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Περιβαλλοντική Ρύπανση των Ποταμών, Λιμνών και Υγροτόπων της Ελλάδας.

Περιβαλλοντικές έρευνες και εκθέσεις για την κατάσταση των Ελληνικών πηγών γλυκού νερού

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Περίληψη . Η Ελλάδα έχει 45 ποτάμια (από τα οποία τα 21 μεγάλου μήκους) και 40 αξιόλογες λίμνες γλυκού νερού με επιφάνεια, περίπου, 560 km^2. Επίσης, η Ελλάδα έχει αξιόλογους υγροτόπους με πλούσια οικοσυστήματα. Τέσσερα σημαντικά ποτάμια που διαρρέουν την Ελλάδα, Έβρος, Νέστος, Στρυμόνας και Αξιός πηγάζουν από τις Βόρειες Βαλκανικές χώρες. Τα μεγαλύτερα ελληνικά ποτάμια είναι ο Αλιάκμονας, ο Αχελώος, ο θεσσαλικός Πηνειός, ο Έβρος και ο Νέστος. Οι λίμνες είναι κυρίως φυσικές αλλά υπάρχουν και τεχνητές. Οι περισσότερες λίμνες γλυκού νερού είναι αποτέλεσμα τεκτονικών και ηφαιστειακών δυνάμεων. Η Ελλάδα για να διασφαλίσει γλυκό νερό από τα ποτάμια για όλες τις εποχές του χρόνου έχει κατασκευάσει φράγματα και δημιούργησε τεχνητές λίμνες στα σημαντικότερα ποτάμια. Το νερό των ποταμών και των λιμνών χρησιμοποιείται σε υπερβολικό βαθμό για την άρδευση γεωργικών καλλιεργειών, για την ύδρευση πόλεων και για την παραγωγή ηλεκτρικού ρεύματος. Η μεγαλύτερη ελληνική φυσική λίμνη είναι η Τριχωνίδα και η μεγαλύτερη τεχνητή είναι η Λίμνη Κρεμαστών. Μελέτες τις τελευταίες δεκαετίες δείχνουν ότι η στάθμη πολλών λιμνών παρουσιάζει συνεχή πτώση (Βεγορίτιδα, Κορώνεια, Δοϊράνη κ.ά.) λόγω της εντατικής άντλησής του για άρδευση καλλιεργειών, τη μείωση των βροχοπτώσεων και τις κλιματικές αλλαγές. Επιπλέον, η διάβρωση και η απόθεση των φερτών υλικών στις τεχνητές λίμνες μειώνουν τη διάρκεια της ζωής τους, αφού ελαττώνουν σταθερά το βάθος τους. Τα ποτάμια και οι λίμνες στην Ελλάδα ρυπαίνονται από αστικά λύματα σε αρκετές περιοχές με μεγάλες και μεσαίου μεγέθους πόλεις.

Η ρύπανση ποταμών, λιμνών και υγροτόπων είναι επίσης αποτέλεσμα της εντατικής χρήσης λιπασμάτων (νιτρικά, αμμωνιακά και φωσφορικά άλατα) και φυτοφαρμάκων (ζιζανιοκτόνα, εντομοκτόνα), τα βιομηχανικά λύματα (από βιομηχανίες και εργοστάσια ζάχαρης, γαλακτοβιομηχανίες, κονσερβοποιίες κ.α.). Τα υγρά λύματα κτηνοτροφικών μονάδων είναι ένα ακόμη σοβαρό πρόβλημα ρύπανσης λιμνών και ποταμών. Κάδμιο, υδράργυρος, μόλυβδος, νικέλιο και χαλκός σε υψηλές συγκεντρώσεις έχουν ανιχνευθεί σε πολλούς ποταμούς και λίμνες. Επίσης, ρύπανση από τοξικές χημικές ουσίες και ουσίες με ενδοκρινικές ιδιότητες είναι ένα σημαντικό πρόβλημα ρύπανσης. Σημαντικός παράγοντας ρύπανσης είναι τα υγρά λύματα από εκπλύσεις αστικών και βιομηχανικών αποβλήτων (π.χ. χωματερές), ρύποι από πετρελαιοειδή και άλλες τοξικές ουσίες. Οι διασυνοριακοί ρύποι στην περίπτωση του Αξιού προέρχονται από τις βόρειες Βαλκανικές χώρες. Ο Αλιάκμονας και ο Αξιός δέχονται μεγάλες ποσότητες επεξεργασμένων και μη αποβλήτων από αρκετές πυκνοκατοικημένες περιοχές και βιομηχανικές εγκαταστάσεις. Ο Λουδίας, λόγω των αγροτικών αποβλήτων και των αποβλήτων από τις βιομηχανίες επεξεργασίας φρούτων και ζάχαρης είναι ένας από τους πλέον ρυπασμένους ποταμούς. Στην ανασκόπηση αυτή εξετάζονται τα σημαντικότερα προβλήματα ρύπανσης των ποταμών και λιμνών της Ελλάδας, καθώς και τα μέτρα που έχουν ληφθεί για να περιορισθεί η ρύπανση και η προστασία των ποτάμιων και λιμναίων οικοσυστημάτων.

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<Επιστροφή στη λίστα επιστημονικών θεμάτων και ανακοινώσεων>

ENVIRONMENTAL POLLUTION OF RIVERS, LAKES AND WETLANDS IN GREECE

Environmental Research and Reports on the State of Greek Freshwater Resources

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Abstract

Greece has in its territory 45 rivers (of which 21 are major rivers) and 40 lakes with a total surface of approximately 560 km^2. Also, Greece has excellent wetlands with important and rich ecosystems. Four of the longest flowing rivers in Greece are the Evros, Nestos, Strymonas and Axios and the Axios have their springs in the northern Balkan countries. The longest Greek rivers are Aliaknon, Acheloos, Pinios in Thessaly, Evros and Nestos. There are natural and artificial lakes in Greece, as well as many lagoons. Most lakes are freshwater and have formed mainly far from the coastlines as a result of tectonic or volcanic forces, or from the melting of glaciers. Greece in order to secure adequate fresh water from the rivers throughout the annual circle constructed numerous damns and artificial lakes in the most important rivers. It is known from studies that water from rivers and lakes is used excessively for agricultural use, for drinking water of cities and towns and for the generation of electricity. The biggest natural lake is Trichonida and the largest artificial is Lake Kremaston. Studies of the last decades showed that the water levels of lakes is lowering continuously (Vegoritida, Koronia, Doirani, etc). The most important factor is the excessive use of their water for farming, the reduction of rain seasons and climatic changes. Also, erosion of soil surrounding lakes precipitates in the bottom reducing their sizes. Rivers, lakes and wetlands are polluted by liquid urban waste especially produced by highly populated cities and towns.

Most of the major Greek rivers are characterized by point-pollution sources which are mainly concentrated near urban centres, as well as extensive arable areas. Pollution of rivers, lakes and lagoons is the result of excessive use of fertilizers as well as pesticides. Nutrient concentrations from agricultural activities in major Greek rivers has been an important pollution issue. High nitrate and phosphate, nitrite and ammonium concentrations can be found in all major Greek rivers. Heavy metals in rivers and lakes is another serious environmental problem. Cadmium, mercury, lead, nickel and copper concentrations have been measured in major Greek rivers. Regarding lead, nickel copper and zinc, their levels in Greek rivers are in general higher. In the last decades other pollutants, such as toxic chemicals and endocrine disrupting substances have been measured in Greek rivers and lakes. Liquid waste from stock farming activities is another important environmental problem. Pollution of rivers, lakes and lagoons is the result of washing and leachates from illegal urban and industrial solid waste tips. Crude petrol and toxic substances from industrial waste has been found in many rivers and lakes. Transboundary pollution of Axios from the northern Balkan countries is a serious issue. Water quality in the rivers Aliakmonas and Axios is influenced by liquid waste from highly populated areas and industrial facilities. Loudias river, because of agricultural effluents and liquid waste from food and sugar industrial activities, has been the most polluted river. In this review the most important environmental and pollution issues are presented in a comprehensive way from scientific studies and reports of the last decades and the preventative measures to reduce pollution and protect water quality and freshwater ecosystems.

Introduction: Rivers, Lakes and Wetlands in Greece

There are about 45 rivers in the Greek territory and 40 lakes with a total surface of approximately 560 km^2. Greece is located in the Mediterranean temperate climatic zone, with an uneven spatial mean annual and seasonal rainfall distribution. The variable geomorphologic profile and geological background of the Greek peninsula, gives rise to major differentiations with respect to the geographical distribution and the hydrological variations of its rivers and lakes. High amounts of interregional water are consumed in the upstream neighbouring countries (Bulgaria and former Yugoslavia), while large-scale drainage and land reclamation projects have drastically reduced surface runoff and the lakes' surface. Also, excessive sedimentation rates, enhanced by extensive soil erosion due to deforestation, have dramatically reduced the lakes' volume. Greek rivers are heavily polluted by municipal liquid waste in most highly populated areas of Greece. Fertilizers and pesticides from agricultural activities and liquid waste from stock farming. Industrial liquid and solid waste is another serious source of river pollution (sugar refineries, milk, cheese and food production and packaging facilities).[1-4] The most important rivers of Greece are presented in Table 1.

Table 1. Rivers in Greece, their length, geographical region, and basic characteristics

Rivers	**Length (Km)**	**Characteristics of rivers**
Acheloos	220 km	Western Greece , on exiting the Kremasta reservoir, the river flows southwest into Aetolia-Acarnania, feeding the Kastraki reservoir, west of the Panaitoliko range
Evinos or Fidaris	113	The upper part has fast running waters, flows into Patraikos Gulf
Alfios	110	The biggest river in the Peloponnisos
Lousios	23	Tributary of Alfios
Arachthos	110	River in Epirus, north of Pindos mountain, flows to Amvrakikos gulf
Aliakmonas	310	the longest in Greek river, in Macedonia , rising in the Grámmos Mountains of the E Pindus (Píndos) Range on the Albanian frontier
Evros	204	Natural border between Greece and Turkey. It forms a vast delta, wetland (200 square Km)
Karpenisiotis	15	Evritania. Sources in the mountain of Tymfristos
Pinios	205	Thessaly, principal stream of Thessaly rising in the Óros Lákmos of the Pindus Mountains, just east of Métsovon in the Tríkala; navigable in its lower course.
Strymonas	118	Strymónas (Bulgarian Struma, Turkish Karasu 'black water') river in Bulgaria and Greece. Its catchment area takes its source from Vitosha Mountain
Thiamis	115	Also known as Glykys (Γλυκύς) or Kalamas is a river in the Epirus region of Greece. It flows into the Ionian Sea.
Asopos	80	River of Boeotia originating on Mt. Cithaeron and flowing through the district of Plataea into the Euripus Strait.
Louros	80	River in Epirus region, in NW Greece. It emerges from the ground in a large spring north of the village of Vouliasta
Sperchios	80	The river begins in the Tymfristos mountains on the border with Evrytania. It flows along the towns Makrakomi and Leianokladi, and south of the Phthiotidan capital Lamia.

Axios	76	The Vardar or Axios (Macedonian☺. Greek: Αξιός *Axiós* or Βαρδάρης (*Vardárīs*) is the longest and major river in the former Republic of Macedonia and also a major river of Greece. It is 388 km long
Nestos	130	The Nestos or Mesta (Bulgarian), formerly the Mesta Karasu(Ottoman Turkish), is a river in Bulgaria and Greece. Rises in the Rila Mountains and flows into the Aegean Sea near the island of Thasos.
Megdovas	78	Begins in the Agrafa mountains in the W of Karditsa Since the late-1950s it flows into Lake Plastiras (reservoir) that supplies electricity and water to Thessaly and Central Greece,
Mornos	70	Is a river in Phocis and Aetolia-Acarnania in Greece. Its source is in the SE part of the Oiti mountains, near the village of Mavrolithari, Phocis. It flows towards the south, and enters the Mornos Reservoir.
Gallikos	70	River of Macedonia, near Thessaloniki and village Kalochori
Ladonas	70	The Ladon (modern Greek: Λάδωνας, *Ládonas*) is a river in the Peloponnese peninsula of Greece. It features I Greek mythology. It is a tributary to the river Alfeios river.
Pinios	70	also called Peneus, principal stream of Thessaly (Modern Greek: Thessalía), Greece, rising in the Óros Lákmos of the Pindus (Píndos) Mountains just east of Métsovon

Figure 1. Axios is the second longest river in Greece with a total length of 320 km, of which 76 km are in Greece. It is estimated that Axios receives 1.140.000 m^3 of industrial waste only from Greek industrial enterprises per year

There are more than 40 of natural and artificial lakes in Greece, as well as many lagoons. Most lakes are freshwater and have formed mainly far from the coastlines as a result of tectonic or volcanic forces, or from the melting of glaciers. There are also lakes with salt or brackish water, when the substratum contains many soluble salts or it receives an inflow of saltwater. Greece has artificial lakes, which have been created by the construction of dams in brooks, streams or rivers in order to store water for various objectives (irrigation, farming, drinking water, etc). Lakes in Greece cover a considerable area (560 km^2) and have contributed to the creation of significant ecosystems and substantial wetlands with an abundance of species. The largest natural lake is Lake Trichonida. The two lakes of Prespes [Mikri (Minor) and Megali (Great) Prespa], in the borders between Greece, Albania and former Yugoslavia are very interesting and rich natural lakes with important ecosystems. Lake Ioannina, Lake Kastoria, Lake Kerkini and Lake Doirani in northern Greece have rich ecosystems with great variety of birds. The most famous artificial lake in Greece is Lake Plastira in Thessaly. Other artificial lakes in Greece are Lake Mornos, Kremasta, Ladon and Marathon in Athens.[5,6]

Table 2. The most important natural and artificial lakes in Greece

Lakes (* artificial)	**Square km (Km^2) or ha (hectare, 10,000 sq m)**	**Region, physical characteristics**
Mitrikou (Ismarida)	6500 ha	Lake in Thrace. A coastal wetland complex. It consists of the fresh*water* Lake Mitrikou, surrounded by extensive reedbeds (*Phragmites*), coastal lagoons and saltmarshes.
Vistonis	15300 ha	Lake in Thrace, NE, Xanthi-Komotini
Kerkini (*)	109 km^2	Macedonia, Strymon river, reservoir, constructed 1932,(http://www.ramel.org/lake-kerkini/project.html)
Volvi Koronia	68 km2 45 km2	Thessaloniki region, Ramsar list,
Doirani	43.1 km2	Macedonia, overuse lake's water for agriculture
Mikri Prespa	46.8 km2	Balkan lake (Albania, Greece), important wetland ecosystem, Dalmatian pelican
Megali Prespa	259 km2	Balkan lake (Albania, Greece, FYROM)
Sfikia		Artificial Sfikia is a Lake in Imathia in the Macedonia Region of Greece and it is also a dam.
Aoou (*)		Aoos Lake is a Lake in Ioannina in the Epirus Region of Greece
Ioanninon (Pamvotis)	19.4 km2	Lake in the city of Ioannina, Epirus, http://www.thetoc.gr/eng/family-health/article/pollution-in-ioanninas-lake
Lourou (*)		Formed by artificial dam. This area is a complex ecosystem comprising the double delta of the Louros and Arachthos Rivers, a series of salt water lakes including three large lagoons (Rhodia, Tsoukalio and Logarou).
Plastira (*)		The famous Lake Plastira, located in the Prefecture of Karditsa, was named after Nikolaos Plastiras, a former Prime Minister of Greece. It is situated 30 km west of Karditsa town
Kastraki (*)		The Kastraki Dam is an earth-fill embankment dam on the Acheloos River near the village of Kastraki in Aitoloakarnania. It was completed in 1969, hydroelectric power generator, flood control and irrigation.
Asomaton		Artificial lake, reservoir, next to Polýdendron located in Central Macedonia,

List of Names of Lakes in Greece. The* indicates artificial lake or reservoir: Mitrikou (Thrace), Vistonis (Porto Lagos,), Kerkini* (Macedonia), Volvi, Koronia, Doirani, Vegoritis, Petron, Zazari , Chimaditis, Kastoria, Mikri Prespa, Megali Prespa, Polyphytos*, Sfikia*, Asomaton*, Aoou*, Ioanninon , Pournari*, Lourou*, Plastira*, Kremasta*, Kastraki*, Stratos*, Amvrakia, Ozeros, Lysimachia, Trichonida, Mornou*, Paralimni, Iliki, Piniou*

Figure 2. The spectacular and significant Great Prespa Lake shared under a landmark agreement between Greece, Albania and the Former Yugoslav Republic of Macedonia (photo from *Vlachogianni Thomais, photostream, 2015,* https://www.flickr.com/photos/thomais/).

Greece has Internationally Significant Wetlands

Greece has internationally significant protected wetlands that are included in the International Convention of Ramsar (1971), signed by Greece and ratified by virtue of Legislative Decree 191/74. There are 10 wetlands listed below: There are numerous inventories and conferences on Greek wetlands and their significance.[7,8]

1. Amvrakikos Bay: Etoloakarnania, Preveza, Arta [Information Center: (Hill of Salaora, close to Arta town (from the Arta town to the Koronissia village), West Greece)]
2. Axiou Delta - Loudia – Aliakmona: Thessaloniki, Imathia, Pieria [liakmon-Loudias-Axios-Gallikos Delta & Kitros Salinas (close to Thessaloniki town, North Greece)]
3. Evros Delta: Evros [Evros Delta (NE Greece, border with Turkey) (Traianoupolis, 14 km east of Alexandroupolis)]
4. Kotychiou Lagoon: Ileia [Kotichi Lagoon-Strofilia Forest (NW Peloponnisos)]
5. Mikri Prespa Lake: Florina, NW Greece [Small and Great Prespa, two freshwater lakes in southeast Europe, shared by Albania, Greece, and the former Republic of Macedonia,.]
6. Vistonis Lake, Porto Lagos, Ismaris Lake (Mitrikou) and Mesis Lagoons: Rodopi, Xanthi [Vistonis Lake-Porto Lagos Lagoons(Thrace, NE Greece) (Porto Lagos, on the National Road from Xanthi town to Komotini]
7. Koroneia or Koronia Lake (60 km from Thessaloniki town), Volvi Lake (Apollonia village, south of the Lake Volvi shores)
8. Mesolongi Lagoon : Etoloakarnania [Messolongi-Aetolikon Lagoons (close to Messolongi town, SW Greece)]
9. Nestou Delta and adjacent Lagoons: near the town of Xanthi, NE Greece
10. Kerkine Lake: Serres [birds breeding in the Kerkíni wetlands include various species of grebes, terns, egrets, ducks, geese, ibis, spoonbills, avocets and pelicans, plus raptors].

Figure 3. Messolongi lagoon [*Photo by Thomais Vlachogianni, Photostream, 2014*].

Figure 4. Kerkini lake (left) in spring and summer is a veritable paradise for birdwatchers. Agras-vritta-nisi wetland (right), situated 7 km NW of Edessa and covers an area of 600 ha.

Environmental Pollution in Greek Rivers

Greek rivers are heavily polluted by municipal liquid waste in most highly populated areas of Greece. Also, another very important source of pollution is the use of fertilizers and pesticides in agriculture and liquid waste from animal breeding as well industrial pollutants from a variety of industries (such as sugar refineries, milk and cheese production, fruit and vegetable packaging, metal production and refining, agricultural fertilizers, paper and plastic packaging facilities, petroleum refining, etc).

The first study of heavy metal distribution in unfiltrated water samples of the most important rivers and lakes of northern Greece was carried out in the 1980s. Metals Pb, Cd, Cr, Cu, Zn, Fe and Hg were monitored in samples from rivers and lakes of Northern Greece. Measurements showed that the high level of heavy metals found in some of the water systems was indicative of anthropogenic contamination. The heavy metal concentrations were correlated with the pollution sources and compared with those of other regions.[9] The second paper by the same authors examined partitioning of heavy metals in sediments form rivers in North Greece. The study measured the chemical association of heavy metals , such as Pb, Fe, Mn, Zn and Cr with major sedimentary phases (exchangeable cations, easily reducible compounds, organic sulfidic phases, carbonates and residual components) in samples from rivers in northern Greece (Axios and Aliakmon). The results showed that metal contaminants introduced into the aquatic system from anthropogenic sources usually exists in relatively unstable chemical forms. A high proportion of the elements studied remains in the residual fraction for the Axios river and in the organic fraction for the Aliakmon.[10]

Aliakmonas river

Pinios river

Figure 5. Aliakmonas and Pinios rives receive high volumes of municipal effluents industrial waste and agricultural nutrients.

The rivers of Greece in areas with highly populated cities receive large amounts of municipal effluents, as well as industrial liquid waste and agricultural nutrients from farming activities. It is estimated that Axios receives 1.140.000 m^3 of industrial waste only from Greek industrial enterprises per year. Transboundary pollution with municipal waste, petroleum residues and toxic substances is the case for the Axios river. The degree of pollution of the River Axios in Northern Greece was evaluated by determination of certain chemical parameters, such as dissolved oxygen, pH, conductivity, nutrients and heavy metals. The samples were collected from three sampling stations within the Greek section of the river, and they were surface water and surface sediments.[11,12] The increased pollution levels in the Axios river resulted in high concentration of pollutants in the Thermaikos Gulf (Thessaloniki) because most of the phosphorous (43%) and nitrogen nutrients (56%) resulting from the river effluents reaching the gulf waters.[13]

One of the most polluted river in the North of Greece is Loudias. This is the result of industrial effluents from food and sugar refilling industries A study by the University of Thessaloniki studied the organic pollution in natural waters of Northern Greece and various physicochemical parameters [measurement of TOC (total organic carbon), conductance, hardness, hardness, alkalinity and total iron content]. The results showed that Agios Vasilios lake was the most heavily polluted whereas the river Loudias had the greatest organic charge compared to Axios.[14]

Figure 6. The Axios-Loudias-Aliakmonas Delta has a very important biodiversity. The Axios delta (left). The Loudias river (right) is the most polluted river in the North of Greece as a result of industrial effluents from food and sugar refilling industries

Heavy metal concentrations and natural radioactivity were measured on the surface waters of rivers Aoos, Kalamas, Louros (Epirus), Aliakmonas (Macedonia) and Pinios (Thessaly) in the period 2004–2006. Concentrations for metals were lower than the ones usually found in polluted rivers. Gross-alpha and -beta activities (Gross alpha/beta measurements, radioanalytical procedures applied widely in the field of radioecology) in the five Greek rivers were within the range usually observed in other European and world rivers. All ^{226}Ra (Radium, isotope of radium with a half-life of 1600 years.^{226}Ra occurs in the decay chain of ^{238}Uranium) concentrations were lower than the world mean of 0.015 Bq L^{-1}. Statistical analysis of variance and correlation analysis of the measured heavy metals showed limited significant differences between sampling sites or periods, suggesting influence from geologic factors rather than from point sources. High concentration of Lead (Pb) in the river's water suggesting use of pesticides containing the metal. Significant differences between the three studied sites of Aliakmonas river were observed for gross-alpha and ^{226}Ra activities. The result was attributed to the influence of the coal mines in the region and/or the runoff of fertilizers from agricultural activities in this area.[15] Four rivers Axios, Loudias, Aliakmon, and Gallikos constitute the major sources of material input into the marine system of the Thermaikos Gulf (Thessaloniki). The Gulf receives domestic, agricultural and industrial effluents not only through the rivers but also in sewage from the city of Thessaloniki.[16,17]

Environmental pollution of the river of Pinios in Thessaly is the result of anthropogenic activities along the river banks and its tributaries. A survey of the physicochemical characteristics of pollution was took place in 1996-98. Most of the parameters (physical or chemical) measured exhibited high spatial and temporal variability. High temperatures during the warm period, attributed both to meteorological conditions and to the geographical relief of Thessaly plain, cause a restriction of the water flow, and resulted in the accumulation of organic matter and the depletion of the dissolved oxygen in the river water. Conductivity and hardness are high during the warm and wet period for different reasons. At the seaward part of the river high conductivity and hardness values indicate extended admixture of seawater. COD (chemical oxygen demand) values fluctuated seasonally. Among the studied stations along the Pinios River the most polluted was the area where the river has passed the city of Larissa (municipal liquid and solid waste).[18]

Figure 7. Greek rivers are heavily polluted in most highly populated areas. Effluents of fertilizers and pesticides from agriculture, liquid waste from stock farming and industries are main pollutants of Greek rivers. [http://www.mapsofworld.com/greece/greece-river-map.html

A study in the 1990s surveyed major Greek rivers and tributaries which yield 80% of the total surface discharges in the Mediterranean Sea. The rivers were: Evros-Ardas, Nestos-Arkoudoremma, Strymon, Argitis, Gallikos, Axios, Aliakmon, Pinios, Sperchios, and Louros. The physicochemical characteristics studied pH, dissolved O_2, alkalinity, Chlorine (Cl), (calcium) Ca, (magnesium) Mg, (sodium) Na, (potassium) K, (sulphate) SO_4, (nitrate) NO_3, (phosphate) PO_4, silicate, dissolved organic carbon, total suspended solids, particulate organic carbon, nitrogen (N) copper (Cu), lead (Pb) and zinc (Zn). The influence of environmental pollution on Greek river-water composition is clearly shown in the case of the Evros, which due to its high pollution differs hydrochemically from the other northern Greek rivers with similar petrographic and climatic features. Samples from Evros indicated that there are high nitrate and phosphate concentrations. Also, Axios has sixfold total phosphorous enrichment as well as higher nitrate and ammonium concentrations from other major rivers. Measurements of heavy metals in major rivers, such as Cd, Hg, Pb, Ni and Cu showed that their concentrations were lower than the maximum permissible levels in drinking water [19,20]

The plain of the river Axios in Macedonia produces more than the 70% of the Greek rice production. In spring the rice-cultures are flooded and until September there is high use of pesticides which threatened birds and other sensitive animals. Intensive river water pumping during the summer months for irrigating purposes in the delta area as well as in former Yugoslavia reduces the freshwater flow in the lower parts of the Axios river, while the consumption of water by the industries makes the situation more serious. The increased salinity of the water and, occasionally, the complete drying up of the delta have unknown impacts on the fish populations upon which many birds depend.[21-25]

A three year survey was contacted in major rivers of Macedonia (Aliakmon, Axios, Loudias. Gallikos and Strymonas) in 25 key sampling sites on monthly basis (total of more than 22 thousand observations). The sampling analysis involved various physicochemical parameters, toxic pollutants, nutrients, soil-leaching, etc. The dataset was treated using cluster analysis, principal component analysis and multiple regression analysis on principal components. Six latent factors were identified as responsible for the data structure explaining 90% of the total variance of the dataset and are conditionally named organic, nutrient, physicochemical, weathering, soil-leaching and toxic-anthropogenic factors.[26]

Another study (1995) in the Acheloos river (W. Greece) studied heavy metals in the sediments. In the area dams, agricultural practices, traffic, and other pollutants influence the estuarine system of Acheloos and in combination with the hydrological, mineralogical and morphological characteristics of the estuary affect the chemical behaviour and the distribution patterns of trace metals in its sediments. The concentrations of most metals (Al, Fe, Cu, Ni, Zn) are elevated in three of these zones (upstream, sill and seawards). A different behaviour was observed for Mn due to its association with carbonates that were observed in significant concentrations throughout the estuarine zone. Although Acheloos is not considered to be heavily polluted river, some metals have shown an enrichment in the surface sediments as a result of general anthropogenic activities not derived from point sources.[27]

Pollution sources and concentrations of pollutants were measured in a small Mediterranean riverine system of the Litheos river (Trikala, 1991-92). The pollution sources include urban activities, agriculture effluents, sewage from industrial activities and small scale handicraft activities. The mean values of the main pollutants were: NO_3^-4.0 mg N/1, NH_3 0.23 mg N/1, NO_2^- 0.10 mg N/1, P 0.37 mg P/1, Cu 7.1 μg/l, Pb 4.8 μg/l, Zn 3.9 μg/l, Ni 12.8 μg/l, Cr 3.5 μg/l. These values characterized Litheos as a moderately polluted river, but the observation of eutrophication phenomena and the appearance of some high concentrations of heavy metals and/or organic pollutants in certain parts of the river need measures to reduce further pollution levels.[28]

Volatile Organic Compounds (VOCs, e;g. carbon tetrachloride, benzene, toluene, xylene, methylene chloride, chlorofluorocarbons, paints, etc) were measured in rivers, lakes, seawater and treated wastewater in Greece (1998-99). The determination of 41 VOCs by GC-MS was performed in samples collected seasonally from 10 Greek rivers, seven lakes, three gulfs and four wastewater treatment plants. The results suggested that not only agricultural and industrial activity within the Greek territory, but also transboundary pollution from neighbouring countries consist important sources of VOCs in surface waters of Greece. The measured concentrations did not exceed the guideline values proposed by the European Union.[29]. The initial study by the same research team for VOCs in 4 Greek rivers and 5 lakes showed that the most common VOCs were carbon tetrachloride, trichloroethylene, dichlorobromomethane, tetrachloroethylene, and chlorodibromomethane.[30]

A study was contacted to measure the levels of radioactive contamination by artificial radioCesium (Cs-137, Cs-134) as well as the concentrations of natural radioisotopes (K-40, Ra-226, Ra-228, Th-228) in sediments and aquatic plants in selected aquatic biotopes (rivers and lakes) in Macedonia. Cs-137 is significantly higher in the river Axios than in the rivers Strymon and Aliakmon. Also, the river Axios and Prespa Lake are more contaminated from Cs-137 and Cs-134. Whereas K-40 activity is significantly higher in the river Axios (rivers Aliakmon and Pinios showed lower levels), and in Prespa Lake. High activities of Ra-226, Ra-228, Th-228, and K-40 were found in Polyphytos Lake, presumably as a result of the operation of the coal power plants in this area.[31]

Pesticide Pollution of Greek Rivers and Lakes

A review on monitoring programmes and scientific papers on the pollution of rivers and lakes by pesticides in Greece was published in 2006. Pesticide classes that were mostly detected in the research projects were herbicides used extensively in corn, cotton and rice production, organophosphorus insecticides as well as the banned organochlorines insecticides due to their persistence in the aquatic environment. The compounds most frequently detected were atrazine, simazine, alachlor, metolachlor and trifluralin of the herbicides, diazinon, parathion methyl of the insecticides and lindane, endosulfan and aldrin of the organochlorine pesticides. Rivers were found to be more polluted than lakes. The detected concentrations of most pesticides follow a seasonal variation, with maximum values occurring during the late spring and summer period followed by a decrease during winter. Nationwide, in many cases the reported concentrations ranged in low ppb levels. However, elevated concentrations were recorded in areas of high pesticide use and intense agricultural practices. Generally, similar trends and levels of pesticides were found in Greek rivers compared to pesticide contamination in other European rivers.[32]

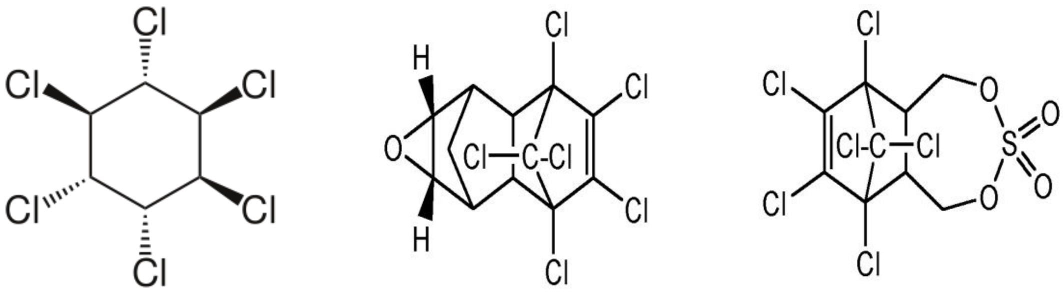
Water quality measurements for pesticides were carried out in the Aliakmon river (8 sampling stations, Macedonia) for two years in the beginning of the 1990s in relation with the agricultural activities in the area. The 8 pesticides analysed were alachlor, atrazine, 2,4D (2,4-dichlorophenoxyacetic acid), EPTC (thiocarbamate herbicide), MCPA (2-merthy-4-chlorophenoxyacetic acid), metolachlor, simazine and trifluralin were identified in river waters as well as 4 insecticides, diazinon, fenthion, lindane and methyl parathion. were also detected in the same places. High concentrations of pesticides occur during the period from May to August. Highest concentrations were determined for the pesticides: alachlor (0.21 μg/L), atrazine (2.16 μg/L), MCPA (1.56 μg/L), methyl parathion (0.21 μgL), metolachlor (0.34 μg/L), simazine (0.34 μg/L) and trifluralin (0.55 μg/L).[33]

Organochlorine pesticides were analysed (1992-93) in birds and frogs in the wetlands of the Thermaikos Gulf (Thessaloniki). Organochlorine insecticides were determined in eggs and freshly dead chicks of the Squacco heron (*Ardeola ralloides*), Little Egret (*Egretta garzetta*) and Night Heron (*Nycticorax nycticorax*), as well as in frogs (*Rana* sp.), the main heron prey. Residues of the organochlorine pesticides α-BHC (a-Benzenehexachloride), β-BHC, lindane, 4,4′-DDD, 4,4′-DDE, heptachlor and dieldrin were found in the eggs, chicks and prey of the herons. α-BHC, β-BHC, and lindane had highest concentration in the Night Heron and lowest in the Little Egret. Variation in the pesticide contents in the different heron species is attributed to different feeding habits. The concentrations of pesticides detected in the study were too low to affect eggshell thickness in the Heron or have other effects on the wildlife of the area.[34]

Figure 8. Many rivers and lakes in Greec have rich biodiversity. Heron. Herons are long-legged freshwater and coastal birds in the family of Ardeldae. Little Egret, (*Egretta garzetta*), is a small white heron.

Another study was carried out in the 1999-2007 period for pesticide concentrations in surface river waters in NW Greece and Greek/Bulgarian/Turkish borders. The monitoring study covered 147 chemical compounds with 88 sampling events. Sampling points were in the rivers Ardas, Evros and Erythropotamos. Pesticides were extracted by solid-phase extraction and analyzed by gas chromatography–mass spectrometry (GC-MS). Aquatic risk concerning the detected pesticides was assessed on the basis of the risk quotient. From the 28 compounds (pesticides, metabolites and caffeine) that were detected in surface waters of NW Greece the soil applied pesticides were the most frequently detected. High pesticide concentrations were detected within 2 months of their application, whereas very high pesticide concentrations were detected in the beginning of the irrigation season or after high rainfall events. Low level concentrations of pesticide residues were observed in the Greek/Bulgarian borders of all rivers. The pesticides *o′*, *p′* DDT, *o′*,*p′* DDE (metabolite of DDT) and γ-HCH (Hexachlorocyclohexane) were mainly detected as well as atrazine, DEA (dimethyl atrazine), alachlor, trifluralin, prometryne, molinate, carbofuran, carbaryl and diazinon. Aquatic risk assessment revealed that from the 28 compounds that were constantly detected 12 showed non-acceptable risk.[35]

Various studies were carried out for the presence of highly persistent organochorine pesticides in surface waters (rivers and lakes) in North Greece. A survey collected surface water samples (seasonally) from 4 rivers and 5 lakes for a period of two years and analysed by Gas Chromatography. The most commonly encountered pesticides were the isomers of hexachlorocyclohexane (α-, β- and γ-HCH), aldrin, dieldrin and endosulfan sulfate. In some cases the concentrations detected were higher than the qualitative target levels set by the European Union (hexachlorocyclohexane, aldrin) and can be attributed to intense agricultural activity as well as to transboundary pollution of surface waters.[36]



α-Hexachlorocyclohexane Dieldrin Endosulfan sulfate

Figure 9. Some chemical structures of organochorine pesticides. Many of these pesticides because of their toxicity and high persistence have been banned in many countries.

In another study ecotoxicological data has been undertaken to assess pesticide presence in drainage canals of two transboundary rivers of NE Greece (near Greek/Bulgarian/Turkish borders) as well as the subsequent risk to non-target aquatic organisms. Aquatic risk assessment was based on the Risk Quotient (RQ=MEC/PNEC) regarding three trophic levels, algae, aquatic invertebrates and fish. Alachlor, atrazine, carbaryl, carbofuran, cypermethrin, DEA (desethylatrazine), DIA (deisopropylatrazine), diazinon, dimethoate, endosulfan, metolachlor, monilate, prometryn and trifluralin were the pesticides detected at the highest concentrations. Extreme concentrations were observed just after high rainfall events during the month of pesticide application. Aquatic risk assessment revealed non-acceptable risk for 10 compounds. However, should extreme concentrations be taken into account, 15 compounds were considered as likely to pose a threat to aquatic organisms.[37]

In the corn-growing areas in Greece farmers use high amounts of pesticides (atrazine, alachlor, metolachlor, DEA). A study was carried out in the years 1996−1997 to analyse concentrations of residues of selected pesticides used in corn cultivation. Monitoring was carried out in 80 wells (both irrigation and drinking water wells) in the main corn-growing areas (Pieria, Thessaloniki, Serres, Kavala, and Evros) of North Greece. Very low concentrations (lower than the analytical detection limit) of pesticide residues were found in

48% of the wells up to <0.1 μg/L, and in 9 wells (Evros, Ardas valley) the pesticide residues were higher than 0.1 μg/L (μg=10^{-6} g/Litter). The frequency of occurrence, in descending order, was atrazine > DEA > alachlor = metolachlor; however, the order of descending concentrations was atrazine > metolachlor > DEA > alachlor. The distribution patterns of pesticide residues indicate that at the groundwater quality is favorable throughout the corn-growing areas of Greece with the exception of the Ardas Valley.[38]

A large-scale study was implemented to monitor triazine and phenylurea herbicides in the main surface water bodies of continental Greece from October 1998 to September 1999. Samples from 10 rivers and 7 lakes were analyzed for the presence of five triazine (atrazine, cyanazine, prometryne, simazine, terbuthylazine) and five phenylurea (chlorotoluron, diuron, linuron, metobromuron, monolinuron) herbicides. The samples analyzed by HPLC-diode array detection (HPLC-DAD). The most frequently detected herbicides were atrazine, followed by prometryne, cyanazine, and simazine at concentrations lower than 0.78 μ g/L, that are not considered harmful for the freshwater ecosystem. Most of the positive samples were taken from the water bodies of northern Greece where agricultural activity is more intense.[39]

The European Union issued a Directive in 1976 (76/464/EEC) for over 90 priority pollutants of surface waters. A monitoring study was conducted to evaluate the occurrence of 92 toxic compounds, 64 of which belong to priority compounds of List II and candidates for List I, in surface waters and wastewater through the developed network of 62 sampling stations covering the whole Greek territory. The analytical determination was performed by GC-MS and HPLC-MS, for organic pollutants and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES) for metals and organotin substances. The concentrations of VOCs and insecticides detected in the surface waters of Greece were very low, whereas the concentrations of herbicides and metals ranged generally at moderate levels. VOCs were detected almost exclusively in the rivers and very rarely in the lakes, while the frequency of occurrence of insecticides, herbicides and metals was similar for rivers and lakes.[40]

Ecological Quality and State of Surface Waters (rivers, lakes) in the Balkans and in Greece

In Greece the Institute of Marine and Biological Resources and Inland Waters [IMBRIW, http://imbriw.hcmr.gr/en/mission/, Anavissos Attica (Inland Waters), Ag. Kosmas and Heraklion Crete (Marine Biological Resources)], is the leading public research institution with a key role in the Mediterranean region and the European Union, spearheading fisheries and inland water research. The mission of IMBRIW is to support the conservation and management of aquatic biological resources, habitats and ecosystems; to provide scientific guidance and services to national, Mediterranean, EU and other International bodies on environmental conservation and management; and to sensitize the public on issues related to the conservation of aquatic biological resources, habitats and ecosystems.

A 4 year programme for monitoring the ecological quality of rivers, coastal and transitional waters of Greece started in 2011 by the IMBRIW in 8 Regions of Greece

(Macedonia & Thrace, Thessaly, Epirus, Ionian Islands, W. Greece, Peloponnese, N.Aegean, Crete). This study was undertaken under the Article 8 of the Water Framework Directive 2000/60 EU, ESPA 2007-2013. The study took into account the particular geomorphological characteristics and climatic conditions of Greece (coastal areas, islands, high biodiversity, etc.). Also, under the Operational Programme "Environment – Sustainable Development" it formulated a basis for a targeted funding policy in the Greek Prefectures with a number of projects related to the protection, enhancement and rational management of the environment [Institute of Marine Biological Resources and Inland Waters, http://imbriw.hcmr.gr/en/monitoring-the-ecological-quality-in-8-regions-of-greece/].

Various studies assessed the ecological quality of rivers' water by using biological elements, such as benthic macroinvertebrates and fish. Researchers assessed the ecological quality of a Greek river (RM4 type, small/medium Mediterranean mountainous river)), during autumn 2003 and spring 2004 at 10 sites. Hydromorphological and physicochemical parameters, habitat structure, and riparian vegetation were also considered. Pollution sensitive macroinvertebrate taxa were more abundant at headwaters, which had good/excellent water quality according to the Hellenic Evaluation System (HES). The main river reaches possessed moderate water quality, while downstream sites were mainly characterised as having bad or poor water quality, dominated by pollution-tolerant macroinvertebrate taxa. Fish were absent from the severely impacted lower river reaches.[41.42]

The water quality of the rivers Alfeios and Pineios was investigated by using a number of bioindicators and biotic indices and scores based on benthic macroinvertebrates, diatoms, fishes, aquatic and riparian vegetation in relation to physicochemical parameters of the rivers' water. The results showed that the water quality in both rivers varied from very poor to very good. Among the bioindicators used, the benthic macroinvertebrates seem to be the most reliable.[43]

There is a number of research investigations and assessments of water quality and ecological state of rivers in various areas of Greece.[44-50]

The environmental state of 15 major Balkan rivers (with most of the inflows in Eastern Mediterranean) were examined and the results were presented in a review (2009). The study in was contacted in the DPSIR framework (DPSIR is a causal framework for describing the interactions between society and the environment. **D**riving forces, **P**ressures, **S**tates, **I**mpacts, **R**esponses). Physicogeographic and hydrochemical conditions differ substantially among river basins, which may be roughly classified into three main zones. Most of the rivers were liable to flash floods and during the summer months had low water flows. Decreasing precipitation and (mis)management caused a dramatic reduction in water discharge over the decades. Political instability (civil wars in the region of Jugoslavia 1991-2001 and breakup of the country), economical crises over the past decades, combined with administrative and structural constraints and poor environmental planning imposed significant pressures on rivers. Large wetland areas were drained in favour of widespread intensive agriculture. The treatment of municipal wastewaters is barely adequate in Greece and management and treatment of mining and industrial wastewaters is overall poor. In general, lowland river sections are hydro-morphologically modified and are at the greatest pollution risk, while upstream areas mostly retain their natural conditions. Nutrient concentrations in a number of central and eastern Balkan rivers often exceed quality standards, whereas pesticides and heavy metals (partly of geochemical origin), exceed quality standards occasionally. Reservoirs retain vast masses of sediments, thus adversely affecting delta evolution, while dam operation disturbs the seasonal hydrological and hydrochemical regimes. Almost all Balkan countries face daunting water resource challenges because of urgently needed investments in water supply, sanitation, irrigation, and hydroelectricity. Constraints arise from long-standing top-down planning traditions, inadequate planning of national environmental policies, poor administrative capacities, and heavy investment requirements, often combined with a lack of environmental awareness.[2,51]

Microbiological Pollution and Eutrophication in Rivers and Lakes

Aliakmonas, Axios, Loudias, Mavroneri and Pineios were examined for their microbiological quality of waters (2002-2003). The microbiological tests were forTotal Microbial Flora (TMF) at 22 C and 37 C, Total Coliforms (TC), Fecal Coliforms (FC), enterococci, staphylococci, *Pseudomonas*, fungi, *Giardia* spp. and *Cryptosporidium* spp. The results of the study showed that there is moderate to high microbiological pollution, with the highest levels of microbial pollution found in Mavroneri and Pineios rivers. Moderate pollution levels was observed in Aliakmonas, Axios and Loudias rivers. The microbiological pollution was attributed to various degrees of anthropogenic municipal effluents (liquid waste) and to lack of ample pollution monitoring systems.[52]

Microbiological detailed examinations were contacted in Axios and Aliakmon because these rivers can be potential pathways for animal contamination with *Salmonella* spp. (cause illnesses such as typhoid fever, paratyphoid fever, and food poisoning). The prevalence and diversity of *Salmonella* spp., filamentous fungi, and yeasts and their correlation with fecal pollution indicators (total coliforms, fecal coliforms, enterococci) and total heterotrophic bacteria counts were investigated in 95 water samples from Aliakmon and Axios. The frequency of *Salmonella* isolation was higher in the Axios (36.8%) than in the Aliakmon (21.0%) river. 23 genera of filamentous fungi and 3 genera of yeasts were identified in river waters (most frequent fungi were *Penicillium* and *Aspergillus).* The results of this study indicate that these rivers may be potential pathways for human and other animal contamination with *Salmonella* spp., filamentous fungi, and yeasts, which contribute to the pollution of marine waters and the surrounding environment.[53]

Another study examined the microbiological investigation of 5 rivers in NW Greece. The study focused on the presence of *Giardia* cysts and *Cryptosporidium* oocysts in natural, drinking and recreational waters Aoos, Arachthos, Kalamas, Louros, and Voidomatis rivers and one lake (Pamvotis lake, Ioannina) were investigated. Drinking and recreational water (swimming pools) from the area were also examined. Both *Giardia* cysts and *Cryptosporidium* oocysts were isolated from Pamvotis Ioannina Lake (15 positive of 27 examined samples). Significantly lower numbers of *Cryptosporidium* oocysts were detected in Arachthos River (1/5), Voidomatis River (1/5), drinking water (1/7), and pool water samples (1/9). No *Giardia* cysts were detected, neither in river water, nor in drinking, and pool water samples. The results clearly show that, with the exception of Pamvotis Ioannina Lake, where contamination of high level was observed, natural water sources of the investigated area have low pollution, resulting in low contamination with parasites.[54]

A study evaluated the microbial ecosystem of cultivated soils along the Evros river in NE Greece. Along the Evros riverside watery ecosystem systematic agro-cultures were developed such as wheat, corn and vegetable cultures. The study observed considerable discrimination of water quality when chemical and microbiological parameters of the Evros river ecosystem were analysed. Ardas river (a tributary of the Maritsa (Greek *Evros*) with Its source in the Bulgarian Rhodope Mountains near the village of Arda) possesses a better water quality than Evros and Erythropotamos (a river with sources in southern Bulgaria, Haskovo Province, and northeastern Greece), which is mainly due to the higher quantities that these two rivers accumulate from industrial, farming and urban residues leading to higher degree of pollution. Monitoring showed that an increased microbial pollution in two of the three rivers and a direct relation in microbial and chemical charging between water and cultivated-soil ecosystems. Changes in agricultural practices and control of anthropogenic activities are needed to protect the ecological state of the rivers.[55]

Evros river

Pamvotis lake (Ioannina, Epirus)

Figure 10. Evros river accumulate effluents from industrial sites, farming and urban pollution sources. The lake Pamvotis (Ioannina) is impaired by pollutants from sewage, which significantly exceed permissible limits.

High concentrations of nutrients and increased eutrophication cases during the hot summer months occurs in many Greek rivers. The fluctuation of nutrients along the Pinios river and its tributaries were studied (1996-1998) and subsequent events of eutrophication. High concentrations of nutrients were observed first in winter (wet period), caused by leaching of fertilizers from terrestrial systems after heavy rainfall, later during the warm months due to low water flow of the river, and in autumn season when plant organisms began to decompose. The intensive algal and macrophyte growth (spring, summer) resulted in severe depletion of nutrients. Organic carbon showed no seasonal trend but its values were high near the estuaries. Nitrate fluxes were high at the initial station (sources) and the Titarisios tributary, whereas nitrites and ammonium were low. In contrary, the Kalentzis tributary with relatively low nitrate values showed increased values of nitrite ammonium or total nitrogen. On the other hand, the Enipeas tributary showed high SO_4^{2-} (sulphate) values. Phosphates are remarkably present mainly after the city of Larissa, where sewage and industrial discharges occur. Concentrations of nutrients and organic carbon increased as a consequence of anthropogenic inputs, particularly point discharges from sewage treatment plants as well as diffuse urban and/or agricultural runoff over long areas during storm events. The agricultural management, the urban pollution, mainly from Larissa City, and the climate conditions in the catchment basin (Thessalia Plain) of Pinios river and its tributaries greatly affect the chemical composition of their waters. For the Pinios river the most polluted sampling sites were in the area where the river has passed the city of Larissa.[56]

A survey (1997-98) has been conducted for major rivers in Macedonia and North Greece aiming to establish national data bases concerning the quality of surface waters. The physicochemical parameters measured were: pH, conductivity, total suspended solids, temperature, organic pollution parameters (BOD_5, Biological oxygen demand, unit of measurement: mg/l of oxygen consumed in 5 days at a constant temperature of 20°C in the dark, COD Chemical oxygen demand) and the major N (nitrogen) and P (phosphorous) species (NO_3^-, NO_2^-, NH_4^+,organic N, orthophosphates and total P). Sampling sites were located on main rivers, tributaries, streams and ditches, agricultural, urban and industrial areas of N. Greece. The eutrophication status of the examined systems was evaluated by means of N/P ratios. Mean N/P ratios showed large variations among sampling sites ranging from potential N- to P-limitation conditions. N/P ratios at particular sampling sites showed also great temporal variability thus suggesting temporary states of N- or P- limitation. Most frequently, highest N/P ratio values were observed during winter and early spring.[57]

The long-term development of eutrophication of lake Pamvotis (a shallow lake, near the city of Ioannina) was the focus of 3 year study (1985-89, 1998-99, 2004-05) because of the importance as a conservation site and its rich biodiversity. In the last 30 years the trophic status of the lake has changed as a result of anthropogenic activity (irrigation and municipal and domestic sewage discharge), resulting in serious environmental problems. Water samples were collected and analyzed (water temperature, pH, dissolved oxygen, nutrients, chlorophyll-*α*).The high nutrient concentrations in the lake and as its eutrophic to hypertrophic status reflect the degree of impact of anthropogenic activity that has affected the quality of lake's water. The municipal sewage diversion in 1996, led to a reduction in external nutrient load and consequently to lower in-lake nutrients and chlorophyll-*a* concentrations. Orthophosphate concentration decreased by about 87%, nitrates fell below 1.20 mg/l and the total reduction of inorganic N compounds showed a weaker downward trend. After a shortterm recovery the eutrophic status of the lake remains eight years later (2004–2005), suggesting the importance of greater restoration efforts.[58]

The inorganic nutrient load and phosphate content (causes of eutriphication) were measured (2000-2001) in 3 different rivers basins in Epirus. The study involved measurements of COD, BOD, NO_2^-, NO_3^-, NH_4^+ and PO_4^{3-}. The values of the above parameters were also compared with those awkward in the Fresh Water Fisheries Directive (78/659/EEC). It was found that the phosphate content was much higher than the upper limiting criteria for eutrophication for salmonid waters, whereas nitrate levels were lower than the permissible criteria according to the Nitrates Directive 91/676/EEC for drinking water. The inorganic nutrient load was mostly attributed to sites that drain agricultural areas, especially during winter and spring.[59]

Various physicochemical parameters (BOD, COD, total phosphorous, chlorophyll-α, ammonium, nitrite, etc and heavy metals) were monitored (2004-2005) in the Polyphytos reservoir of Aliakmon river and compared to measurements in the 1987-88 and 1991-93 , to determine the eutrophication of the lake. The results showed that the watershed on the lake environment, mostly through Aliakmon River, is significant, and it accelerates the eutrophication of the lake. The anoxic zones, which were defined in the lake, reinforce this conclusion. Nitrate, nitrite and ammonia were measured at lower concentrations compared to previous studies, while total phosphorus and chlorophyll-α were found at increased concentrations. The mean concentrations of metals Fe, Mn, Cu, Cr, Pb, and Cd were below the potable water standards set by WHO and EU.[60]

Environmental Pollution in Greek Lakes

Greek lakes have similar environmental problems as inland fresh water sources and Greek rivers. Scientific investigations have subdivided Greek lakes into three categories: a) warm monomictic deep lakes, b) warm monomictic shallow lakes, and c) dimictic shallow lakes. Measurements and surveys of environmental pollution showed that the water quality of Greek lakes is influenced by the presence of high concentrations of nutrients and heavy metals. The Institute of Inland Waters in Greece has investigated the physical, chemical and biological characteristics of major Greek lakes, with regard to water use, quality and trophic status. Based on this and other limnological investigations the water quality of some Greek lakes demonstrates environmental pollution from municipal effluents, agricultural fertilizers and heavy metals, with reduced concentrations of diluted oxygen. High concentrations of ammonia, nitrate and phosphate are found in many lakes, while anaerobic hypolimnia are usually found in shallow lakes. Phosphorus is the main nutrient responsible for eutrophication because it is the limiting factor in most of the lakes that were investigated.[61]

The Lake Pamvotis (NW Greece, near Ioannina) has been thoroughly investigated by scientists from the University of Ioannina. One of the monitoring studies focused on pesticide residues in water samples. The pesticides detected were: atrazine, desethylatrazine (DEA), simazine, diazinon, malathion, oxamyl, carbofuran, and ethion in water and atrazine, desethylatrazine, diazinon, and *s*-ethyl dipropylthiocarbamate (EPTC) in sediments. The highest residue levels for most pesticides in both water and sediment matrices occurred in the May to July period with the exception of atrazine and DEA, which show highest levels in water during the September to November period.[62]

The presence of copper (Cu) and zinc (Zn) in fish species of the Lake Pamvotis was the subject of a study for the heavy metal pollution at high concentrations in the waters of the lake. The fish species studied were *Cyprinus carpio*, *Silurus aristotelis*, *Rutilus ylikiensis*, and *Carassius gibelio.* Metal concentrations were measured in three different tissues of fish (muscle, liver, gonads). The study showed that *C. carpio* and *R. ylikiensis* presented the highest metal content. Metal concentration in the edible part of the examined fish (muscle) were in the safety-permissible levels for human consumption.[63]

Cyprinus carpio
κυπρίνος ή γριβάδι

Silurus aristotelis
Γλανίδι

Carassius gibello
Εμπειρικό όνομα πεταλούδα

Figure 10. High metal concentrations (such as Cu and Zn) were detected in the tissues of fish in the lake Pamvotis (Ioannina) but in the range of safety-permissible levels.

The presence of heavy metals in the surface water and sediments is a good indicator for environmental pollution problems.Two lakes of high ecological significance, Doirani and Kerkini (Northern Greece) were the subject of a study for measurements of 8 metals (Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn) in lake's water, total suspended solids, fine and coarse sediments.The lake Doirani presents higher metal concentrations in aqueous phase than lake Kerkini. The concentrations measured of Cd, Cu, Ni, Pb and Zn were above the chronic freshwater quality criteria for aquatic life. In both lakes, Fe and Mn were the most abundant elements in total suspended solids whereas Cd the less abundant. The Lake Kerkini exhibits higher concentrations of all the examined metals in sediments comparing to the Lake Doirani, however the concentrations are lower than the sediment quality guidelines.[64]

Lake Koronia (or Koroneia) was among the lakes of Greece with the biggest fish production. In the 1970s lake's surface area was 45 km² and had a depth of about 5 m. Since then the lake has shrunk to about one third of its original area, and its depth has decreased to less than 1 m. Although it is a wetland of international importance (recognized by the Ramsar Convention), the lake suffers from environmental pollution and intensive agricultural effluents. In a press release on 27/1/2011, the European Commission (EC) announced that referred Greece to the European Court of Justice for its failure to protect Lake Koronia. The lake has been seriously affected by pollution and illegal water extraction, with serious consequences for local fauna and flora. Although a comprehensive plan is in place to rehabilitate the lake, with many actions partly financed by EU funds, progress has been slow. At the recommendation of Environment Commissioner Janez Potočnik, the EC resorted to bring the case to the Court of Justice [http://europa.eu/rapid/press-release_IP-11-89_en.htm].

Figure 11. Lake Koron(e)ia. The surface of the 4^{th} largest lake in Greece declined progressively in 30 years and its volume and surface area of water was reduced by 80%. The lake was surrounded by farmland and in the 1980s it suffered from increasingly intensive agriculture, industrial liquid waste and municipal waste water from the neighbouring town of Lagadas

An extensive survey was carried out during the period from 1998-99 in the lakes Koronia, Volvi, Doirani, Mikri Prespa and Megali Prespa located in N. Greece. Water quality parameters (pH, conductivity, etc), organic indices [COD, BOD5), and N- and P-species nitrate, nitrite, ammonium and phosphate, etc] were determined for surface water. Statistical treatment of the data was employed. The physicochemical parameters revealed a high temporal variation. The trophic state of the lakes ranged from meso- to hypertrophic. The nutrient limiting factor varied among lakes suggesting either P-limitation conditions or mixed conditions changing from P- to N-limitation throughout the year. Urban/industrial activities and agricultural runoff are the major factors affecting all lakes.[65]

Lake Koronia is shallow, polymictic, hypertrophic and until recently was the fourth largest lake in Greece. Although exceeding 5 m in the past, lake depth has declined progressively from 3.8 m in 1980 to < 1 m in 1997, reducing surface area and water volume by 50% and 80%, respectively. The laboratory of environmental chemistry of the University of Thessaloniki followed for years the physicochemical characteristics of lake’s waters. Specific conductivity increased from 1300 μS cm^{-1} in 1977 to >6000 μS cm Increased phosphate concentrations from the late 1970's (8–45 μg/L) to the late 1990's (100–1000 μg/L) document that the previously eutrophic system with a limited littoral zone switched to hypertrophy dominated by massive cyanobacteria blooms. Oxygen saturation of the water column increased progressively from about 80% in 1983 to full saturation about 1993, after which it decreased progressively to only 20% saturation in 1997. In spite of cyanobacteria dominance, community metabolism of the lake switched from progressively increasing autotrophy to rapidly advancing heterotrophy associated with progressive water-level reduction leading to fish extirpation in the lake.[66]

Lakes Volvi and Koronia were the subject of an investigation for metal pollution. Samples from sediments of the lakes were analysed. The distribution of seven metallic elements (Cd, Pb, Cr, Cu, Mn, Zn, Fe) in sediments of the lakes were determined for two seasons. The accuracy evaluated by comparing total trace metal concentrations with the sum of the five individual fractions proved to be satisfactory. The levels of metals in the two lakes are not very high. The scientists suggested that the lakes were not yet been polluted. There were no significant changes in the individual seasonal concentrations of metallic elements. Metals Cd, Pb, Cu and Cr are associated with the oxidizable, carbonates and residual fractions. Metals Zn and Fe are associated with residual and reducible fractions.[67]

The studies for lakes Koronia and Volvi were extended in recent years for physicochemical parameters, nutrients (N and P compounds) and heavy metals. Nutrient concentrations were higher in lake Koronia than in Volvi showing relatively small temporal and spatial variations. Samples for heavy metals in sediments showed that Koronia is considerably more polluted than Volvi, especially with the metals Fe, Mn, Zn, Pb and Cd.[68]

Environmental contamination by agricultural chemicals and industrial waste disposal results in adverse effects on reproduction of exposed birds in lakes and wetlands. Pollutants that cause reproductive effects include organochlorine and organophosphate pesticides and industrial pollutants, heavy metals, herbicides, and fungicides. o,p'-DDT, PCBs and mixtures of organochlorines have been identified as environmental estrogens. Various studies in Greece were focused on monitoring birds' reproductive success in Greek lakes and wetlands. Eggs of the Dalmatian pelican, *Pelecanus crispus* (1984-86) from lake Mikri Prespa (NW Greece) were analysed. Samples showed that eggs contained residues of trace elements and PCBs at low concentrations, and of DDE (metabolite of DDT) at rather high concentrations. DDE is negatively related to eggshell thickness. Eggshell thickness was reduced by 12–20% in comparison with the pre-1947 measurements (before DDT use). However, this decrease did not affect the reproductive success of this species. The main fish species eaten by the Dalmatian pelican at lake Mikri Prespa were analyzed for pollutants. All the fish contained low concentrations of residues. The contribution of the diet while the birds are on the wintering grounds is unknown.[69]

Lake Koumoundourou (Koumoundourou lake, fed from springs of mount Parnes, west foot of Mt Aigaleo), ancient name Rheitoi). A study examined the level of pollution attributed to heavy metals (Cr, Ni, Cu, Zn, As and Pb) and PAHs in sediments by using several pollution indicators. The results indicated that lake Koumoundourou is contaminated with heavy metals in a moderate degree. As far as PAHs are concerned, around 60 % of the samples can be occasionally associated to toxic biological effects according to the effect-range classification for phenanthrene, benzo(a)anthracene, chrysene and pyrene.[70]

Environmental Pollution in Greek Wetlands

Greece has a great number of wetlands with very interesting and rich biodiversity. During the 20th century, starting from the 1920s and especially the mid 1960s, 2/3 of wetland area of Greece was drained for health and flooding reasons. Losses concerned mainly marshes and certain lakes and rivers. Drainage had been deemed necessary in order to confront the health problems of malaria, extensive flooding, the supply of irrigation water for agriculture, the acquisition of more arable areas for cultivation, construction of dams and clearing riverbeds. Large scale land reclamation projects in the plain of Serres (1928-1936) were the result of urgent refugee problem after the Asia Minor disaster and malaria that was seriously afflicting the agricultural population.[71]

Greece has characterized 10 Wetlands of international importance according to the Ramsar Convention Law 191/784, Offic. Gaz 350/A/1974)**.** The Ramsar wetlands cover a total area of 167.301 hectares. According to the digitized boundaries, the total area corresponds to 0.85% of the total land area of the country, and the marine part occupies an area of 55.617 hectares. The Ramsar wetlands are also included in the Natura. The Greek Biotope/Wetland Centre (or EKBY, Ελληνικό Κέντρο Βιοτόπων-Υγροτόπων, by its Greek initials) has its roots in the Goulandris Natural History Museum. EKBY is based at Thermi, close to the city of Thessaloniki, where its facilities are located [http://www.ekby.gr/ekby/en/PA_main_en.html#ramsar].

The most important environmental threats for the wetlands and their ecosystems in Greece, and in the Mediterranean region in general, are the agricultural activities, farming fertilizers, pesticides and stock farming liquid waste. This threat was investigated in 13 internationally important wetland (Ramsar) sites of Greece. The effects of ten activities commonly practised in the surrounding agroecosystems on four wetland functions and four wetland values were evaluated. The functions were: nutrient removal/transformation, sediment/toxicant retention, food flow alteration, and ground water discharge. The values were: biodiversity, fishing, hunting, and recreation. Irrigation is the most decisive activity negatively influencing all functions and values, followed by cropland expansion and overgrazing. Coastal lagoons are the least affected by agricultural activities. The study concluded that in Greece the sustainability of wetland ecosystems depends to a significant degree on the sustainability of agroecosystems. The reverse is also true because wetlands provide irrigation water, crop pollinators, some frost protection, and predators of crop pests. The two ecosystem types are functionally closely linked. Therefore, a national policy for the sustainable development of the soil, water, and genetic resources of Greece must integratively consider both these ecosystems types.[72]

In 1989 a workshop on Greek wetlands was held in Thessaloniki. The proceedings of the workshop contain some interesting chapters on the state of geek wetlands. Case studies of lake Kerkini, lake Vistonis and former lake Karla rehabilitation were also presented in the workshop.[73] There is also a 1996 publication of Greek wetlands.[74]

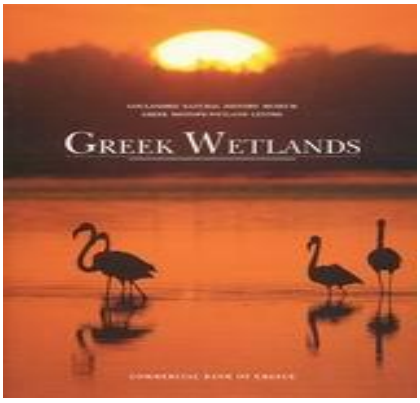


Figure 12. Books on wetlands are limited. The most mportant publication on Greek Wetlands (1996).

The Evros delta is a very important wetland in term of biodiversity. The wetland was investigated in the period1992-93 for the impact of transported pollution generated in the greater catchment basin of the river in Bulgaria, Turkey and Greece. Organic matter concentrations increased to higher levels during summer, while nutrients concentrations increased during the early winter months. Nitrogen concentrations remained high throughout spring but soluble reactive phosphorus concentrations decreased considerably during the same period. The wetland watercourses were influenced by agriculture and animal breeding in the western part. The results of the preliminary study indicate that river transported pollution is the major factor for the quality degradation of the wetland's waters.[75]

A study in the end of the 1990s identified levels of organochlorine pollutants in 4 Greek wetlands of international importance (Evros and Axios Deltas, and Kerkini and Prespa Lakes). The researchers used the cormorant *Phalacrocorax carbo sinensis* as a suitable bioindicator*. The* great cormorant, *Phalacrocorax carbo*, known as the great black cormorant is very common and widespread bird species. It feeds on fish at sea, in estuaries, and on freshwater lakes and rivers. Residue levels of 8 polychlorinated biphenyl (PCB) congeners and 13 organochlorine pesticide (OC) compounds were measured in cormorant eggs. Most PCBs and OCs (except dieldrin and endrin) were found in at least some of the study areas. Median concentrations of 5 PCBs and of six OCs (α-BHC, β-BHC, lindane, heptachlor, 4,4′-DDE and 4,4′-DDT) differed significantly among the areas. The median totals of the PCBs were highly significant among the areas, being unexpectedly highest in Prespa Lake (68.43 ppb), despite its remoteness, and lowest in Evros Delta samples (12.17 ppb). Aldrin that was found in samples from Evros, Axios and Prespa probably accumulated in wintering grounds. Differences were attributed to large variations in the cormorants' diet between areas. The ∑OCs/∑PCBs ratio indicates agrochemical pollution in all areas. An important finding was that levels of both pollutant groups were too low to have any biological implications on the cormorants and, additionally, suggest that they have a negligible impact on the environment of the wetlands studied.[76]

Cormorant (*Phalacrocorax carbo sinensis)*

Mediterranean gull (*Larus melanocephalus*)

Figure 13. Birds in wetlands. Environmental pollution and concentrations of organochlorine pesticides and heavy metals can become useful bioindicators in ecotoxicological studies.

An inventory with data from Greek wetlands identified the possible impact of anthropogenic activities on the ecological character of Greek wetlands. More than 1200 questionnaires were distributed and data for 291 wetlands were compiled into a data base GRIN (GReek INventory) that provided information on the factors of degradation of different kinds of wetlands (deltas, estuaries, lagoons, lakes, reservoirs, rivers, marshes, and springs). From the results it was concluded that the most important factors were: agricultural and municipal pollution (54%), housing and expansion of agriculture causing loss of wetlands (36%), overpumping, land clearing, and illegal hunting, causing depletion of natural resources (26%); construction of irrigation schemes and diversion of water courses, causing changes in water regime (12%).[77]

Heavy metal pollution in wetlands is another important issues of anthropogenic impact. Metal concentrations of toxic lead (Pb) and cadmium (Cd) were measured in eggs of collonially nesting waterbirds (bioindicators) with different position in the food chains of Greek wetlands. Differences were found between species in the levels of both Pb and Cd in the Evros and Axios Deltas attributable to their different diets. The concentration of metals in eggs was unrelated to the position of each species studied in its food chain and no significant difference in Pb levels among four wetlands sampled for the cormorant and in Cd levels among three wetlands sampled for the Mediterranean gull (*Larus melanocephalus*), probably implying species-specific accumulation patterns. A higher lead pollution of the Axios Delta area was only reflected in the eggs of the Mediterranean gull. The very low concentrations of both metals found in the eggs may either suggest low environmental inputs or lack of sensitivity in using eggs as lead and cadmium biomonitors.[78]

The most important wetlands in Greece are protected by the Ramsar Convention Law resulting in restrictions on activities of local people and communities. A study was carried out in 32 communities neighbouring four Ramsar wetlands in Northern Greece (Evros and Nestos deltas, lakes Koronia and Mitrikou). The study recorded local residents' attitudes regarding the ways of management and exploitation of the wetlands and their sociological features, using the opinion poll method (1600 questionnaires were distributed, 1997-98). The aim of this investigation was the evaluation of findings for planning of effective management and conservation policy of wetlands, incorporating the opinions of local residents. The increased awareness of local residents of the value of wetlands, tourism or agriculture development (in some cases), as well as more governmental support, became obvious results from this research.[79] A similar study on reformation of cropland in the ecological sensitive area of lake Vegoritis was carried out.[80]

Figure 14. Greece has some spectacular wetlands. Voidokilia beach, Gialova lagoon (Γιάλοβα), SW Peloponnese (Navarino Bay). It is a Natura 2000 site of major importance (photo *Thomais Vlachogianni, photostream*)

Environmental Pollution of the Asopos River: a special case

The Asopos river basin is located in the Region of Sterea Elladas, constitutes one of the most threatened water bodies (surface and groundwater).The Asopos river basin environmental problem has been in the centre of international attention for almost fifteen years, because of the unique nature of the environmental damage that has been occurring in the area for more than forty years. In the wider area of the middle and lower river reaches, near town of Inofyta, an unofficial Industrial Zone was established in after the 1970 and at the same time Asopos river was declared an effluents receiver, and remained so until May 2010 when the resulting situation was characterized as an “environmental crisis” and appropriate legislative action was taken by the Greek Government. Underground disposal of untreated or poorly treated industrial effluents, uncontrolled sludge and solid waste disposal, non-filtered air emissions, are some of various ways of pollution. Groundwater in Asopos river basin has foregone any ability to provide services to both humans and the ecosystem.

In the broad Asopos area from the 1970s until today, and in particular in Oinofita-Schimatari region, a great number of industrial activities were established supporting 1300 industrial facilities, such as metal processing agrochemical, and food/drinks industries among others. The daily produced quantity of industrial waste water were discharged untreated. The main flow of the produced industrial waste waters was coming primarily from the sectors of textile and leather industries, metallurgy related industries and foods and drinks industries at 25%, 21% and 30% respectively.[81]

An additional environmental pressure in the Asopos area was the agricultural activity which includes arable and tree crops. Furthermore, it has been noted that apart from the intense anthropogenic activities the Asopos River there were human expansion of settlements, traffic during the summer months, and illegal discharge of waste illegal waste tips by locals and unauthorised deliveries of municipal waste along the river from neighbouring municipalities. A number of roads form blocks and the residential pressure goes up to the coastline. Within the wetland toward the Oropos area the pressure from the filling and movement of vehicles is obvious. Part of the area at the mouth of Asopos River has been covered by the aviation with a variety of antennas and some of the area on both sides of the riverbed has been fenced.[82]

Apart from the obvious anthropogenic environmental impacts in the area there were also worrying impacts due to the presence of the highly toxic heavy metal hexavalent chromium (CrVI) which was traced at high concentrations (ranging from 10 ppbs to 330 ppbs) in both surface and groundwater samples from the area. The presence of CrVI has been shown that part of it is linked to industrial pollution of soils and waters from illegal discharge of industrial, hazardous waste and sludge. Other studies showed that part of Cr in the Asopos river is of geogenic origin.[82]

A field and laboratory study was conducted (samples in 2012) to assess the origin and mobility of CrVI in Asopos basin in Greece. Sampling was designed in such way as to capture the spatial variability of chromium occurring in sediments and soils in different lithological units in the area. Heavy metal analysis and local geology study support the hypothesis that the main source of chromium is of geogenic origin. Chromium distribution in Asopos river bed was influenced from the eroded products derived from extensive areas with ultramafic rocks. The mobility studies showed that leaching process was very fast and sorption capacity was significant and capable to retain chromium in case of waste release in the river.[83]

The concluding remarks of various studies on Asopos suggested that the impact of the industrial activity on the environmental pollution of river water use is important. It has been observed that some of the industrial units have a considerable production of waste water of diverse pollutants which depend on the type of production. Regarding the estimation of the pressures on the water quality due to the industrial activity, scientists suggested that is necessary to analyze in detail the total amount of polluting material in the area as well as the part of the polluting material that is related to the industrial activity. In general, it is observed that the industrial sectors of basic metals and foods and drinks industries which are of great importance in the area produce a considerable number of wastes compared to the other sectors. Also, studies observed that geogenic metals in the soil and river sediments showed high mobility.[84-92]

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