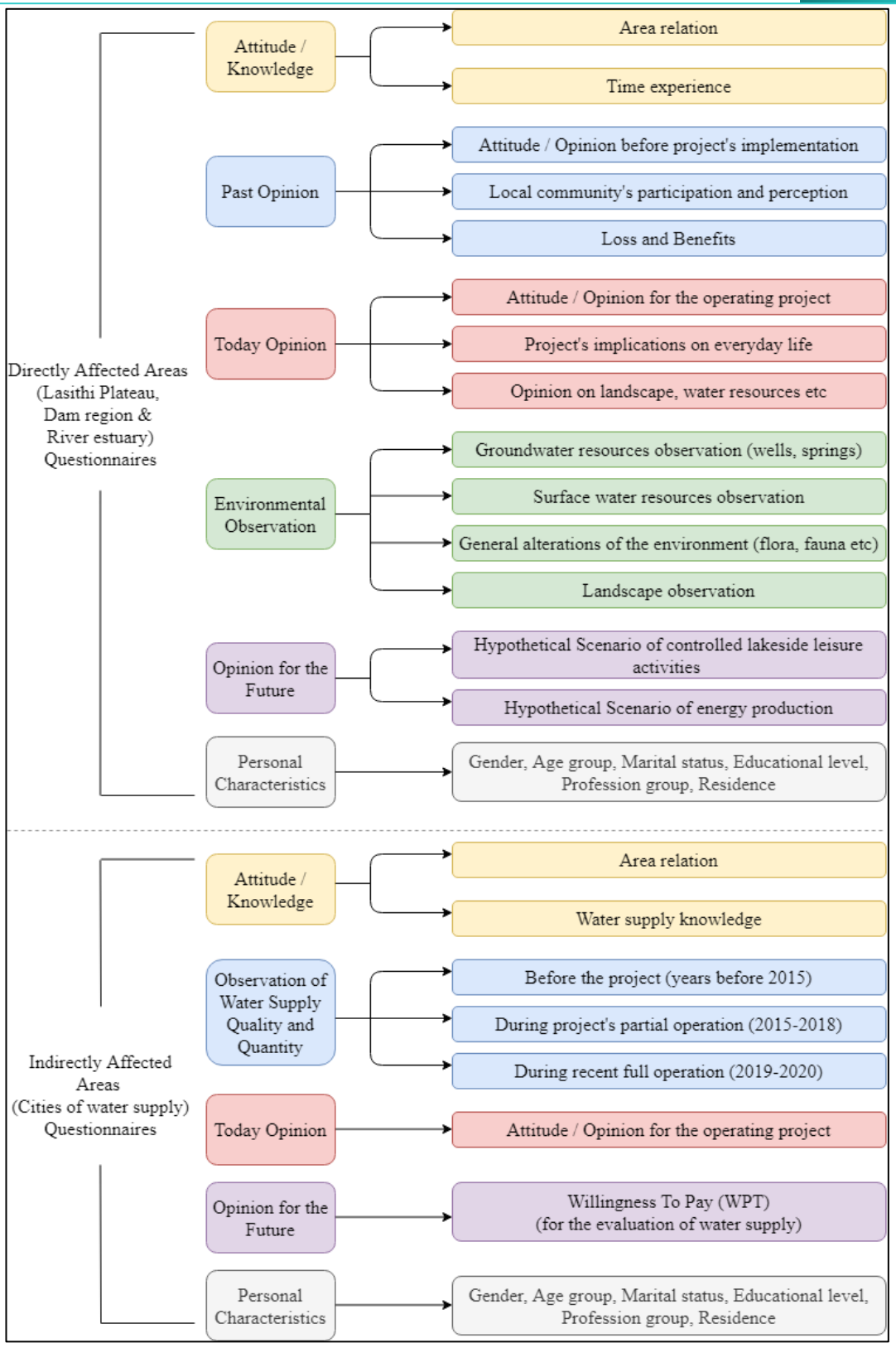

Fig. 2: Questionnaire's matrix framework.

3. RESULTS AND DISCUSSION

3.1. Field Research Results

3.1.1. Lasithi Plateau

The diversion works are mainly located at Plateau's NW part (Fig. 3), causing only partial landscape disturbance. Flood occurrence in the plateau is frequent during winter time (Fig. S11, Fig.S12; see supplement section). Aposelemis project, with emphasis on the diversion tunnel, is used for Plateau's flood water drainage. The diversion tunnel operates during certain periods of time and year, in association with weather conditions and reservoir water level. Water discharge into Chonos sinkhole may be either banned or allowed.

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 (Papagrigoriou et al., 2018). Irrigation needs are primarily covered by groundwater pumping of wells, which cease providing water during the mid-summer period, due to alluvial aquifer's over-pumping. Two artificial reservoirs (Fig. S10, Fig. S18; see supplement section) have been constructed to cover irrigation needs, as project's compensation measure (Papagrigoriou et al., 2018). Local citizens observe faster plateau's flood water drainage due to tunnel's operation. During the recent agricultural period (2019), certain participants observed lower groundwater level and diminished pumping duration period than the previous years, in certain wells of the Plateau (Fig. 4).

3.1.2. Aposelemis dam area

The former landscape has been widely altered by the project. Where once were Aposelemis valley, cultivated land and olive trees, Sfendyli village (Fig. S5-S8; see supplement section) and the road section of Heraklion – Lasithi Plateau, today lies the dam's lake (Fig. 5). Sfendyli's inhabitants have been scattered, since the organized community resettlement never took place (Chifos et al., 2019).

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

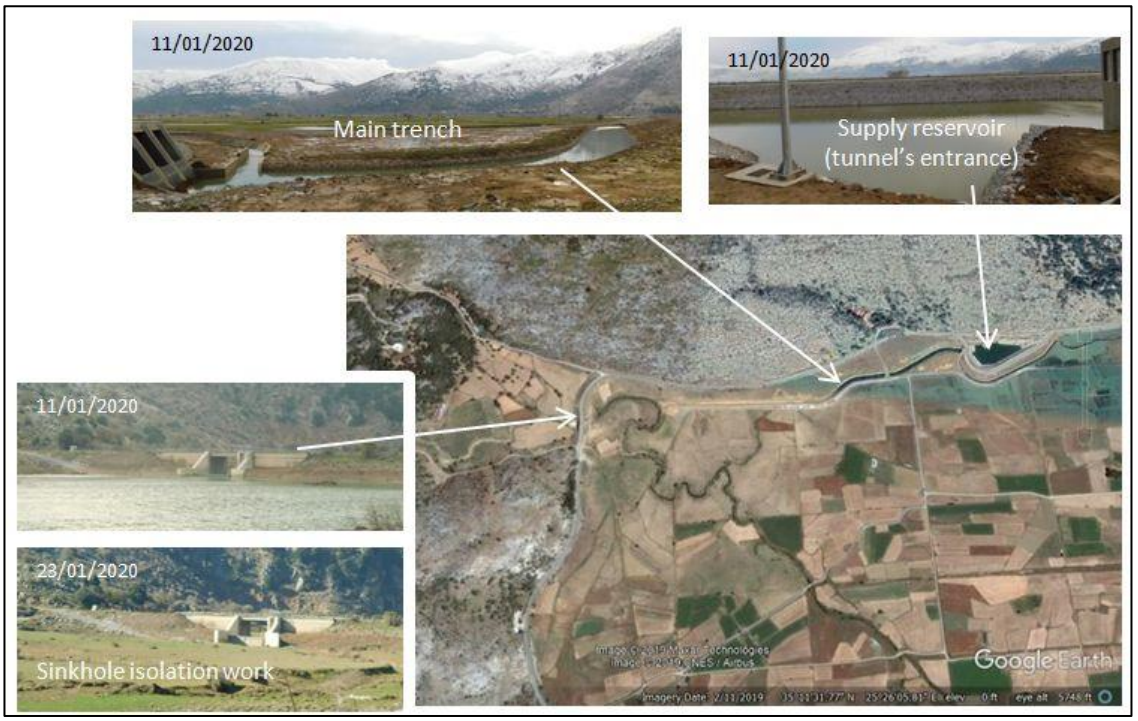

Fig. 3: Aposelemis water supply project diversion works at the NW part of Lasithi Plateau. Base map *Source* Google Earth Pro (2019).

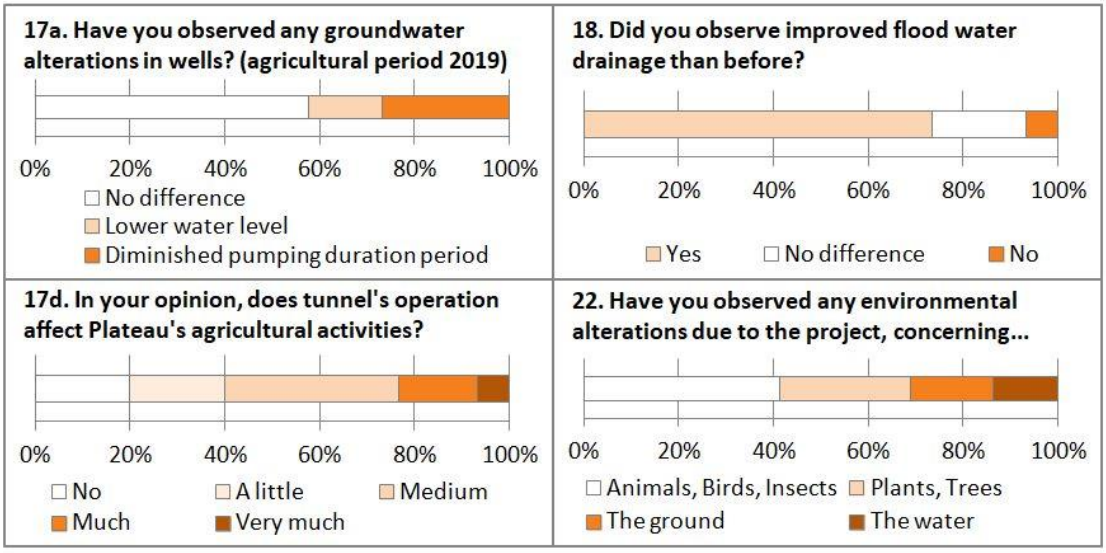

Fig. 4: Answers to Questions No.17a, 17d, 18 & 22 of Lasithi Plateau Questionnaire.

The main characteristic during the recent winters (2019 and 2020), concerns the rapid reservoir filling and the subsequent procedures of controlled dam's overflow, for security reasons. During recent summer periods, the reservoir maintains sufficient water volume, despite certain amounts extracted for water supply purposes and lost due to high evaporation rates. Under fine weather conditions, few recreational activities may take place at the lakeside area. On August 2019, the first lakeside running road race was organized by the local communities. Immediate downstream lakeside residents of Potamies village observe intense alteration of former daily activities. Living near the dam increases insecurity (Fig. 6), while during cases of emergency overflow, inhabitants of Potamies village feel anxious, stressed and afraid. Corresponding dam failure studies (Tsakiris et al., 2010) have concerned the residents in the past.

Locals are concerned about lake's water quality, due to potential agricultural or other pollution, enhanced by a dead fish incident in August of 2019. Nevertheless, the latter does not indicate pollution according to the corresponding study (OAK S.A., 2019). Within the immediate downstream area, groundwater resources quantity degradation is observed, referring to lower groundwater level and cases of completely dry wells (Fig. 6).

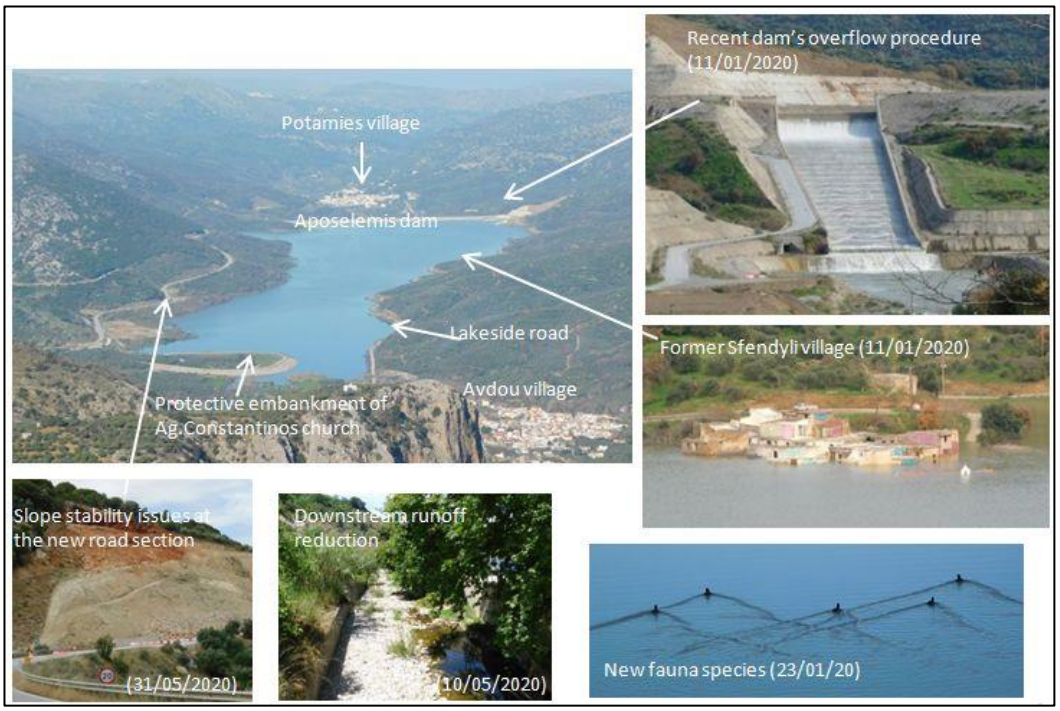

Fig. 5: Aposelemis dam and reservoir region.

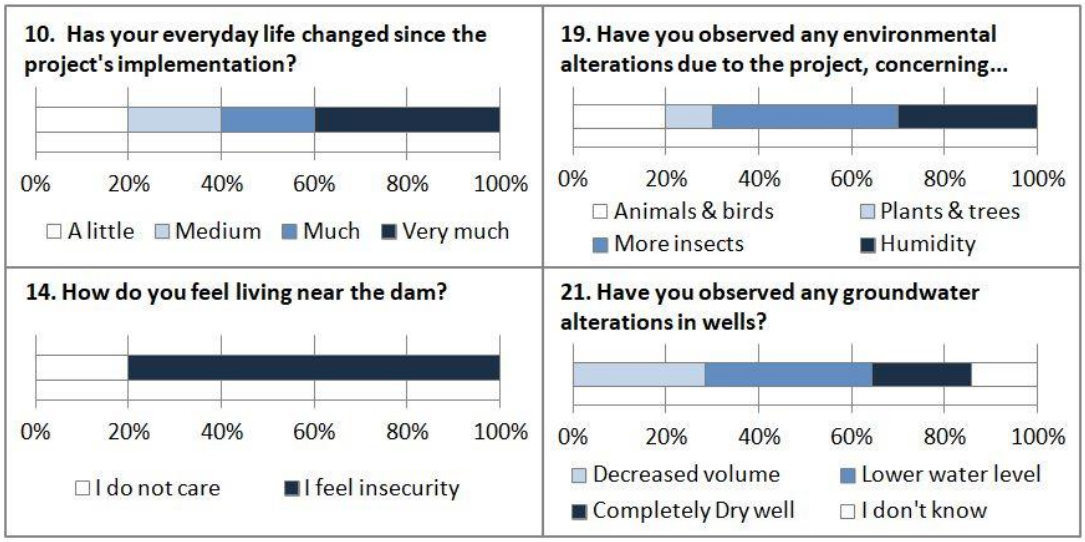

Fig. 6: Answers to Questions No.10, 14, 19 & 21 of Dam's Region Questionnaire. The answers presented concern mainly the immediate downstream village of Potamies.

3.1.3. Aposelemis river estuary and wetland

River estuary is located at a distance of approximately 11.5 km NNW of Aposelemis dam, and consists a wetland of great ecological importance (WWF Hellas, 2008). However, due to certain disturbance behaviours and absence of ecological protection, the wetland suffers from degradation throughout time (Malakou and Catsadorakis, 1992; Legakis et al., 1993; The Greek Ombudsman, 2016). According to Papagrigoriou et al. (2018), the establishment of the protection law framework for the wetland is pending for years. Project's design obtains an environmental flow of unrefined reservoir water (15 L s^{-1}) straight into Aposelemis wetland at the estuary, in order to sustain freshwater and estuarine ecosystems as well as the human livelihoods (Papagrigoriou et al., 2018). Also, a wetland monitoring program consists part of the organization's duties (Papagrigoriou et al., 2018). The landscape depends greatly on season and weather conditions. The river may be observed as disconnected by the sea (Fig. a), with brackish characteristics, while occasionally surface sea inflow can be detected. Posterior to intense rainfall events, flood conditions within the riverbed and outflow to the sea, may occur. Streamflow at the estuary was observed in great width and volume during the recent procedures of dam's-controlled overflow upstream (Fig. b). The dry hydrological period coincides with region's tourist season. Various accommodation complexes exist at the area, while occasional constructions have affected the coastal front (Papagrigoriou et al., 2018). Uncontrolled tourist activities (i.e., sand dunes

vehicle disturbance, solid waste pollution etc.) often disturb and degrade the natural environment. Because of the intense human activities and constructions within the estuary's wider area, as well as due to the upstream flow infiltration into karstic formations (Voudouris et al., 2007), the project's impact cannot be easily detected. Since the construction of the dam upstream, approximately six years before our survey, certain participants observe reduced streamflow, wetland's flora and fauna alteration (Fig.) and relatively reduced coast width at the river estuary. For the past decades, groundwater resources of the wider downstream area suffer from seawater intrusion (YPEN, 2017a). Locals observed increased brackish characteristics and lower groundwater level in wells, during the last six years. However, groundwater quality and quantity were observed to be relatively improved during recent years 2019 and 2020 (Fig.).

Fig. 7: Aposelemis estuary. (a) Surface flow discontinuity between the river and the sea, and (b) river outflow during recent dam's controlled overflow (11/01/2020).

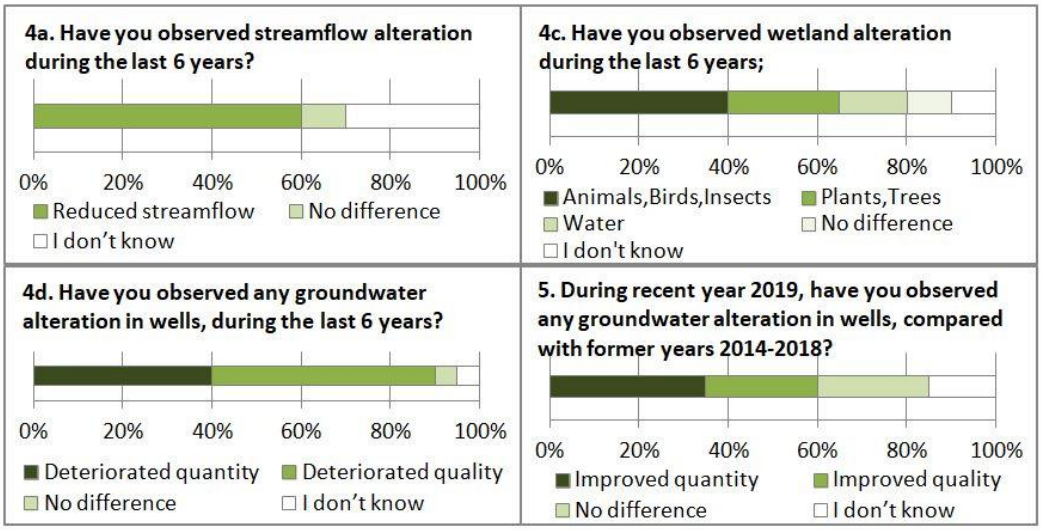

Fig. 8: Answers to Questions No.4a, 4c, 4d & 5 of River Estuary Area Questionnaire.

3.1.4. Cities of water supply

The survey focused on Heraklion city, due to recorded water supply issues (Chalkiadakis, 2012). Diminished water quantity and quality characteristics are also caused due to city's old and insufficient water supply network. According to Tsakiris et al. (2015) approximately 42% of the total inflows are recorded as losses in the entire municipal water supply and distribution system, mainly due to inadequate metering practices and distribution network's ageing parts. The conditions lead to extensive bottled water consumption, while water for domestic use is often pumped from the city network and stored in tanks on the building tops. The research concludes that during past years (up to 2018), the city suffered from intense water supply quantity and quality problems, while interruption events were not infrequent. However, during recent years (2019-2020), quantity and quality of water supply appear to have improved, and an increasing improvement trend throughout time is observed according to citizens' perception (Fig. 9). Participants estimate that Aposelemis project poses a positive influence on city's activities, and declare great interest in supply network's improvement.

3.2. 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 (Table 1 & Table 2). Current environmental impacts are directly correlated with the high precipitation rates over the recent reported years (2019 – 2020).

3.2.1. Positive environmental impacts

- High-quality water supplies today several urban areas, with emphasis on Heraklion city (DEYAH, 2019). The impact is expected to emerge in a significantly greater size in the future, after the upcoming improvement of city's supply network, which is further instructed by the high-quality water provided. As secondary impacts of the above are expected the following:

- reduction of bottled water consumption
- saving of household resources (i.e., expenses on bottled water purchase, electricity required for pumping)
- improvement in citizens' health, related to water-network quality

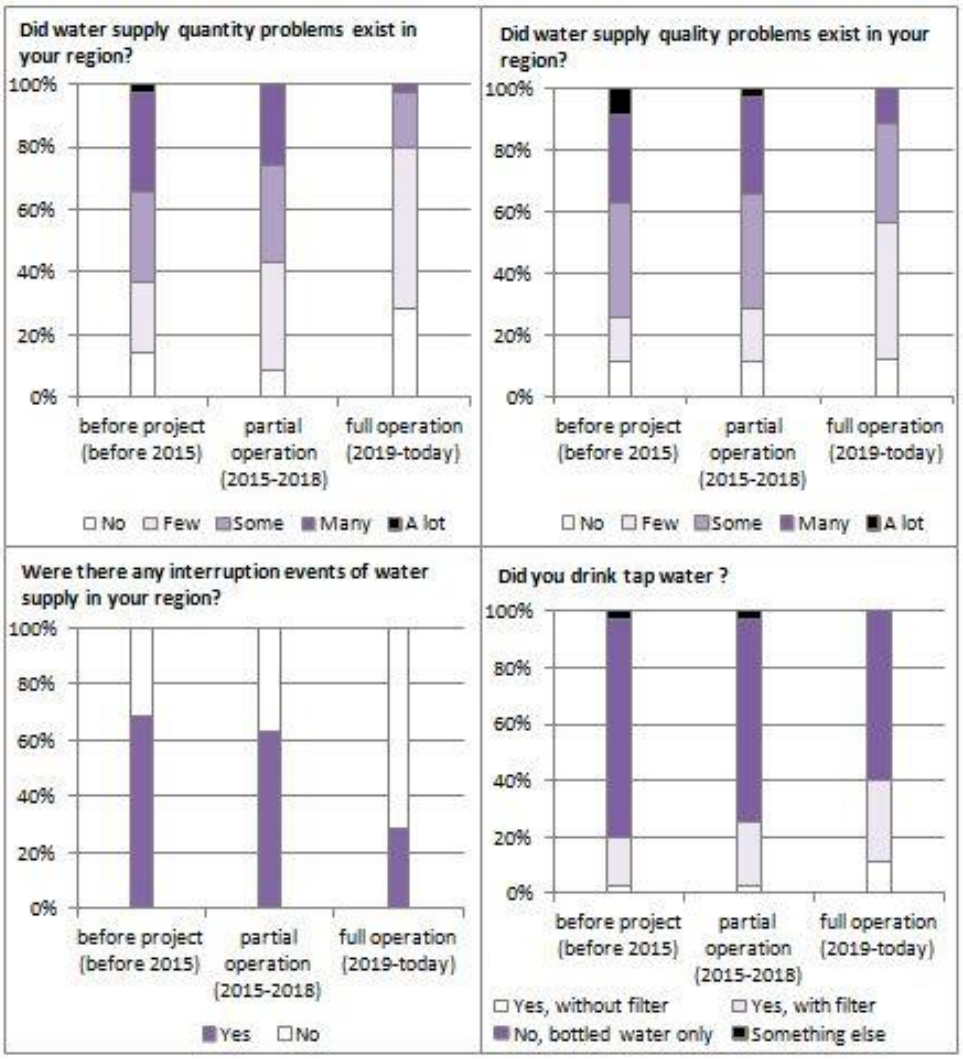

Fig. 9: Answers to Questions No.5a-5d, 6a-6d & 7a-7d of Water Supplied Cities Questionnaire. The answers presented concern mainly Heraklion city. The results are presented in groups for optimum apprehension.

- improvement of the urban landscape, by removing no longer needed storage tanks from building tops
- reduction of municipal solid waste, in the form of discarded plastic bottles.

- Tunnel's intensive operation during emergencies, improved flood water drainage in Lasithi Plateau, with subsequent improvements concerning security and facilitation of certain agricultural activities (i.e., livestock etc.). The reported flood water drainage improvement is compatible with the national flood risk management plan (YPEN, 2017b).
- A new wetland has been created at the dam's lake. Apart from the ecological importance, lake's landscape is appreciated by many visitors, affecting positively their mental health and inspiring art production (i.e., photographic capture etc.), while few recreational activities take place (i.e., the organized running race).
- Dam's water availability has a positive effect on reducing groundwater pumping. The impact is just starting being slightly observed, and is expected to acquire a greater size in the future. It concerns aquifers at various locations that used to provide water for the cities. According to Tsakiris et al. (2015), a number of aquifers providing water supply for Heraklion city have exhibited qualitative or quantitative problems, which emphasizes the need of water withdrawal reductions towards groundwater resources sustainability. Potential pumping reduction concerns also island's karstic aquifers of bottled water extraction.

3.2.2. Negative environmental impacts

- Surface flow downstream has been significantly reduced, as a common consequence of damming a river (McCartney, 2009). However, during dam's overflow emergency procedures, large amounts of water were led to the immediate downstream riverbed area.
- Groundwater resources of three distinct areas are affected:

    - Downstream aquifers are affected due to their supply connection with the diminished adjacent surface runoff. Subsequent secondary impacts concern the disturbance of certain agricultural activities downstream (i.e. reduced water availability in irrigation wells).
    - Sinkhole isolation work in Plateau possibly disturbs formerly supplied karstic aquifers, expected at various regions of the wider area (Voudouris et al., 2007). During recent years, certain amounts of water were discharged into Chonos sinkhole, despite tunnel's intensive operation. The impact has not been fully observed today, but is expected crucial during future dry hydrological years.

- Plateau's alluvial aquifers' recharge may be disturbed due to the faster drainage. Flood water previously remained longer, recharging the aquifers for greater time. During summer 2019, reduced water quantity was observed in certain wells of south and east regions.

- A new microclimate has emerged at reservoir's region. The new lake increases humidity levels and welcomes insects' populations. Subsequently, related health disturbance in certain cases of lakeside residents is observed.
- Water diverted through the tunnel into the reservoir may carry agricultural pollution load. As a prevention measure, tunnel's operation is avoided during autumn period (Papagrigoriou et al., 2018). The impact is also based on recorded local opinion and perception.
- The dam increases insecurity among lakeside residents of the immediate downstream village. The impact acquires greater size during the cases of emergency, when many inhabitants of Potamies village express feelings of anxiety, stress and fear.
- Flooded Sfendyli village led to a community resettlement as a consequence of a dam structure (Piggott-McKellar et al., 2020). Sfendyli residents, although economically compensated, were finally scattered, and their organized relocation never took place (Chifos et al., 2019).
- The former ecosystem of the dam region has been greatly altered. Cultivated land and olive grove fields, "famous for high-quality olive oil" (Chifos et al., 2019) have been submerged.
- The loss of family acquisitions expropriated by the project often creates feelings of sadness or melancholy. As Boyer et al. (2019) noted, people often show a strong emotional attachment to the environment they live in.
- Project's constructions affected soil / rock resources of certain regions.
- Slope stability issues emerged at the new road section, with emphasis on a landslide event (in spring 2020) that led to traffic interruption for over a month.

- Slope stability issues were observed at the lakeside area after lake's first filling (Papagrigoriou et al., 2018). A major landslide emerged on spillway's slope (winter 2015) (Papagrigoriou et al., 2018).
- An underground karst cavity system was disturbed during the construction of the tunnel (July 2016) (Gütter and Rudigier, 2016).

- Downstream sedimentation disturbance is a common consequence of dam constructions (McCartney, 2009; Ji et al., 2020; Lyu et al., 2020). The impact is based on certain locals' observations of coastal width reduction at river estuary. It is a cumulative impact, due to additional disturbance caused by coastal constructions in the wide area, and cannot be straightly attributed to the project alone.
- In certain regions, the constructions affect the landscape (e.g., at tunnel's exit).
- At the NW part of Plateau, in vicinity to the sinkhole isolation work, persistent flood incidents occur. The impact is estimated of a small size and importance.

3.3. Proposed measures and good practices towards sustainability

Recommendation for *Lasithi Plateau and upland area*:

- Implementation of groundwater observation programs on both the alluvial and karstic aquifer, in order to monitor possible effects and apply adequate prevention and mitigation measures for groundwater resources protection. Malagò et al. (2016) developed a simulation karst-flow model for the island of Crete, as a methodology and a tool for the integrated management, conservation, preservation and sustainability of karst water resources of the area.
- Sustainable agricultural techniques, allowing to reduce production inputs, especially irrigation water and fertilizers (Provenzano et al., 2013). Certain promote policies are mandatory to ensure farmers' adoption (Bechini et al., 2020). Optimization of fertilizer usage may affect positively reservoir's water quality, leading to subsequent reduction in treatment costs, water price and CO_2 emissions (Kandris et al., 2019).

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

Natural Parameters	Impact's Description	Reference Area	Character	Current Period		Future Estimation	
				Size	Importance	Size	Importance
Surface Water	Lasithi Plateau's flood water drainage	P	+	H	H	H	H
	Reduction of the surface runoff downstream	DS	-	M	M/H	M	M/H
	Agricultural pollution transport into the reservoir	D	-	M	M	M	M
	Flood conditions at NW part of Lasithi Plateau	P	-	L	L	L	L
Ground Water	Disturbance of groundwater supply downstream	DS	-	M/H	M	H	H
	Disturbance of upland karstic aquifers' supply	U	-	L	L/M	H	H
	Disturbance of Plateau's alluvial aquifers' recharge	P	-	L	L	M	M
	Reduction of groundwater pumping	G	+	L	L	H	H
Soil-Rock Resources	Disturbance of sedimentation downstream	DS	-	L	L	H	H
	New alignment's slope stability issues	D	-	L	M	L	M
	Lakeside area's slope stability issues	D	-	L*	L*	L*	L*
	Disturbance of underground karstic cave	U	-	L*	L*	L*	L*
Landscape	New landscape of dam's lake	D	+	H	H	H	H
	Landscape disturbance at technical works' areas	P, D	-	L	L	L	L
	Improvement of urban landscape	C	+	L*	L*	M	L/M
Climate	Alteration of lakeside area's microclimate	D	-	M	M	M	M
Ecosystem	Wetland's supply disturbance	E	-	L	L	M/H	M/H
	Formation of new wetland at the dam's lake	D	+	H	H	H	H
	Alteration of dam's area former habitat	D	-	H	L	H	L
General	Municipal solid waste reduction	G	+	L	L	H	H

Reference Area: C Cities, D Dam's region, DS Downstream area, E Estuary, G General, P Lasithi Plateau, U Upland area.

Character: [+] Positive. [-] Negative.

Size / Importance: H High, M Medium, L Low, [*] Not currently observed. Potential future impact.

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

Human Parameters	Impact's Description	Reference Area	Character	Current Period		Future Estimation	
				Size	Importance	Size	Importance
Socio-Economic Parameters	Water supply for several urban areas	C	+	H	H	H	H
	Improvement of network in the city of Heraklion	C	+	L	L	H	H
	Household resources saving	C	+	L	L	L/M	L/M
	Tourist activities facilitation	C	+	L	L	H	H
	Sfendyli former inhabitants displacement	D	-	L	L	L	L
	Improved flood security in Lasithi Plateau	P	+	H	M	H	M
Physical Health	Lakeside residents disturbance due to new microclimate characteristics (humidity, insects etc)	D	-	M	L	M	L
	Improvement of citizens' health related to water-network quality	C	+	L	L	L	L
Mental Health	Increasing insecurity, anxiety and fear of immediate downstream lakeside residents	D	-	H	L	M/H	L
	Sadness of former owners' loss	D	-	L	L	L	L
	Lake's landscape affects positively the mental health of visitors	D	+	L	L	L	L
Land Uses	New lakeside activities	D	+	L	L	M/H	M/H
	Cultivated area loss	D	-	H	L	L	L
	Agricultural activities in the downstream area	DS	-	M	L	M	L
	Agricultural activities in Lasithi Plateau	P	+	L	L	L	L

Reference Area: C Cities, D Dam's region, DS Downstream area, P Lasithi Plateau.

Character: [+] Positive. [-] Negative.
Size / Importance: H High, M Medium, L Low.

In *dam's region*, the sustainable development of the reservoir is very important (Ho and Goethals, 2019). Sustainability goals combine environmental quality with socio-economic improvements. The recommendations include:

- Ecotourism and organized leisure activities near the lake, that respect the environment while involving and providing economic benefits to the local community, according to UNESCO principles (Idajati and Widiyahwati, 2018).
- Application of sustainable energy projects, such as a small hydro turbine at the end of the diversion tunnel (Nikolaou et al., 2017) and photovoltaic systems on existing infrastructures (OAK S.A., 2018).
- Implementation of wastewater treatment plant, removal of certain materials within the reservoir area, and slope stability measures implementation. As Wilk-Woźniak et al. (2021) noted, "keeping the catchment tidy and unpolluted is the basic recommendation for managing of dam reservoirs".
- Proper administrative policies in order to facilitate lakeside residents' everyday life and reduce any negative feelings.

Recommendation for the *downstream area, river estuary and wetland*:

- The establishment of the pending protection law framework for Aposelemis wetland (Papagrigoriou et al., 2018) is crucial for its preservation and sustainability.
- The anticipated wetland observation program, a duty of project's organization (Papagrigoriou et al., 2018), may indicate additional protection measures concerning the downstream ecological water flow and sedimentation. As Albert et al. (2021) noted, "conservation actions are most effective when they are implemented with full recognition of the genuine fragility of ecosystems".
- Due to the degraded groundwater characteristics –seawater intrusion– of the wide area, protection and mitigation measures should be applied. Basic recommendations concern the implementation of groundwater observation programs, the application of a complete water management plan, which can be combined with artificial recharge techniques.

Recommendation for the *cities of water supply*:

- Implementation of actions that complete project's scope, such as the supply network improvement of Heraklion city, and pending constructions for the supply of tourist areas in Lasithi district.

- Effective management of freshwater resources, as one of humanity's highest priorities (Albert et al., 2021), with emphasis on policies that inform and educate citizens in order to raise consumption awareness and promote water resources sustainability.

4. CONCLUSIONS

As "subsidy restoration may require a different set of actions from simply reversing the pathway of degradation" (Buckner et al., 2018), the observation of environmental impacts is crucial even from the initial time period of a human project's operation. On this basis, the current investigation concerns environmental impacts due to Aposelemis water supply project, observed during the first years of its full operation.

Among the observed positive effects are urban areas' water supply and improved Lasithi Plateau flood drainage, while among the negative consequences appear water resources impact and feelings of downstream lakeside residents. The recorded environmental impact is directly correlated with the high precipitation rates of the investigated period. 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 investigation indicates project's initial environmental impact and sets the main axes for further future research.

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