Hydrological and Limnological Factors Influencing Aquaculture on Pond: A Review

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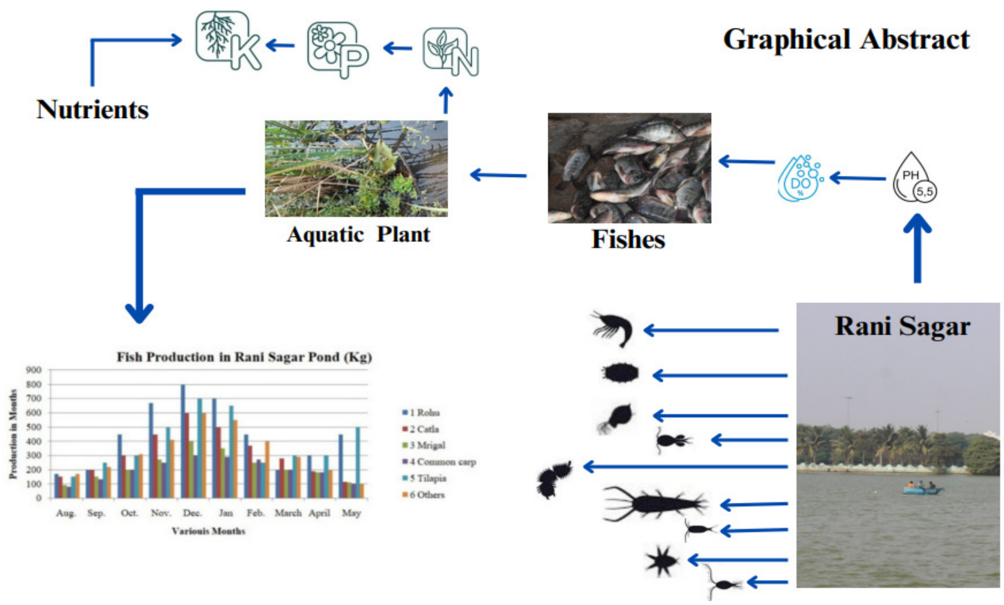
Abstract: Pond aquaculture is a critical source of protein and livelihood for millions globally, particularly in developing regions. The productivity and sustainability of pond-based aquaculture systems are heavily influenced by a combination of hydrological and limnological factors. This paper examines the interrelated effects of these factors on aquaculture performance, focusing on water quality, fish health, and yield optimization. Hydrological variables such as water source, inflow and outflow dynamics, seasonal rainfall, evaporation rates, and water residence time shape the physical and chemical stability of pond ecosystems. These, in turn, influence key limnological parameters, including temperature, dissolved oxygen (DO), pH, turbidity, nutrient concentrations (nitrogen and phosphorus), and plankton diversity. Limnological processes directly affect the biological productivity of ponds by regulating nutrient cycling and primary production, which form the base of the aquatic food web. Imbalances, such as excessive nutrient loading or stagnation, can result in eutrophication, algal blooms, and oxygen depletion, negatively impacting fish survival and growth. Moreover, poor hydrological management can exacerbate thermal stratification and sediment accumulation, leading to habitat degradation.

Keywords: Aquaculture, Eutrophication, Fish Health, Hydrology, Limnology, Pond Ecosystems, Water Attributes.



Introduction: Aquaculture the farming of aquatic organisms including fish, crustaceans, mollusks, and aquatic plants has emerged as a cornerstone of global food security and economic development [1, 2, 3]. Among the diverse aquaculture systems, pond-based aquaculture remains one of the most widely practiced methods across the world, especially in Asia, Africa, and parts of South America [4, 5]. These systems are often favored due to their relatively low setup cost, adaptability to small-scale farming, and ease of management [6,7]. In countries such as India, Bangladesh, China, and Nigeria, ponds are not only used for intensive and semi-intensive fish culture but also contribute significantly to rural livelihoods and nutrition [8, 9, 10]. The success of pond aquaculture, however, is deeply influenced by the quality and stability of the pond environment [11]. Unlike natural water bodies, pond ecosystems are semi-controlled environments that require careful management to optimize conditions for fish growth and survival [12]. The ecological balance of the pond is highly sensitive to both external inputs (e.g., feed, fertilizers) and natural environmental variables [13, 14]. This makes understanding the physical, chemical, and biological dynamics of ponds crucial for efficient aquaculture practices [15, 16, 17]. As aquaculture expands to meet the protein demands of a growing global population, environmental sustainability is increasingly becoming a central concern [19, 20, 21]. Overreliance on artificial inputs such as commercial feed and fertilizers, along with poor water quality management, has led to several environmental challenges, including eutrophication, fish kills, disease outbreaks, and degradation of water bodies [22, 23, 24]. In this context, the need for a more ecologically informed approach to pond aquaculture becomes evident one that emphasizes the natural processes governing water quality and ecosystem health [25, 26, 27, 28, 29]. This brings into focus the disciplines of hydrology and limnology. While hydrology deals with the movement, distribution, and properties of water within the pond system, limnology focuses on the biological, chemical, and physical characteristics of inland waters [30, 31, 32, 33, 34]. In pond aquaculture, water quality is often considered the single most important factor determining the health, growth, and productivity of cultured organisms [35, 36, 37, 38]. Environmental factors such as temperature, dissolved oxygen (DO), pH, turbidity, salinity, and nutrient levels form the foundation of water quality assessment [39, 40, 41].

Review of Literature: The present study evaluates the effects of nutrients and their ratios in determining the composition of phytoplankton communities. Cyanophytes and chlorophytes exhibited their predominance in a relatively high ammonia level zone (upper estuary).

The present study explained the restricted bloom of Merismopedia sp.(Meyen, 1839) in the upper estuary stations U7 and U8 during post-monsoon. Regression analysis of environmental variables against Merismopedia sp. density observed that silicate concentration (28.1%) was the most important variable that influenced Merismopedia sp. density. Shannon-Weiner diversity index as pollution index suggested that the estuary was moderate to good during monsoon season suggesting a cleansing of the estuary through huge freshwater inflow from seasonal precipitation. Whereas, the diversity decreased as it ranged from 1.4 to 2.4, turning the estuary from moderate to bad as the seasons changed, especially in the mid estuary, as the anthropogenic nutrient levels increased with the least flushing [42].

Finally, for the third question (3), we experimentally tested the effects of five different feeding levels and reduced dietary protein levels (2 experiments) on growth performance and muscle composition of juvenile P. clarkii with natural food Hydrilla verticillata. Results showed that reducing the amounts of an artificial diet to 60% satiation and/or reducing the dietary protein level of the artificial diet to a level of 26% did not significantly affect the growth performance and muscle composition of P. clarkii. Stable isotope analysis suggested that crayfish switched diets to easily available H. verticillata when feeding levels or dietary protein levels decreased. This thesis thus explored new alternatives to traditional crayfish aquaculture by adjusting fishing effort and season, manipulating crayfish culture temperature, and refining feeding strategies to reduce production costs while improving the productivity and sustainability of crayfish aquaculture [43].

Limnological features in relation to prawn catch at Asejire Lake and Erin-Ijesa waterfalls were studied from 2007 to 2009. The results of physical and chemical parameters revealed that the mean water Temperature, Transparency, Depth, Dissolved Oxygen, pH, Alkalinity, Total Dissolved Solid, Conductivity, Nitrate and phosphate were 27.52±2.050C, 1.5 ± 0.44m, 3.16±1.3m, 6.70±0.82mg/l, 7.28 ± 0.55, 144.17 ± 30.05mg/l, 388.46± 211.48mg/l, 82.90±1.60µohms/cm, 4.62±0.79mg/l and 0.27± 0.04mg/l respectively at Asejire lake which were not significantly different (P<0.05) from the values of Erin-Ijesa waterfalls which were 27.77 ± 2.270C, 1.71 ± 0.39m, 1.43±0.22m,6.21±0.77mg/l,7.25±0.68, 136.62±41.6mg/l,402.13±253.25mg/l,83.40±1.86µohms/cm,4.76±0.76mg/land0.2 ±0.05mg/ respectively. Both water bodies exhibited features that are typical of tropical environment, as almost similar limnological factors were recorded which fell within the range that can support aquatic life. High value in Condition factor for both species under investigation shows the total well being of the prawns and suitability of their environment for sustainability [44].

In the past, considerable attention has been paid by workers in many fields of research to bogs and bog lakes. The unique set of environmental conditions represented by a bog lake, with its comparative isolation from outside influences, is particularly attractive to ecologists in several biological fields. From the limnologist's viewpoint, the bog lake, with its acid and extremely soft-water conditions and its encroaching bog mat, presents an object of study which is totally different in many respe'cts from all other bodies of water, and workers in this field have studied bog lakes in many investigational researches (Welch, 1936a, b, 1938a, b, 1945, Jewell and Brown, 1929, Gorham, 1931, and others). However, despite the abundance of these lakes in certain regions of northern Michigan and Wisconsin where sports fisheries are extremely important, it has not been until recently that this type of lake has been included in developmental research programs aimed at proper management of bog lakes as sport fishery resources [49].

In China, collection of millions of early fry of major carps from rivers and stocking them in nurseries for rearing is a common |practice in India, particularly in Bengal, Bihar and Orissa. Different types of ponds, small or large, seasonal or perennial, shallow or deep, are used as nurseries; and different methods of preparation of the ponds are followed. There is, however, very little reliable information about these practices, most of which are known only to a few farmers who keep the information as family secrets handed down from generation to generation. On such important aspects like the density of stocking and percentage of survival, also, our information is meagre. Even the expert fish farmer is unable to ensure that his nursery pond will yield a satisfactory return every year [50].

Most lakes have been disturbed to varying degrees but for an individual lake the timescale of these disturbances is rarely known. Lake sediments, however, can be used as natural archives of perturbation histories, eg acidification and eutrophication. At present the use of simple weighted averaging models permits the reconstruction of a variety of water chemical variables from diatom and other microfossils preserved in lake sediments (pH, total phosphorus, salinity and lakewater temperature) [52].

This comprehensive textbook is intended for readers with a biological background. The emphasis is on the application of the principles discussed, and exhaustive reviews of research are avoided. Roughly half of the book is devoted to the general principles, and includes chapters on national planning for aquaculture, selection of sites, choice of species, the design and construction of aquafarms, nutrition and feeds, reproduction and genetic selection, health and diseases, harvesting and post-harvest technology, marketing, economics and financing of aquaculture, and farm management.

The remaining half of the book comprises chapters describing current practices in the large-scale production of the main types of aquatic species (including fish, crustaceans, molluscs and seaweeds), the integration of aquaculture with crop and livestock farming, the stocking of open waters, and the ranching of anadromous species. The book is illustrated with monochrome photographs and diagrams. The references at the end of each chapter list the main sources of information used in compiling the book. A subject index is provided [53].

The conclusion about the iron-sulphur-phosphorus and the calcium-carbonate-phosphorus system must be that it is not yet possible to know which type of sorption or precipitation is the main process in a given mud after the addition of phosphate. It is extremely urgent to know more about the systems combined. It is desirable to start quantitative investigations with the Ca-CO_3-PO_4-system and the F-S-PO_4-system separately, and to combine both systems after we have learned to distinguish between $FePO_4$, $Fe(OH)_3$~P and *[*$Ca_3(PO_4)_2$*]*, whatever the composition of the last precipitate may be. The hypothesis (Neess, 1949) that the addition of lime before fertilization with phosphate will save the latter from precipitation in iron-phosphorus complexes, still seems very doubtful [54].

The concentrations of heavy metals (Fe > Zn > Cu > Pb > Ag) in bottom sediments and fish gills in Ohana Lake, were found to be significantly high and far exceeded FEPA and WHO environmental standards for water quality by 1.5 to 18 times, respectively. Six classes of each of phytoplankton and zooplankton with a total of 35 phytoplankton taxa comprising 46 species i.e. 35(46) and 22(28) faunal were observed. The class Chlorophyceae dominated the phytoplankton community with 18(22) followed by Cyanobacteria 6(10). The aquatic fauna was dominated by the Rotifera 8(11), followed by the Copepoda 6(9). The benthic flora community consisted of five classes of phytoplankton made up of 28(36). The class Bacillariophyceae 11(15) dominated the group followed by Chlorophyceae 10(11). Benthic fauna were made up of seven classes of 13(13). The dominant class Nemata 4(4) was followed closely by Protozoa 2(3). Ohana Lake is fast turning to a eutrophic ecosystem with accompanied algal bloom due to very high nutrient contents. The equitability or evenness indices (J) for both phytoplankton and zooplankton were lowly indicating generally low species diversities as well as predominantly unstable ecosystem. The aquacultural implications of these parameters are discussed [55].

The parameters studied were DO, pH, Conductivity, Temperature, Sodium, Potassium, Dissolve Oxygen, Total Solid, Chloride, Alkalinity, Hardness, Sulphate, Chemical Oxygen Demand, Nitrate, Phosphate and Fluoride. Water quality index was calculated by using NSF water quality index. Analyzed data were compared with the standard IS: 2296 (Surface Water Quality Standard) and IS: 10500 (Drinking water Quality Standard). The maximum pH of 7.91 ± 0.17 was found at Jagannath Ghat. Maximum average conductivity was found as 559.28 ± 8.92 µS/cm in tube well water of Jagannath colony and minimum was 90.66 ± 1.15 µS/cm in Tarini Ghat. Temperature was maximum 28.5°C ± 0.36°C in tube well water of C.W.S. Colony. The maximum Sodium, Potassium, Chloride, Alkalinity and Nitrate content was recorded as 12.37 ± 1.23, 95.9 ± 7.75, 541.66 ± 2.84 and 24.27 ± 0.61 mg/L respectively in tube well water of Balanda colony [56].

The study was carried out using 328 Clarias gariepinus specimens over a period of two years, from Oba reservoir (08°3'N to 08°12'N and 004°6'E to 004°12'E) Ogbomoso, Oyo State, Nigeria. Standard methods were used to determine length-weight relationship, condition factor, and enteroparasitic infestation of the fish in the reservoir. Generally, Fish growth was positively allometric, while infested male and female fishes had negative allometric growth. The general well-being of the male fish was better than that of the female fish. Smaller sized fishes were better adapted to the ecological conditions of the reservoir than the bigger fishes. Parasites recovered were two Nematodes (Procamallanus laevionchus, Paracamallanus cyathopharynx), three Cestodes (Anomotaenia sp. Monobothrium sp., Polyonchobothrium clariae), and one Acanthocephalan (Neoechinorhynchus rutili). Sex ratio was 1.3:1 (male: female). Parasitic prevalence and intensity in the fish were sex and season dependent. The effect of enteroparasites in the life of infested C. gariepinus was found to probably be a major factor responsible for the low percentage of good fit to the line of regression (R2) in females. Infestation also led to loss of weight in infested fishes and this affected morphometric values in which body weight was an index [59].

An increasing number of impoundments in Southeast Asian countries is now becoming available for fishery management purposes. This report is an overview of reservoir fisheries experience, based both on temperate and tropical countries. It provides a synthesis of information of fish population studies, including predictions of fish potential yield, alternatives for management of fish populations and for management of the habitat. It should assist in planning fishery management strategies for new reservoirs, and improve the management of existing reservoir fisheries in Southeast Asia [60].

Our country in endowed with a rich and vast diversity of natural resources, water being the most precious of them. Water security, water management and its development is of immense importance in all walks of human life and also for all living beings integrated water management is essential for environmental systems, sustainable economic development of the country and for bettering human life through poverty reduction [66].

Regional disparities prevail within different districts of Maharashtra. Previous work has highlighted the disparities within the districts. The present work is an attempt at bringing out the regional disparities within the tehsils from the Konkan region (excluding Mumbai). This indicated that the agricultural development is more sensitive to the infrastructural conditions. For considering the future development of the region, model tehsils have been identified for enhancing the level of overall socio-economic development. Low developed tehsils require improvement of various dimensions in most of the indicators for enhancing the level of overall development [67].

Transparency showed positive correlation with total alkalinity. The Transparency also showed negative correlation with chlorides. In present study maximum transparency was observed in December and January Bhatt and Singh (1986). Have also observed the minimum visibility of pond during summer and rainy season and maximum in winter [68].

In many fish ponds, blue-green algae (cyanobacteria) constitute the greater part of the phytoplanktonic biomass during the summer. They sometimes form spectacular water blooms, often with harmful consequences such as massive mortality among the fish, mainly caused by depletion of oxygen after the bloom collapses. Their specific properties render them better able than other phytoplankton to adapt to certain conditions usually encountered in fish-ponds: reduced light penetration, nitrogen depletion in the upper layer. Blue-green algae are of poor food value to zooplankton, their large size making them inaccessible to the filter-feeding entomostraca. The substances produced by many species of cyanobacteria are toxic to aquatic plants and animals. The algicides used to limit their development are effective but are often detrimental to the environment. Another solution would be to increase the N:P ratio to 5 or more, which benefits chlorophyceae and reduces the number of cyanobacteria. The use of aerators to break vertical stratification and avoid low concentrations of oxygen also makes water conditions unfavourable to blue-green algae. In spite of very abundant research on cyanobacteria, every summer they cause many fish-kills in ponds [70].

A mathematical model to stimulate thermal stratification in shallow aquaculture ponds is described. The dynamic, mechanistic model was developed to simulate the water column of ponds in discrete, completely mixed, horizontal volume elements.

Energy exchanges between the pond's surface and atmosphere were calculated with theoretical and empirical relationships commonly applied to heat balance calculations in lakes, reservoirs and waste treatment ponds. Energy transfer between the volume elements caused by turbulent mixing were simulated as functions of the temperature gradient in the water column and a diffusion coefficient. The value of the diffusion coefficient was calculated in each time step as a function of wind speed, depth, and the water column density gradient. The model was implemented using a dynamics simulation language (STELLA™) using an Apple Macintosh™ microcomputer. Also described are the model calibration and verification procedure and results [71].

This report is a compilation of numerous studies related to Black and Chignik lakes on the Alaska Peninsula during 1991. The large fluctuations of adult salmon returning to Black Lake have been a major concern to Chignik fishermen. Ruggerone et al. (1991) described potential factors causing the large fluctuations of adult salmon. Ruggerone and Denman (1990) reported that Alec River, the primary spawning river in the Chignik system, is changing course and discharging towards Chignik Lake rather than the main body of Black Lake. The Black Lake studies reported here are related to ongoing investigations of adult salmon fluctuations and the course change of Alec River. The reader should refer to aforementioned reports to gain a better understanding of the purpose of each study described below. The studies at Chignik Lake include ongoing baseline studies. The intention of this report is to quickly communicate data collected in 1991 rather than provide a comprehensive report [72].

This work assessed modes of irrigation on vegetable production in fifty (50) vegetable gardens from ten (10) sampled areas in the Accra Metropolis. Irrigation water sources include: pipe, segment, gutter, dug-well, dam, river, and drains. Demographic survey, nature of the surrounding of the water bodies, physico-chemical and microbiological analysis of irrigation waters were carried out and contrasted with standard values. The analysis of the parameters of various water samples was within the accepted standard values, except the Chemical Oxygen Demand (COD) value for the irrigation water from Opeibea (3020) and Kasoa (340), which were relatively high compared to standard value of 250. The faecal coliform counts for irrigation water at Abossey-Okai are also high (1150/100 ml) compared to the standard values of 1000/100 ml irrigation water. The vegetable farming was found to be a male dominated activity (86%), mostly practised by 21 - 30 year age group (69%). However the education levels of farmers are low; 70% either do not have formal education or only up to primary education levels. A greater percentage (68%) of the water used for irrigation was waste water, mostly from gutters and segments. Proper management practices of effluent are recommended for vegetable production [73].

In 1992, studies were conducted to (1) determine whether juvenile sockeye salmon inhabited Black Lake throughout the summer, (2) identify the depth contours of Black Lake, (3) measure sediment transport in Alec River as a potential cause of reduced lake depth, (4) remeasure the sandspit that separates Black Lake from the outlet area and reduces access of sockeye fry to the lake, (5) enumerate the upstream migration of sockeye fry and other fishes in Black River in order to evaluate concepts to stabilize lake level by placing structures in Black River, and (6) evaluate the condition of sockeye stocks in Chignik Lake. The following text describes studies in Black Lake and is followed by a discussion of studies in Chignilc Lake. To gain further insight to the following studies, the reader should examine the following: Ruggerone (1989), Ruggerone and Denman (1990), Ruggerone et al. (1991, 1992), and Ruggerone 1992 [74].

Soil chemical analyses were conducted on samples from 358 freshwater fish ponds and 346 brackishwater shrimp ponds. Freshwater ponds were located in Honduras, Rwanda, Bhutan, and the United States. Ponds in the United States were in Alabama, Georgia, Mississippi, Florida, and South Carolina. Brackishwater ponds were in Thailand, Ecuador, Philippines, and Venezuela. Soils of freshwater and brackishwater ponds did not differ greatly in average concentrations and concentration ranges for carbon, nitrogen, calcium, and pH. Concentrations of copper and barium tended to be higher in freshwater soils than in brackishwater ones. All other measured chemical constitutents tended to be more abundant in the soils of brackishwater ponds than in those of freshwater ponds. For the most part, ranges of pond soil chemical properties were similar to those of terrestrial soils, with freshwater pond soils resembling terrestrial soils from humid areas and brackishwater soils being similar in many respects to soils of arid regions. However, some brackishwater pond soils were highly acidic, acid-sulfate soils. Data were arranged into concentration categories (very low, low, medium, high, and very high) to facilitate comparisons of the present data set with other data on soil chemical properties for aquaculture ponds. All ponds included in the present study were used for aquaculture, showing that it is possible to rear fish and shrimp across an extremely wide range of soil chemical properties [75].

Cyanobacteria (blue-green algae) in the genera *Anabaena, Aphanizomenon, Microcystis*, and *Oscillatoria* often form extensive and persistent blooms in freshwater aquaculture ponds. Bloom-forming cyanobacteria are undesirable in aquaculture ponds because: 1) they are a relatively poor base for aquatic food chains; 2) they are poor oxygenators of the water and have undesirable growth habits; 3) some species produce odorous metabolites that impart undesirable flavors to the cultured animal; and 4) some species may produce compounds that are toxic to aquatic animals. Development of cyanobacterial blooms is favored under conditions of high nutrient loading rates (particularly if the availability of nitrogen is limited relative to phosphorus), low rates of vertical mixing, and warm water temperatures.

Under those conditions, dominance of phytoplankton communities by cyanobacteria is the result of certain unique physiological attributes (in particular, N_2 fixation and buoyancy regulation) that allow cyanobacteria to compete effectively with other phytoplankton. The ability to fix N_2 provides a competitive advantage under severe nitrogen limitation because it allows certain cyanobacterial species to make use of a source of nitrogen unavailable to other phytoplankton. The ability to regulate cell buoyancy through environmentally-controlled collapse ad reformation of intracellular gas vacuoles is perhaps the primary reason for the frequent dominance of aquaculture pond phytoplankton communities by cyanobacteria [76].

Limnology, the integrative science of inland aquatic ecosystems, is making fundamental scientific advances and playing a critical role in management of inland water while suffering from fragmentation and lack of identity at North American universities. Educational programs at undergraduate and graduate levels require substantial improvement. In light of such concerns, the U.S. National Research Council commissioned a study on the nature and future of the academic teaching of limnology in North America. As is expected from such endeavors, the committee's report, published to high professional standards, combines scholarly background on the development of limnology with recommendations for actions. University professors and graduate students teaching limnology and related fields, as well as managers of water resources, will find the committee's report valuable [77].

Cultured bivalves, *Crassostrea gigas* and *Tapes philippinarum* efficiently removed particulate matter from fish-pond effluents under two hydrological regimes. Two reactor types, a Plug Flow Reactor and a Continuous Stirred Flow Reactor were tested. Under the experimental conditions, the Plug Flow Reactor was found to be more efficient in deputing aquaculture effluents. A mixture of juvenile bivalves of both species further increased treatment efficiency. Flow rate and reactor length influence vertical settling of the non-planktonic particles. A mathematical model is proposed to predict particle removal by the bivalves under the conditions of the two rector types [78].

There are fifty-nine coldwater indigenous and two exotic fish species in Nepal. Among the 59 indigenous species, Neolissocheilus hexagonolepis, Schizothoraichthys spp, Schizothorax spp and Tor spp are the most economically important fish, considering their table fish and sport fish values. Their biology, behaviour and propagation is well known and understood. More effort is needed in the direction of developing a successful technology for their reproduction under controlled conditions. Wild stocks in cold waters of Nepal need to be better protected from over-exploitation and their management could be considerably improved. Due to the lack of other economic opportunities, such as agriculture, fishing may often be the only source of animal protein for the local people of hills and mountains of Nepal.

Deforestation due to the lack of other fuel and fodder resources causes soil erosion and sedimentation problems, which negatively impact fish habitats including their breeding grounds. Further constraints are the presence of hydroelectric dams on some rivers, destructive fishing methods and discharge of untreated effluents. Government assistence is needed for development of coldwater aquaculture and in production of stocking material for cold waters, as well as for raising the awareness of the fisherfolk about the danger of fish stock over-exploitation and advising on sustainability of coldwater fish stocks. In 1995/96 the annual fish production in Nepal was 10,300 t [79].

Hydro-geochemistry, morphometry and geographic position are the three fundamental determinants of limnological processes and dynamics of lake ecosystems. Reservoirs, man-made inland water bodies constructed for a variety of human benefits, have resulted in manifold environmental impacts changing the ecosystem continuum at different levels. Trophic characteristics such as nutrients, abundance and species dominance of planktonic algae and chlorophyll-a were examined at 32 reservoirs (e.g. irrigation, hydropower) in eight river basins in Sri Lanka. Similar parameters were examined monthly in a man-made aesthetic water body (Kandy Lake) for two years. The primary objective of this comparative cross-section and time series study at the Kandy Lake was to determine the impact of human manipulation of water budget on trophic characteristics of reservoir ecosystems. The abundance and species dominance of planktonic algae varied from reservoir to reservoir. Aulacoseira granulata was the dominant phytoplankton in a majority of reservoirs while Microcystis aeruginosa was the most important cyanobacterium in hypertrophic reservoirs. Trophic status changed from mesotrophic to hypertrophic but the majority of reservoirs were eutrophic. M. granulata and Pediastrum simplex were oscillating in the Kandy Lake. Although nitrate-nitrogen concentration was relatively low in remote irrigation reservoirs, phosphorus plays a significant role with respect to hyper-eutrophication of the Kandy Lake. The concentration of major nutrients (i.e. nitrate and total phosphorus) did not show a statistically significant correlation with chlorophyll-a content [80].

Phytoplankton and environmental variables have been monitored in the large Swedish lakes Mälaren, Hjälmaren, Vättern and Vänern since the 1960s. Measures to reduce phosphorus input and industrial waste products were taken during the 1970s. The phosphorus loading was then reduced by 90–95% resulting in a halving of the phosphorus concentrations in the most affected basins. The phytoplankton community reacted rapidly with decreased biomasses of cyanobacteria in summer as well as decreased biomasses of spring diatoms and cryptophycean flagellates. Other reactions were a contracted period of waterbloom, an increased taxon richness, an increased evenness in the biomass over the growth season, and a change in the species size structure within the phytoplankton community.

Furthermore, the species richness in the large lakes is compared in relation to lake characteristics. A presentation of the occurrence of toxic cyanobacteria in the lakes is also given. Maximum–minimum values of 13–0.1 μg microcystin L^{-1} are established in connection with waterblooms in Hjälmaren and Mälaren. The use of phytoplankton as a monitoring variable to detect water-quality changes is outlined and assessment criteria are presented [81].

Although black crappie Pomoxis nigromaculatus and white crappie P. annularis represent important sport fisheries in North America, we still know little about what influences their variable recruitment. Several abiotic (e.g., water level fluctuations) and biotic (e.g., prey abundance and size structure) factors have been suggested as important to crappie recruitment, but results have not been consistent among studies. We quantified adult characteristics, larval abundance, growth, diet, and postlarval juvenile abundance of crappies in three Alabama impoundments to determine factors consistently affecting crappie life stages across systems. Although adult condition (relative weight, Wr), fecundity, egg diameter, gonadosomatic index, and ovary weight differed among the three impoundments, the differences were not consistent with among-lake differences in chlorophyll-a concentration. Larval density was highest in the least productive system (Lake Martin), and larval production was not related to either adult condition or fecundity [82].

Fisheries Research Institute (FRI) has been conducting research on the Chignik lakes system since the 1950s. During that time funding has come from both the Federal Government through the Anadromous Fish Conservation Act (Public Law 89-304), and the Chignik fishermen through the Chignik Regional Aquaculture Association (CRAA). Both institutions have funded FRI with the goal of maintaining the health of the sockeye runs in the Chignik lakes. The government feels the maintenance of the long-term data set of biological data is important to the understanding of ecosystem health, and CRAA feels that analysis of physical changes in the environment and fisheries management are crucial to the health of the fish and the commercial and subsistence fisheries. The purpose of this report is to present analysis of data that recognizes the requests of both parties [83].

The influent and effluent water quality of two ponds at four aquaculture facilities (two intensive and two semiintensive growout systems) located on the Northwest coast of Mexico was monitored. Temperature, salinity, pH, dissolved oxygen, biochemical oxygen demand (self–consumption in 48 hours), total suspended solids, particulate organic material, nitrite, nitrate, ammonium, reactive and total phosphate, and chlorophyll *a* were analyzed every 2 weeks during two consecutive growout cycles. Changes recorded in most of these water quality variables were not strongly related to the management practices of the ponds, but rather to environmental factors.

The mean percent differences between inflowing and outflowing water that were observed indicated that water used for culture returned to the natural environment depleted of nutrients (inorganic nitrogen and reactive phosphate), and it was evident that the rearing activities promoted the exportation of particulate material to the surrounding environment[84].

The goal of mangrove restoration projects should be to improve community structure and ecosystem function of degraded coastal landscapes. This requires the ability to forecast how mangrove structure and function will respond to prescribed changes in site conditions including hydrology, topography, and geophysical energies. There are global, regional, and local factors that can explain gradients of regulators (e.g., salinity, sulfides), resources (nutrients, light, water), and hydroperiod (frequency, duration of flooding) that collectively account for stressors that result in diverse patterns of mangrove properties across a variety of environmental settings. Simulation models of hydrology, nutrient biogeochemistry, and vegetation dynamics have been developed to forecast patterns in mangroves in the Florida Coastal Everglades. These models provide insight to mangrove response to specific restoration alternatives, testing causal mechanisms of system degradation. We propose that these models can also assist in selecting performance measures for monitoring programs that evaluate project effectiveness. This selection process in turn improves model development and calibration for forecasting mangrove response to restoration alternatives. Hydrologic performance measures include soil regulators, particularly soil salinity, surface topography of mangrove landscape, and hydroperiod, including both the frequency and duration of flooding [85].

The University of Washington Fisheries Research Institute (FRI) has been conducting research on the anadromous and resident (ie non-anadromous) fishes of the Chignik lakes system since the 1950s. The Chignik Lake system is situated on the south side of the Alaska Peninsula (56◦ 16’N Lat., 158◦ 50’W), and produces the vast majority of the sockeye in the region. The system consists of two interconnected lakes draining into the Gulf of Alaska (Fig. 1). Chignik Lake is small (22 km2), relatively deep (64 m), and is surrounded by precipitous mountains. In contrast, the upper lake, Black Lake, is larger (41 km2) and extremely shallow (3 m maximum depth) and turbid, resting in a shallow tundra depression. Black Lake drains via the Black River into Chignik Lake. The outlet of Chignik Lake flows into a semi-enclosed estuary, Chignik Lagoon, and eventually into the Gulf of Alaska (Narver 1966, Dahlberg 1968, Ruggerone

1989b). Funding for FRI's work has come from both the Federal Government through the Anadromous Fish Conservation Act (Public Law 89-304), and the Chignik fishermen through the Chignik Regional Aquaculture Association (CRAA). These institutions have supported FRI with the goal of maintaining the health of the sockeye runs in the Chignik lakes. Both parties feel that the maintenance of FRI's unique long-term data set provides an invaluable tool with which we can better understand the structure and functioning of the ecosystem.

Ultimately, this understanding allows better management of the salmon resources of the area and facilitates analysis of how physical changes in the environment have potentially altered the fish community [86].

Limnological features of Oyan and Asejire lakes, South-Western Nigeria, were investigated between July 2000 and December 2001. Rainy season (April-October) mean monthly rainfall values of 120.3 ±52.4 mm and 15.9 ± 10.3 were recorded for Oyan and Asejire lakes respectively, while corresponding dry season (November-March) values were 18.2 ± 34.7 and 4.2 ± 3.81 mm, respectively.. The mean surface water temperature, transparency, dissolved oxygen content and pH were 29.9 ± 2.34°C, 1.5 ±0.19 m, 7.1 ± 0.96 mg/L and 7.4 ± 0.43, respectively, in Oyan lake and for Asejire lake the values were 28.5 ± 1.91°C, 1.3 ± 0.35 m, 6.9 ± 1.33 mg/L and 7.4± 0.54, respectively. The physicochemical properties of the two lakes vary with seasonal changes in the rainfall of the drainage area. Oyan and Asejire lakes exhibited features that are typical of tropical environment. The high dissolved oxygen content values indicate that the water bodies can successfully support aquatic life including fish [87].

Experimental seasonal wetland-based integrated aquaculture–agriculture systems called 'Fingerponds' were established at two sites (Nyangera and Kusa villages) at the shores of Lake Victoria in Kenya to enhance the wetland fishery potential. This paper examines the hydrological characteristics of Fingerponds. In Fingerponds' design, the water supply is un-regulated and the water balance is maintained by natural losses and gains. At the beginning of the season, flood events are critically important for the initial water supply to the ponds. During their functional period (which lasted for about 6 months into the dry season after flood recession), precipitation accounted for nearly 90% of the total water gains while seepage and evaporation contributed an average of 30–70% of the losses, respectively. Seasonal pond water budgets indicated that the losses outweighed the gains leading to a progressive decline of water depth during the dry season. A prediction of the effect of pond volume and weather conditions on the functional period for fish production was carried out using a dynamic simulation model. The results indicated that the culture period can be extended by 2.5 months by deepening the ponds to an average depth of 1.5 m: this would increase the overall fish harvest. Drier weather accelerated losses and shortened the culture period by 1–2 months [88].

In 1992, a court-ordered consent decree committed the United States EnvironmentalProtection Agency (USEPA) to a schedule for proposing and developing national effluentguidelines for new industries. As part of the consent decree, USEPA agreed to publish alist of candidate industries for rule making every two years. Five years later theEnvironmental Defense Fund (EDF) published Murky Waters: Environmental Effects ofAquaculture in the United States. In that widely read report, EDF recommended that thefederal government implement the Clean Water Act for aquaculture by developing nationaleffluent limitations.

As a consequence of those two events, USEPA announced in January2000 that it would undertake formal rule making for commercial and public aquaculturefacilities. This decision resulted in a multiyear national dialogue to evaluate effluentmanagement options for United States aquaculture facilities [89].

Grass carp (Ctenopharyngodon idella Val.) stocked (29 kg/ha) in a small pond reduced the biomass of aquatic macrophytes from 109 g/m2 to 33 g/m2 during one growing season. The only changes in hydrochemical parameters (pH, alkalinity, acidity, BOD5, CODMn, NH4-N, NO2-N, NO3-N, TN, PO4-P and TP) associated with the grass carp stocking were a decrease in pH (from 8.43 to 7.57) and in NO3-N concentration (from 0.99 mg/l to 0.56 mg/l). The increases in organic matter content and NO3-N concentration in the surface sediment layer were higher in the control pond than in the pond stocked with grass carp. No changes were detected in the other parameters (NH4-N, PO4-P and TP) in the upper sediment layer and between all parameters measured in the lower inorganic layer. The grass carp grazing had no impact on phytoplankton biomass (concentration of chlorophyll-a) or species composition. There were no changes either in the abundance or in the species composition of zooplankton and zoobenthos induced by grass carp. Statistically significant indirect changes (in water and sediment chemistry) following the grass carp stocking were connected especially with a reduction in the biomass of the filamentous alga (Cladophora globulina) or rather with its maintenance in the control pond [90].

The document herewith deals with the geography, geology, and climate of the Mexican territory as the basis to further explain the development of Limnology as a science in this country. An early knowledge started with the Aztecs, with evidence of practical solutions for a life within a lake. After the conquest of the American territories by the Spaniards, the exploration of the new territories provided the main source of information relative to natural resources. In 1938, the Mexican government established the Estación Limnológica de Pátzcuaro and the pioneer studies appeared under the name of Spanish scientists not only here but also at the Universidad Nacional Autónoma de México and the Instituto Politécnico Nacional. During the 1970s, the participation of Mexican limnologists began and the attempt to build-up a conceptual framework in its own for lakes, reservoirs, and rivers. This article outlines the main limnological characteristics of Mexican water bodies, highlights the peculiarities of a transitional zone between the tropics and subtropics, and describes the government structure for management and administration. A fast development in this area of knowledge got underway with the creation of the Asociación Mexicana de Limnología in 1997 and the collaboration with international counterparts [91].

The prediction for dissolved oxygen (DO) in aquaculture ponds is a problem of multi-variables, nonlinearity and long-time lag. Neural networks (NNs) have become one of ideal tools in modeling nonlinear relationship between inputs and outputs.

In this work, GA-LM, a neural network model combining Levenberg–Marquardt(LM) algorithm and Genetic Algorithm (GA) was developed for predicting DO in an aquaculture pond at Dalian, China. LM was used to train NNs, showing faster convergence rate. The network architecture was optimized by GA. The performance of GA-LM has been compared with that of conventional Back-Propagation (BP) algorithm and Levenberg–Marquardt(LM) algorithm. The comparison indicates that the predicted DO values using GA-LM model are in good agreement with the measured data. It is demonstrated here that the model is capable of predicting DO accurately, and can offer stronger and better performance than conventional neural networks when used as a quick interpolation and extrapolation tool [92].

In the centre-west regions of France, the deep water outlet system known as a “monk” is used in 13% of bodies of water. The authorities are strongly encouraging this to increase, arguing that this system would reduce pond induced warming of the hydrographical network. We have measured the water temperature in four monk equipped ponds for 13 years to such an extent that this paper draws on an analysis of 142,200 original measurements. Compared to a surface outflow, a monk is a system which shifts the warming of the emissary water course to the end of summer and the autumn which reduces average annual warming by about 1°C. This reduces the heating of diurnal maxima but increases warming of the minima. A monk equipped pond warms the river with deep water which has acquired its heat by mechanical convection generated by the wind, as opposed to a weir equipped pond which provides surface water warmed by insolation. In winter the monk equipped pond does not damage the thermal living conditions for Fario trout embryos and larvae under the gravel. In summer, the monk prevents night time cooling of the emissary and increases the temperature of the minima excessively for sensitive species [93].

The potential impact of Nile Tilapia (*Oreochromis niloticus*) cage culture on water quality and pelagic community composition was investigated in two Ethiopian small water bodies, one located in the highlands (Yemlo) and the other in the Great Rift Valley (Allage). This study was designed to assess the difference between the cages and open water in relation to those water quality changes attributable to intensive inputs of fish waste and left-over fish feed. All physico-chemical water quality parameters including inorganic nutrients varied temporally, coupled with dry and wet periods. The reservoir's trophic state ranged from eutrophic to hypereutrophic, with a strong correlation between chlorophyll-*a* and total phosphorus. The phytoplankton community was dominated by Cyanobacteria (84% of total phytoplankton abundance), in particular by *Anabaenopsis* sp. in Allage reservoir, whereas Chlorophyta (70%), with *Pediastrum simplex* as the dominant taxon, prevailed in Yemlo reservoir.

A total of 23 zooplankton taxa were recorded during our sampling; rotifers were the richest group with 14 taxa distributed in 6 genera, followed by cladocerans represented by 6 taxa (5 genera) and copepods by 3 taxa (1 genus). Dissolved inorganic nutrient concentrations and other physical parameters showed no significant differences between the cages and open water. The exceptions were dissolved oxygen and ammonium nitrogen, which were lower and higher in the cages, respectively. For the whole study period of 240 days, the mean net weight and daily growth rate per fish were 183.3 g and 1.1 g d^{-1}, respectively [94].

This is a comprehensive review of phytoplankton ecology in freshwater lakes of India. A review study was undertaken for the better understanding of the phytoplankton distribution. In broad terms, authors discussed the relations of phytoplankton with factors like lake temperature, sunlight exposure period, sunlight penetration, water pH, wind, transparency, seasonal variations, water characteristics, nutrient enrichment and prey-predator relation in the lakes of India. From the results, authors noticed that each lake habitat is different from other lake habitat. Finally, authors concluded that phytoplankton ecology is an indicator for the evaluation of impacts of influencing factors. These factors provide a suitable management plan for lakes. Phytoplankton ecology provides a ground for monitoring and assessing the strategies of the fresh water lake management [95].

It has been found that management of wetlands has received inadequate attention in the national water sector agenda. As a result, many of the wetlands are subject to anthropogenic pressures, including land use changes in the catchment; pollution from industry and households; encroachments; tourism; and over exploitation of their natural resources. Further, majority of research on wetland management in India relates to the limnological aspects and ecological/environmental economics of wetland management. But, the physical (such as hydrological and land use changes in the catchment) and socio-economic processes leading to limnological changes have not been explored substantially [96].

The Central Plains of Argentina is a heterogeneous environment, but the lakes there share some fundamental features: they are all shallow and polymictic as being well exposed to wind. First, we provide a synthesis of the climate, geology, and hydrological network. We also discussed shallow lakes origin and their limnological and biological salient features. Second, we focus on Pampean shallow lakes from a global perspective, comparing the limnological variables: total phosphorus concentration (TP), total nitrogen concentration (TN), chlorophyll *a* (Chl *a*) concentrations, and Secchi disk reading (SD) from a compiled database. No significant differences in the Chl *a* vs. TP relationship were found between Pampean and other shallow lakes. Otherwise, the chlorophyll yield per unit of phosphorus of Pampean lakes is similar to the world shallow lakes average.

Moreover, the relationship SD vs. Chl *a* differed significantly between Pampean and the remaining world lakes, about 50–60%. When confronted against other lakes worldwide, Pampean shallow lakes depart from most of them as having higher TP, TN, and Chl *a* concentrations and much lower SD transparency, and therefore they stand as extremes of the trophic-state continuum. Despite their highly turbid state, these lakes provide valuable ecosystem services that are highly appreciated and mobilize important economic resources [97].

Since the mid-1980s, fish-killing blooms of *Prymnesium parvum* spread throughout the USA. In the south central USA, *P. parvum* blooms have commonly spanned hundreds of kilometers. There is much evidence that physiological stress brought on by inorganic nutrient limitation enhances toxicity. Other factors influence toxin production as well, such as stress experienced at low salinity and temperature. A better understanding of toxin production by *P. parvum* remains elusive and the identities and functions of chemicals produced are unclear. This limits our understanding of factors that facilitated the spread of *P. parvum* blooms. In the south central USA, not only is there evidence that the spread of blooms was controlled, in part, by migration limitation. But there are also observations that suggest changed environmental conditions, primarily salinity, facilitated the spread of blooms. Other factors that might have played a role include altered hydrology and nutrient loading. Changes in water hardness, herbicide use, system pH, and the presence of toxin-resistant and/or *P. parvum*-inhibiting plankton may also have played a role. Management of *P. parvum* in natural systems has yet to be attempted, but may be guided by successes achieved in small impoundments and mesocosm experiments that employed various chemical and hydraulic control approaches [98].

Over the past 15 years, an increasing number of studies in limnology have been using data from high-frequency measurements (HFM). This new technology offers scientists a chance to investigate lakes at time scales that were not possible earlier and in places where regular sampling would be complicated or even dangerous. This has allowed capturing the effects of episodic or extreme events, such as typhoons on lakes. In the present paper we review the various fields of limnology, such as monitoring, studying highly dynamic processes, lake metabolism studies, and budget calculations, where HFM has been applied, and which have benefitted most from the application. Our meta-analysis showed that more than half of the high-frequency studies from lakes were made in North America and Europe. The main field of application has been lake ecology (monitoring, lake metabolism) followed by physical limnology. Water temperature and dissolved oxygen have been the most universal and commonly measured parameters and we review the various study purposes for which these measurements have been used. Although a considerable challenge for the future, our review highlights that broadening the spatial scale of HFM would substantially broaden the applicability of these data across a spectrum of different fields [99].

Due to its geographical position and climatic characteristics Hungary has many types of surface waters ranging from large rivers to small streams, or from large steppe lakes to small soda pans. These waters have diverse flora and fauna, and provide various ecosystem services for human well-being. Differences among the water types in size, depth, chemistry or biology determine their differential responses to anthropogenic disturbances, and thus their restoration or protection requires different management strategies. With this study the authors aim to review the water-related problems had to be faced and resolved by the experts during the last centuries, and show the achievements reached in the field of water quality management in Hungary [100].

Kettle holes as a specific group of isolated, small *lentic freshwater systems* (LFS) often are (i) hot spots of biogeochemical cycling and (ii) exposed to frequent sediment desiccation and rewetting. Their ecological functioning is greatly determined by immanent carbon and nutrient transformations. The objective of this review is to elucidate effects of a changing hydrological regime (i.e., dry–wet cycles) on carbon and nutrient cycling in kettle hole sediments. Generally, dry–wet cycles have the potential to increase C and N losses as well as P availability. However, their duration and frequency are important controlling factors regarding direction and intensity of biogeochemical and microbiological responses. To evaluate drought impacts on sediment carbon and nutrient cycling in detail requires the context of the LFS hydrological history. For example, frequent drought events induce physiological adaptation of exposed microbial communities and thus flatten metabolic responses, whereas rare events provoke unbalanced, strong microbial responses. Different potential of microbial resilience to drought stress can irretrievably change microbial communities and functional guilds, gearing cascades of functional responses. Hence, dry–wet events can shift the biogeochemical cycling of organic matter and nutrients to a new equilibrium, thus affecting the dynamic balance between carbon burial and mineralization in kettle holes [101].

Anthropogenic impacts on carp pond environments have increased over the last 100–150 years in Central Europe. Present semi-intensive carp pond management combines natural food resources, supplementary feeding and additional intensification measures such as manuring, liming, and winter and summer drainage. Despite increased eutrophication and fish stock pressure, many carp ponds still serve as habitats for threatened biota, including macrophytes. Both the ecologically essential role of aquatic macrophytes and the impacts that reared fish may have on them have been repeatedly reported in the literature; however, information is scattered and there exists no multidisciplinary synthesis of knowledge of fish farming and plant interactions for European carp ponds. In this review, we show that macrophytes from different ecological groups have specific demands regarding optimal ecological conditions (e.g. pH and trophy level); hence, they can act as indicators of a water body's ecological status [102].

Stormwater ponds, such as wet ponds and constructed wetlands, are widely used to manage stormwater runoff volume and water quality. Controlling nutrient levels in flows through stormwater ponds is of increasing concern, with many regions implementing loading limits for receiving waters. Nitrogen and phosphorus loading to stormwater ponds and wider catch basin sources are established. Dominant stormwater pond internal processes and prevalent nutrient forms are discussed. Relative impact of removal vectors and key factors such as temperature, dissolved oxygen, and seasonal impacts are reviewed. The direct and secondary impacts of design considerations such as macrophytes and floating treatment wetlands are discussed. Established design guideline performance standards and actual pond performance are compared. Modern approaches to modelling water quality changes within stormwater ponds are reviewed, within the context of improved pond design moving forward. This review paper intends to provide a broad overview of the nutrient processes in stormwater ponds and potential avenues for designers to improve future performance [103].

In this overview (introductory article to a special issue including 14 papers), we consider all main types of natural and artificial inland freshwater habitas (fwh). For each type, we identify the main biodiversity patterns and ecological features, human impacts on the system and environmental issues, and discuss ways to use this information to improve stewardship. Examples of selected key biodiversity/ecological features (habitat type): narrow endemics, sensitive (groundwater and GDEs); crenobionts, LIHRes (springs); unidirectional flow, nutrient spiraling (streams); naturally turbid, floodplains, large-bodied species (large rivers); depth-variation in benthic communities (lakes); endemism and diversity (ancient lakes); threatened, sensitive species (oxbow lakes, SWE); diverse, reduced littoral (reservoirs); cold-adapted species (Boreal and Arctic fwh); endemism, depauperate (Antarctic fwh); flood pulse, intermittent wetlands, biggest river basins (tropical fwh); variable hydrologic regime periods of drying, flash floods (arid-climate fwh). Effective conservation solutions are dependent on an understanding of connectivity between different freshwater ecosystems (including related terrestrial, coastal and marine systems) [104].

Although agriculture and aquaculture depend on access to increasingly scarce, shared water resources to produce food for human consumption, they are most often considered in isolation. We argue that they should be treated as integrated components of a single complex system that is prone to direct or indirect tradeoffs that should be avoided while also being amenable to synergies that should be sought. Direct tradeoffs such as competition for space or the pollution of shared water resources usually occur when the footprints of agriculture and aquaculture overlap or when the two practices coexist in close proximity to one another. Interactions can be modulated by factors such as hydropower infrastructure and short-term economic incentives, both of which are known to disrupt the balance between aquaculture and agriculture.

Indirect tradeoffs, on the other hand, play out across distances, i.e., when agricultural food sources are diverted to feed animals in aquaculture. Synergies are associated with the culture of aquatic organisms in rice paddies and irrigation waters, seasonal rotations of crop cultivation with aquaculture, and various forms of integrated agriculture–aquaculture (IAA), including *jitang*, a highly developed variant of pond-dike IAA. Policy decisions, socioeconomic considerations, and technology warrant increased scrutiny as determinants of tradeoffs and synergies. Priority issues for the future include guiding the expansion of aquaculture from its traditional base in Asia, taking advantage of the heterogeneity that exists within both agricultural and aquaculture systems, the development of additional metrics of tradeoffs and synergies, and adapting to the effects of climate change [105].

The familiar water cycle is driven by solar radiation, and water is continually transformed back and forth between water vapor and liquid water. In the process, water passes through several distinct compartments of the hydrosphere to include atmospheric moisture, precipitation, runoff, groundwater, standing water bodies, flowing streams, and ocean. Water budgets for water bodies allow concentrations of water quality variables to be used with inflow, outflow, and storage changes to estimate quantities of water quality variables that are contained in and pass through water bodies [106].

The Colorado River is a critical water resource in the southwestern United States, supplying drinking water for 40 million people in the region and water for irrigation of 2.2 million hectares of land. Extended drought in the Upper Colorado River Basin (UCOL) and the prospect of a warmer climate in the future pose water availability challenges for those charged with managing the river. Limited water availability in the future also may negatively affect aquatic ecosystems and wildlife that depend upon them. Water availability components of special importance in the UCOL include streamflow, salinity in groundwater and surface water, groundwater levels and storage, and the role of snow in the UCOL water cycle. This manuscript provides a review of current “state of the science” for these UCOL water availability components with a focus on identifying gaps in data, modeling, and trends in the basin. Trends provide context for evaluations of current conditions and motivation for further investigation and modeling, models allow for investigation of processes and projections of future water availability, and data support both efforts. Information summarized in this manuscript will be valuable in planning integrated assessments of water availability in the UCOL [107].

Monitoring water quality is an essential tool for the control of pollutants and pathogens that can cause damage to the environment and human health. However, water quality analysis is usually performed in laboratory environments, often with the use of high-cost equipment and qualified professionals.

With the progress of nanotechnology and the advance in engineering materials, several studies have shown, in recent years, the development of technologies aimed at monitoring water quality, with the ability to reduce the costs of analysis and accelerate the achievement of results for management and decision-making. In this work, a review was carried out on several low-cost developed technologies and applied in situ for water quality monitoring. Thus, new alternative technologies for the main physical (color, temperature, and turbidity), chemical (chlorine, fluorine, phosphorus, metals, nitrogen, dissolved oxygen, pH, and oxidation–reduction potential), and biological (total coliforms, *Escherichia coli*, algae, and cyanobacteria) water quality parameters were described. It was observed that there has been an increase in the number of publications related to the topic in recent years, mainly since 2012, with 641 studies being published in 2021 [108].

Aquaculture is the fastest growing animal food production sector worldwide and is becoming the main source of aquatic animal foodstuff for human consumption. However, the aquaculture sector has been strongly criticized for its environmental impacts. It can cause discharge and accumulation of residual nutrients in the areas surrounding the production farms. This is because, of the total nutrients supplied to production ponds, only 30% are converted into product, while the rest is usually discharged into the environment to maintain water quality in aquaculture culture systems, thereby altering the physic-chemical characteristics of the receiving water. In contrast, this same accumulation of nutrients is gaining importance within the agricultural sector, as it has been reported that the main nutrients required by plants for their development are found in this aquaculture waste [109].

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usually performed in laboratory environments, often with the use of high-cost equipment and qualified professionals. With the progress of nanotechnology and the advance in engineering materials, several studies have shown, in recent years, the development of technologies aimed at monitoring water quality, with the ability to reduce the costs of analysis and accelerate the achievement of results for management and decision-making. In this work, a review was carried out on several low-cost developed technologies and applied in situ for water quality monitoring. Thus, new alternative technologies for the main physical (color, temperature, and turbidity), chemical (chlorine, fluorine, phosphorus, metals, nitrogen, dissolved oxygen, pH, and oxidation–reduction potential), and biological (total coliforms, *Escherichia coli*, algae, and cyanobacteria) water quality parameters were described. It was observed that there has been an increase in the number of publications related to the topic in recent years, mainly since 2012, with 641 studies being published in 2021 [110].

Climate change and extreme weather events (such as droughts, heatwaves, rainstorms and floods) pose serious challenges for water management, in terms of both water resources availability and water quality. However, the responses and mechanisms of river water quality under more frequent and intense hydroclimatic extremes are not well understood. In this Review, we assess the impacts of hydroclimatic extremes and multidecadal climate change on a wide range of water quality constituents to identify the key responses and driving mechanisms. Comparison of 965 case studies indicates that river water quality generally deteriorates under droughts and heatwaves (68% of compiled cases), rainstorms and floods (51%) and under long-term climate change (56%). Also improvements or mixed responses are reported owing to counteracting mechanisms, for example, increased pollutant mobilization versus dilution during flood events. River water quality responses under multidecadal climate change are driven by hydrological alterations, rises in water and soil temperatures and interactions among hydroclimatic, land use and human drivers. These complex interactions synergistically influence the sources, transport and transformation of all water quality constituents. Future research must target tools, techniques and models that support the design of robust water quality management strategies, in a world that is facing more frequent and severe hydroclimatic extremes [111].

The quantity and quality of surface water are inherently connected yet are overwhelmingly studied separately in the field of remote sensing. Remotely observable water quantity (e.g., water extent, water elevation, lake/reservoir volume, and river discharge) and water quality (e.g., color, turbidity, total suspended solids, chlorophyll *a*, colored dissolved organic matter, and temperature) parameters of inland waterbodies interact through a series of hydrological and biogeochemical processes. In this review, we analyzed trends in remote sensing publications to understand the prevalence of studies on the quantity versus quality of open-surface inland waterbodies (rivers, streams, lakes, and reservoirs) as well as identified opportunities for integrating both water quality and quantity sensing in future work. Our bibliometric analysis found that despite the increasing number of publications using remote sensing for inland waterbodies, few studies to date have used remote sensing tools or approaches to simultaneously study water quantity and quality. Ultimately, by providing insights into potential integration of the water quality and quantity studies, we aim to identify a pathway to advance the understanding of inland water dynamics and freshwater resources through remote sensing [112].

Few factors are as important in determining water quality as land use/land cover (LULC). Many land use activities, including agriculture, urban development, mining, and commercial forestry, tend to be sources of diffuse pollution. By contrast, indigenous vegetation can act as a sink, thus providing some protection from diffuse anthropogenic contamination.

Notwithstanding the large body of research demonstrating these facts, decision-makers require clear and accessible information to assist them in developing effective management plans that are fully cognisant of the manifold impacts of LULC on water resources. Reviewing the available literature, this article offers a critical overview of the typical impacts of LULC on water quality. An important strategy for managing water quality highlighted in this article is the maintenance of a sufficient amount of unfragmented natural vegetation, not only within riparian zones but also across catchment areas [113].

River water quality is crucial to ecosystem health and water security, yet its deterioration under climate change is often overlooked in climate risk assessments. Here we review how climate change influences river water quality via persistent, gradual shifts and episodic, intense extreme events. Although distinct in magnitude, intensity and duration, these changes modulate the structure and hydro-biogeochemical processes on land and in rivers, hence reshaping land–river connectivity and the quality of river waters. To advance understanding of and forecasting capabilities for water quality in future climates, it is essential to perceive land and rivers as interconnected systems. It is also vital to prioritize research under climate extremes, where the dynamics of water quality often challenge existing theories and models and call for shifts in conceptual paradigms [114].

Feed use in aquaculture results in large amounts of embodied land, freshwater, energy and wild fish use. Selection of feed ingredients at feed mills can reduce the amounts of one or more of the four major natural resources embodied in feed. However, better feed management to lessen FCR is more likely the key to lessening resource use at the farm level. Of course, lessening the FCR will reduce the amount of feed that must be purchased and diminish the direct and embodied negative environmental impacts associated with feed. It also is important to note that mechanical aeration applied in many methods of production requires more energy than associated with feed alone. Aeration is necessary for high feed inputs required in intensive production, and without aeration, most types of intensive production would not be possible. The amounts of resource use attributed to feeding and aeration were applied in estimating the resulting quantities of water pollutants in effluents and emission of atmospheric contaminants. Some of the misunderstandings about life cycle assessment (LCA) such as it usually covering all impacts of product systems, and especially its failure to assess the oxygen demand of effluents are mentioned [115].

This comprehensive review explores the transformative role of remote sensing technologies in the detection and monitoring of water pollution. Remote sensing provides dynamic, large-scale, and cost-effective solutions for continuous assessment of water quality.

The review covers the application of remote sensing for detecting a range of pollutants, including chemical contaminants, physical parameters, and biological pollutants. The review systematically analyzed 132 studies selected from the Web of Science database using the keywords “remote sensing” and “water pollution,” covering publications from the 1990s to December 2023. The analysis highlights the use of multispectral and hyperspectral imaging, machine learning algorithms, and statistical models for precise pollutant detection and quantification [116].

Conclusion: Hydrological and limnological factors play a pivotal role in determining the success and sustainability of pond-based aquaculture systems. Elements such as water availability, quality, temperature, pH, dissolved oxygen, and nutrient dynamics directly affect fish health, growth rates, and overall productivity. Stable hydrological conditions ensure consistent water levels and reduce the risk of environmental stress, while appropriate limnological parameters create a balanced aquatic ecosystem that supports both the cultured species and the microorganisms vital to nutrient cycling and water purification. Moreover, the interactions between physical, chemical, and biological components within pond ecosystems must be closely monitored and managed to prevent issues such as eutrophication, disease outbreaks, and oxygen depletion. Understanding these factors enables aquaculture practitioners to implement effective management strategies, such as water exchange, aeration, feeding regimes, and stocking density control, to optimize yields and maintain ecological balance.

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