Evidence-Based Holistic Restoration of Lake Anasagar, Ajmer, Rajasthan, India

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Views expressed in this paper are those of the authors; they do not necessarily represent the views of RSPCB or the institutions to which authors belong.

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1. Introduction

This report has been prepared with the aim to apply the principles of sustainability science for long-term sustainability of lake Anasagar of Ajmer. The material for this report has been drawn from three distinct sources: *scientific knowledge* produced by researchers on Anasagar [1-25], *experiential knowledge* of practitioners contained in various documents produced by practitioners in the area, and the *traditional knowledge* of local communities. Finally, several personal observations during the field inspections by Member Secretary and officials of Rajasthan State Pollution Control Board (RSPCB) have also contributed to the final preparation of the concept document.

A word of caution is in order here. This report should not be mistaken as a theoretical document. It contains practical, useful and usable knowledge. The suggestions noted here are both evidence-based as well as sensitive to the fact that connecting science to decision-making (i.e., linking knowledge to action) is a complex task requiring administrative will, resources and long-term engagement by stakeholders. Suggestions in the report would be valuable for drawing the action plans for individual actions proposed here. Each suggestion would need to be developed into action plans for field implementation, accounting for already ongoing actions as per currently made DPRs, for detailed implementation by departments and organizations responsible for the affairs of the lake.

2. Present status of Lake Anasagar

The Lake Anasagar (26°27'-26°29' N and 74°36'- 74°37' E), built by Anaji of Chauhan dynasty during 1135-1150 AD, is now a critically polluted urban waterbody of Ajmer (25°38′ to 26°58′ North and 73°52′ to 75°22′ East). Later the Mughal emperors made additional constructions to beautify the lake. The 'Baradari', a marble pavilion was built by Shah Jahan and the ' Daulat Bagh ' gardens were laid by Jahangir [18]. The catchment area of lake is 70.55 km^2, and its circumference is 12.88 km [11]. Originally, it was a monsoon-fed, perennial, shallow freshwater lake that was built as an adaptation to climate variability [21]. But anthropogenic stressors such as disposal of raw sewage and municipal wastewater, input of detergents due to washing of clothes and bathing, inputs of pesticides and chemical fertilizers due to unsustainable agriculture, aquaculture and horticulture, and urban settlement have forced the lake into the severely polluted and hyper-eutrophic condition (i.e., very nutrient-rich and highly productive lake characterized by frequent and severe algal blooms and low transparency) [4, 5, 9, 19, 20, 23]. As many ecological warning signals of ecosystem impairment and dysfunction are already visible, if appropriate long-term interventions do not urgently and earnestly begin to be implemented now, the catastrophic collapse of lake ecosystem is a distinct reality as has happened in numerous cases globally [26-33].

3. Multiple stressors degrading the Lake Anasagar

There are several factors that are degrading the lake Anasagar today. Understanding their intensity and quantum is necessary to design long-term solutions for sustainability. However, before discussing Anasagar, it is worth mentioning that environmental health of lakes all over India is not very encouraging.

India is home to a wide range of water harvesting structures located in a diversity of climates, stretching from mountains near the Himalayas in the north, to tropical conditions in the south. The impoundments include natural lakes, wetlands and coastal lagoons, as well as constructed reservoirs, tanks and earthen embankments [21, 34, 35]. We wish to point out that Lakes, in general throughout urban systems, in India are facing serious environmental degradation caused by encroachments, discharge of sewage, wastewater and industrial effluents, and siltation [36-69]. Majority of lakes in India have become eutrophicated due to discharge of sewage, municipal wastewater and industrial effluents [9, 19, 38, 58, 69-85]. Large number of these lakes have also a huge built-up of heavy metals that are being bioaccumulated, and have entered human food-chain with large implications for human health [36-38, 42, 49, 52, 53, 58, 62, 65, 86-95].

Indeed, the degradation of lakes and consequent eutrophication is not an Indian issue alone; it remains a worldwide concern today with a large number of serious efforts to mitigate eutrophication globally [96-115].

Specific stressors that are degrading lake Anasagar are many and often mutually reinforcing. These are discussed below.

3.1. Disposal of raw sewage and municipal wastewater

Anasagar was once a source of water supply to Ajmer. Piped supply started in 1884 from Anasagar reservoir to the then population of 50,000 [18]. Today, around 35% population of Ajmer resides in the catchment area of the lake [9]. Absence of sewer line for domestic wastewater of nearby colonies is being discharged directly into the lake without any treatment through open drain (Kachcha Nallah/Pucca Nallah). Several constructed buildings (both partly constructed and complete) are seen in the lake area. During a rapid field inspection it was observed that the sewage and sullage arising from the households, surrounding the lake, is taken into it through various Nallas namely, the Kazi ka Nallah, Christianganj Nallah-1, Christianganj Nallah-2, Shantipura Nallah, Antend Nallah (near old mittal hospital), Chaurasiawas Nallah (near new mittal hospital) Bandi River Nallah, Ram Nagar Nallah, Mahaveer Colony Nallah, Nagfani Nallah (near Jain mandir) and Nallah Near Maheshwari Public School.

The lake water gets further polluted as a result of disposal of municipal solid wastes in it. The lake is one of the main tourism and recreational spot in Ajmer. The nearby food courts and other shops generate garbage and organic waste that is ultimately dumped into the lake [9]. Unauthorized settlements in the catchment areas and encroachments in the peripheral parts of the lake are also a great threat to its existence as these factors have resulted in reduction of rainwater runoff in the lake and shrinkage thereof [4, 11].

The impact of sewage discharge into lake has been a problem for a very long period of time bringing several long term changes to lake ecosystem. For example, algal diversity in the littoral zone of Anasagar more than two decades ago has been found to be 123 species belonging to 60 genera. Sewage-affected site remains conducive to luxuriant growth of algae. Presence of species such as *Achnanthes hungarica*, *Ankistrodesmus falcatus*, *Chlorella vulgaris*, *Chlorococcum infusionum*, *Pandorina morum*, *Pediastrum tetras*, *Scenedesmus quadricauda*, *Stigeoclonium tenue* and and species of *Navicula* and *Oscillatoria*,indicate show that lake is polluted [23]. Sewage pollution has also contributed to the periodic growth of aquatic weeds, such as *Typha*, *Ipomoea*, *Azolla*, *Vallisneria*, *Trapa* and *Potamogeton* species in large quantities [19].

Discharge of sewage, municipal wastewater and agricultural runoff has increased the primary productivity and physico-chemical values of the lake, resulting into eutrophic condition [4]. GPP value have been reported to be between 1.93 and 6.24 gC/m^2/day, NPP ranging between 0.72 and 4.99 gC/m^2/day and community respiration as 0.26 to 3.6 gC/m^2/day. This is mainly due to concentration of nutrients such as chloride (18.5 to 32.4 mg/l), nitrate (12.9 to 26.4 mg/l) and phosphate (1.2 to 3.2 mg/l) [4, 5]. Despite extensive research during the past five decades, many key questions in eutrophication science remain unanswered [116, 117], yet it is worth noting that phosphorus is the key nutrient responsible for freshwater lake eutrophication [112, 113, 118-123]. In surface waters, phosphorus concentration exceeding 0.05 mg per liter may cause eutrophic conditions [118, 119].

3.2. Discharge of detergents

Inputs of detergents are both through municipal wastewater being discharged directly into the lake as well as cloth washing and bathing in the lake [3, 7, 8]. Bathing and washing of clothes at the banks of the lake provide inputs of Phosphorus to lake water which is a major nutrient input responsible for the eutrophication of lake. The phosphorus also gets deposited in sediment of the lake and can become released and remobilized by various mechanisms causing remediation of eutrophic lake difficult for longer periods

[123-127]. When concentrations of iron are low, phosphorus can be recycled between sediments and water for many years [116]. In extreme cases, internal recycling can contribute over 90% of phosphorus annually available to plankton [116]. In lakes where nitrogen input is not reduced, phosphorus is often rapidly recycled between sediments and water, and phytoplankton is dominated by non–N2-fixing cyanobacteria, such as *Planktolyngbya*, *Oscillatoria*, and toxic *Microcystis*. *Microcystis* can vertically migrate, consume excess phosphorus at the sediment-water interface, and then rise to the water surface to form algal blooms [117].

3.3. Discharge of residual pesticides and fertilizers

Inputs of pesticides and chemical fertilizers are mainly due to unsustainable agriculture, aquaculture and horticulture in the catchment of the lake [3, 7-9, 16]. Agricultural activities in the catchment of lake Anasagar are heavily dependent on the use of chemical fertilizers. The residual quantity of these chemicals is drained into the lake during monsoon rains. In addition, farmers also practice cultivation of *Trapa bispinosa* and fodder crops with the use of inorganic and organic fertilizers. Organochlorine pesticides used for increasing crop production of *Trapa* are retained in the water as residues which are incorporated in the food chain and in aquatic organisms [9]. Gas chromatographic analysis of 120 contaminated water samples collected from the lake Anasagar show that the organochlorine pesticides such as Heptachlor, ß-HCH, Y-HCH, Aldrin, DDT and Endosulfan are found in the range of 0.0224 ppm, 0.1035 ppm, 0.0478 ppm, 0.0041 ppm, 0.1381 ppm and 0.505 ppm, respectively. Water of Anasagar, thus, is highly contaminated with these synthetic pesticides [8]. Effects of pesticides on hormonal and enzyme systems of aquatic population have been found to be adverse [3].

3.4. Sedimentation due to soil erosion

The lake Anasagar receives runoff water from catchment hills such as Nagpahar, Anted and Taragarh which carries large volumes of soil leading to sedimentation in the lake. The hillocks are characterized with steep slopes (>45^0), therefore, large amount of gravel and soil is eroded due to high runoff of rainwater. The heavy rainfall over a short period of time intensifies the erosion and sedimentation [9].

3.5. Challenges of land ownership and encroachment

The lake is under the Urban Improvement Trust / Municipal Corporation of Ajmer. However, a number of fragmented land pockets are under the private ownership, and owners are often unwilling to restrict pollution-causing activities. Furthermore, remediation activities become increasingly difficult due to hurdles by private owners. For example, the safe and regulated aquaculture and agricultural practices are difficult to implement because of private ownership. Some encroachers even try to run brick factories in the catchment that have now been demolished by Ajmer Municipal Corporation. Private owners are also said to allow washer-men for cloth washing releasing large quantities of detergents, and thus phosphorus, into the lake [9].

Government documents suggest that in the absence of availability of land in the vicinity of the city, UIT, Ajmer developed colonies by reclaiming northern part of Anasagar Lake thus paving way for further development/encroachment upon the lake. Earlier, even brick kilns were found operating in the reclaimed land in Anasagar Lake, besides residential colonies such as Vaishali Nagar [18].

4. Holistic restoration of Lake Anasagar

Eutrophication of lake Anasagar threatens the economic, ecological, and social sustainability of urban system of Ajmer. This is one of the visible consequences of imperiled nature-society interactions. Degradation of Anasagar, in conjunction with other threats to urban ecosystems and surrounding catchment, is likely to exacerbate the collapse of urban green infrastructure, livelihood insecurity, and unsustainable urbanization. While various strategies and actions are underway for urban systems [18], it is argued here that a broader vision that incorporates holistic restoration science, urban environmental governance and legal interventions is called for. Indeed, we shall have to draw on sustainability science to address the imperiled nature-society interactions as well as to construct a self-sustaining functional aquatic ecosystem capable of supporting biodiversity, performing ecosystem functioning and providing ecosystem services to society [128-134]. In the sub-sections that follow, we describe a holistic strategy for restoration of Lake Anasagar.

4.1. Waste and sewage management

Prevention, Control and Abatement of pollution of water of lake Anasagar is a long process and requires concerted and graduated efforts at the level of different agencies and authorities of the State as also citizens inhabiting in the area.

The Municipal Corporation Ajmer, throughout its territorial jurisdiction, is required, under the provisions of section 25 of the Water (Prevention and Control of Pollution) Act, 1974 [135], to provide effective and efficient sewage system for collection and conveyance of sewage and sullage arising in the city, install sewage and wastewater effluent treatment plant of adequate capacity, treat the wastewater in conformity to the standards prescribed under the provisions of the Environment (Protection) Act, 1986 [135], and make proper arrangements for disposal of treated wastewater and sludge in a scientific environmentally safe manner. Presently no proper sewerage system is in operation in the city of Ajmer and as a result thereof the entire wastewater generated by population living in urban catchment is being discharged directly into lake Anasagar.

Thus, the Urban Improvement Trust and Municipal Corporation, Ajmer are required to take immediate steps to block the entry of untreated waste water into the lake. The wastewater should be collected at the sewage treatment plants through the closed sewer lines and given adequate treatment so as to conform to prescribed standards. The waste water after treatment may be used for irrigation and other gainful purposes.

The Municipal Corporation, Ajmer is also required, under the provisions of the Solid Wastes (Management and Handling) Rules

2010 made under the provisions of the Environment Protection Act 1986 [135], to provide infrastructure for collection, storage, segregation transportation, processing and disposal of municipal solid waste. There is no proper and efficient infrastructure in Ajmer city for management and handling of municipal solid wastes and it is disposed off indiscriminately in an unscientific manner contrary to the said rules.

Protection of Lake also requires checking the flow of pesticides, insecticides, fertilizers and other pollutants from the catchment areas to the lake. These chemicals could be prevented from entering into aquatic ecosystem of the lake by following good and environment friendly agricultural practices. Restoration of lake also stipulates removal of unauthorized constructions from its catchments areas. Periodic desiltation of lake is also essential not only for maintaining the lake clean but also to keep the water storage capacity of the lake intact. All these activities not only involve substantial question of good governance, but also have bearing on human rights and environmental jurisprudence. This is so because environment has now clearly become a legal and highly contested object in India [136-144].

Large body of evidence demonstrates that the successful control of eutrophication in freshwater lakes such as Anasagar will require construction of sewage and wastewater treatment system to reduce external inputs of phosphorus to lake waters. In addition, as described later, it will also require periodic sediment removal to stop internal recycling of phosphorus from sediments [112, 116, 117, 123]. We want to emphasize here that in Anasagar lake, effective implementation of restrictions on anthropogenic nutrient inputs, such as sewage and municipal wastewater, is essential for the recovery of lake from eutrophication. We also wish to caution here that it may take at least a decade or more for lake to recover from eutrophication, and therefore, sustained and long-term efforts and financial allocations by various stakeholders are essential.

4.2. Forest restoration in the watershed

Deforestation of lake catchments causes long-term increases in the loss of nutrients [122]. In addition, as discussed earlier, applications of manure and chemical fertilizers further increase nutrient exports as fertilized soils can become nutrient saturated, releasing nutrients into receiving lake for decades even after external nutrient additions are reduced or discontinued [116]. Natural vegetation in the lake watershed is likely to act as soil-binder and trap for nutrients. Using the standard principles of tropical dry forest restoration, long-term restoration efforts are required [145-154]. Depending upon the availability of the area, restoration of degraded forests with multiple use trees, shrubs and herbs along with regeneration regimes that necessarily combine rainwater harvesting, direct seeding, resprouting, stake-planting, and plantation of saplings where needed, would provide maximum protection to lake watershed. While a detailed discussion of this subject is beyond the scope of this document, the following strategies must be kept in mind when implementing the forest restoration in the watershed [35, 155-159]:

- Restoration of degraded hills around Anasagr with multiple use local species of trees, shrubs and herbs along with regeneration regimes that necessarily combine rainwater harvesting, direct seeding, resprouting, stake-planting, and plantations of saplings.
- Protection and management of natural regrowth plus enrichment with key species that are commercially, socially, or ecologically useful, and can improve the value of forests to local communities.
- Direct seeding in a combination of both leguminous and non-leguminous species can be used to initiate reforestation in barren areas. Leguminous species can enhance soil microbial biomass and N mineralization and promote growth of other saplings growing in their vicinity.

- Maintenance of woody vegetation in ethnoforestry regimes in landscape continuum (households, cultural rural and urban systems, agroecosystems, and wilderness). Protection to a variety of woody vegetation management regimes in cultural landscape to maximize social and economic benefits to the people as well maintenance of ecosystems functions such as natural pest control, pollination, carbon storage, regulation of hydrological cycle etc.
- Mixed species tree plantation used as a nurse crop with underplantings of native species not otherwise able to establish at the site. Fast-growing nurse crop supplying commercially useful timbers or other goods can facilitate (e.g., via nitrogen fixation and microclimate alterations) the subsequent establishment of more species-rich forests that supply a wider range of goods and services.
- Experiential knowledge as well as recent studies in Aravalli hills have found beneficial effect of rainwater harvesting (RWH) on microhabitats in promoting the growth of plants degraded hills [152]. Particularly, microcatchments around saplings and V-ditches are known to conserve soil and improve growth of plants [160-162]. Harvesting of rainwater can enhance herbage biomass by 24-71% in plots with V-ditch [163]. Thus use of rainwater harvesting to enhance soil water, nutrients, vegetation cover, plant growth and biomass during restoration of degraded hills.

4.3. Sequential restoration of vegetation in sand dunes

Besides barren hills, there are a few sandy pockets/ dunes falling in the catchment of Anasagar. It is necessary to carry out sequential restoration of vegetation in these dunes to arrest the movement of sand. Initially, greening and stabilization of sand dune was an emergency, and tree-cover developed through earlier plantations has served the desired purpose initially (i.e. stabilization, soil enrichment, and protection to infrastructure). Soil properties and moisture regimes have improved due to existence of the green tree cover for a decade or more. But, these dunes are now reactivating due to climatic, environmental and anthropogenic reasons, threatening the farmlands and infrastructure. We now need to enhance biodiversity through enrichment with local species that were not possible to grow, or failed to grow, initially in moving dunes. Sequential restoration with multiple layers of vegetation will enhance productivity, and initiate succession towards indigenous species that will further yield livelihoods goods and services to local people. Such adaptive management approach is likely to result in dynamic and resilient dune systems that can withstand stresses of climate change and anthropogenic effects in the lake catchment [164].

4.4. *Management of urban green infrastructure*

Ajmer is undergoing rapid urbanization such that land development (160.8%) in Ajmer has been found to be more than three times the population growth (50.1%) during 1977-2002 [15]. Even during the last decade the per capita consumption of land for urbanization has increased [12]. Urbanization is bringing significant changes in important watershed characteristics leading to deterioration of its health [165]. In addition, urbanization is also impacting the groundwater due to increase of impervious land surface. For example, groundwater table depth in Ajmer was between 3 and 23 m in 1991 as compared to 10–39 m in year 2005, which indicates an overall decline in groundwater on account of reduced recharge and increase in withdrawal. Indeed, average depletion in groundwater level from 1991 to 2005 has been found as 11.5 m. [12]. Furthermore, concentrations of pollutants in shallow wells have increased since 1992, indicating deterioration of groundwater quality owing to reduction of recharge from the rainfall and increase in recharge from urban wastewater [12]. Some ground water samples have been found to be unfit for domestic use [166], and highly contaminated by bacteria including *Escherichia coli* due to deficient wastewater collection, treatment and disposal system in Ajmer [167]. Thus, protecting urban green infrastructure is necessary for sustainable urbanization.

Urban green infrastructure comprises of all natural, semi-natural and artificial networks of multifunctional ecological systems within, around and between urban areas, at all spatial scales. Green infrastructure can provide numerous ecosystem services such as purification of air and water, pollution control, mitigation of floods and droughts, re-generation of soil fertility, moderation of temperature extremes, carbon sequestration, climate change mitigation and enhancing the landscape quality. Deliberately planned, developed, and maintained green infrastructure has the potential to guide urban development by providing a framework for economic growth and nature conservation across urban systems. Planned approach is essential for integration between urban development, nature conservation and public health promotion.

Creation and maintenance of green infrastructure will include protection to already existing structures such as ponds, lakes, streams, vegetation, forests and other components of natural systems. It will also entail creation of urban green spaces, gardens, constructed wetlands, permeable pavement, peri-urban agroforestry, and integrated rainwater harvesting systems. An important consideration now emerging is that we need to move towards multifunctional urban green spaces, such as "edible landscapes" that provide both goods and services to society. For example, construction of parks, urban green spaces, urban forests, domestic/home gardens, plantations on vacant lands and peri-urban agriculture and agroforestry can immensely contribute in creation of green infrastructure [168-176]. Promoting agroforestry in per-urban farmlands would be very useful for utilization of residual chemical fertilizers that are washed with storm-water in to the lake. Agroforestry and grass buffers improve water quality by reducing non-point source pollution while providing many other benefits such as biodiversity conservation, yield of goods and services, carbon storage in agroecosystems, enhancing soil fertility and providing social and economic well-being to people [177-181]. In addition, as the air pollution in Ajmer city is also significant [182, 183], urban parks and green spaces as key green infrastructure can significantly reduce air pollution load [176, 184].

4.5. Periodic sediment removal from lake

In order to increase the rainwater storage capacity of the lake and prevent the remobilization of phosphorus, removal of sediments from lake-bed needs to be taken up periodically during dry years. In fact sediment removal was a common practice and traditional knowledge on the maintenance of lakes and ponds in India [185]. Sediments of lake beds have on an average 720 mg nitrogen (N), 320 mg phosphorus (P), 310 mg potassium (K) and 9.1 g of organic C per kg of sediment [125]. The sediment of Lake Anasagar is rich in nutrients (N and P) which may be utilized as fertilizers in agricultural fields. The removal of sediment and organic debris from littoral zone should be repeated periodically till the lake resumes its ecological integrity [9]. During the severe drought conditions of 1987, the sediment removal was done with the participation of citizens and educational institutions. Sediment was used in agricultural fields by the farmers. The crop yield of these fields was noted to be significantly high as compared to nearby fields not using the sediment [9].

Sediment removal also increases water retaining capacity of the lake. When a lake has anoxic bottom water in summer and stratifies, the top few millimeters of mud is chemically reduced to a condition that allows the phosphorus to release back into the water and fertilizing the lake for an algal bloom [117, 119]. Periodic removal of sediments from lake is helpful to reduce phosphorus recycling and to save the lake from anoxic state at the bottom [34, 119, 186-188].

4.6. Macrophyte restoration in littoral zone of lake

Reduction in nutrient loading can be brought about through the proposals noted above, yet the lake may take long time to recover from eutrophication due to internal mobilization of nutrients in sediment. Some phosphorus may also remain present in treated wastewater coming out of sewage treatment plant. Thus, In addition to building STP that specifically removes phosphorus from wastewater, constructed wetlands may be necessary at the outlet of STP to further reduce phosphorus and nitrogen. This technique has often yielded useful results in many areas [189, 190]. For example, in China macrophyte restoration, especially submerged macrophyte restoration, was thought to be an effective approach to reducing the nutrient loading and restricting algal bloom recurring in freshwater lakes or ponds [115]. Eutrophication in lake Anasagar has decreased the density of rooted macrophytes, and altered their composition, from several areas, leading to high biomass of phytoplankton and remobilization of sediment and the release of nutrients. Thus macrophytes restoration is necessary.

It must be noted here that excessive growth of vegetation is not desirable in lakes as it reduces the quality of water, but marginal aquatic vegetation particularly rooted and emergent species should be promoted because it improves water quality and reduces algal bloom [191]. However, periodic harvesting of macrophytes is necessary in wetlands to take off large amounts of nutrients incorporated in macrophytes. This also reduces the possibility of water body re-pollution caused by decomposition [192]. For example, based on biomass and decomposition rates of different macrophytes, *Azolla pinnata* and *Trapa bispinosa* are capable of releasing large amount of nitrogen (136.kg ha yr^{-1}) and phosphorous (5.45 kg ha y^{-1}) respectively, along with other nutrients such as calcium and magnesium [193].

4.7. Recovery of costs and reinvestment in urban systems

In order to ensure the continuous functioning and sustainability of urban systems, we need to recover the costs of services such as wastewater treatment, municipal solid waste management and maintenance of urban green infrastructure from residents, and the money so recovered be used for the proper functioning and maintenance of these systems [158, 175]. Transition to a green urban economy now requires a fundamental shift in the design of policy and institutions and in the organization of economic activities so as to enhance efficiency and reduce unsustainable practices. Financial, economic, and market instruments need to be aligned to provide incentives to enhance energy efficiency, encourage recycling and reuse, and greening the urban economy. This necessitates a new role for the governments, moving from its traditional command and control approach towards a market-based economic approach by creating a conductive environment for the proper functioning and interactions of markets, the private sector and other stakeholders [175, 194].

4.8. Institutions, Governance and Collaboration

In order to address complex problem of lake restoration we will require the establishment of new, adaptive, and innovative institutional arrangements that can deal with restoration as well as coordination. Key institutional mechanism that needs to be in place for implementation of restoration of lake Anasagar relates to meaningful and administratively-binding coordination among different agencies and departments that would be involved in implementation. All these departments can report, on the lake restoration issue, to a single agency constituted to look after all aspects of the lake. In addition, a clearly defined policy statement on the management and sustainability of lakes would also help in coherent action.

5. Conclusion

Drawing on the scientific, experiential and traditional knowledge, this report provides an evidence-based strategy for restoration of lake Anasagar. There are multiple stressors degrading the Lake Anasagar including disposal of raw sewage and municipal wastewater, discharge of detergents, discharge of residual pesticides and chemical fertilizers, sedimentation due to soil erosion in the catchment, and challenges of land ownership and encroachment. In order to address these challenges and stressors, a holistic restoration strategy has been proposed for Lake. The key interventions suggested here are waste and sewage management, forest restoration in the watershed, sequential restoration of vegetation in sand dunes, management of urban green infrastructure, periodic sediment removal from lake, macrophyte restoration in littoral zone of lake, recovery of full costs of, and reinvestment in, urban services, and appropriate institutions, governance and collaboration.

It is our firm opinion that the report contains practical, useful and usable knowledge. The suggestions contained in the report are both evidence-based as well as sensitive to the fact linking knowledge to action is a complex task requiring administrative will, resources and long-term engagement by stakeholders. Each suggestion would need to be developed into action plans for field implementation, accounting for already ongoing actions, for detailed implementation by departments and organizations responsible for the affairs of the lake.

References

[1] Pandey DN. Lake Anasagar, Ajmer: Abstracts of some published research. RSPCB, Jaipur, Rajasthan; 2013.

[2] Sharma V, Kumawat R, Meena D, Yadav D, Sharma K. Record of Tailed Jay Butterfly Graphium agamemnon (Linnaeus, 1758)(Lepidoptera, Papilionidae) from central Aravalli foothills, Ajmer, Rajasthan, India. Journal on New Biological Reports. 2012;1:17-20.

[3] Jain S, Sharma G, Y.P.Mathur. Effects of pesticides on hormone and enzyme systems of aqua population: a view over Anasagar lake, Ajmer. IOSR Journal Of Environmental Science, Toxicology And Food Technology. 2012;1:24-8.

[4] Koli VK, Ranga MM. Physicochemical status and primary productivity of Ana Sagar Lake, Ajmer (Rajasthan), India. Universal Journal of Environmental Research and Technology. 2011;1:286-92.

[5] Dubey S, Koli VK, Bhatnagar C, Yaseen M. Primary productivity of Ana Sagar lake, Ajmer, Rajasthan. Proceedings of the Ninety Eighth Session of the Indian Science Congress, Chennai2011.

[6] Praveen M, Sangeeta P, Kriti S, Yati K. Identification and classification of some freshwater invertebrates in Anasagar lake of Ajmer. Current World Environment. 2010;5:137-41.

[7] Khare P, Chaudary N. Remote sensing and GI system in environmental sampling: Case study of Anasagar lake (Rajasthan) India: LAP LAMBERT Academic Publishing (June 4, 2010) 2010.

[8] Charan PD, Renu S, Sharma KC. Gas chromatographie analysis of organochlorine pesticides in lake Anasagar of Ajmer, Rajasthan (India). Journal of Environmental Science and Engineering. 2010;52:37-40.

[9] Sharma KC, Charan PD, Nag M. An integrated restoration plan for Lake Anasagar: A threatened water body of Ajmer, Rajasthan, India. Proceedings of 13th World Lake Conference, 1-5 November, Wuhan, China (wldbilecorjp/data/ilec/WLC13_Papers): http://wldb.ilec.or.jp/data/ilec/WLC13_Papers/others/23.pdf; 2009.

[10] Sharma K, Chouhan C, Charan P, Nag M. Water quality and restoration practices of lake Budha Pushkar - a threatened water body of Ajmer, Rajasthan. Ecoscan. 2009;3:53-8.

[11] Mathur P, Patan S, Sharma K, Nair N, Shobhawat A. Assessment of physico-chemical properties of Anasagar Lake of Ajmer (India). Journal of Environmental Research and Development. 2009;4:780-6.

[12] Jat M, Khare D, Garg P. Urbanization and its impact on groundwater: a remote sensing and GIS-based assessment approach. The Environmentalist. 2009;29:17-32.

[13] GOR. Environmental Management Guidelines and Action Plan of SWRPD for Water Sector in Rajasthan. State Water Resources Planning Department, Sinchai Bhawan, J.L.N. Marg, Jaipur, Rajasthan; 2009.

[14] Sharma K, Chouhan C. Ecology and Restoration of Lake Budha Pushkar–A Threatened Water Body of Ajmer, Rajasthan. 2008.
[15] Jat MK, Garg PK, Khare D. Monitoring and modelling of urban sprawl using remote sensing and GIS techniques. International Journal of Applied Earth Observation and Geoinformation. 2008;10:26-43.
[16] Charan PD, Patni A, Sharma KC. Pesticide contamination in lake anasagar of Ajmer, Rajasthan. Proceedings of Taal2007: The 12th World Lake Conference: 360-365 Available at http://wldbilecorjp/data/ilec/wlc12/B%20-%20Water%20Quality/B-33pdf2007.
[17] Charan PD, Patni A, Sharma K. Pesticide Contamination in Lake Anasagar of Ajmer, Rajasthan. Proceedings of Taal2007: The 12th World Lake Conference2007. p. 365.
[18] GOR. Government of Rajasthan City Development Plan For Ajmer & Pushkar. Govt. of Rajasthan, Jaipur. Available at http://jnnurm.nic.in/nurmudweb/toolkit/final_CDPAjmer-Pushkar.pdf; 2006.
[19] Singh RP, Mathur P. Studies on a polluted lentic waterbody (Anasagar Lake) of Ajmer, with special reference to its physicochemical and biological status. In: Mathur SM, Mathur AN, Trivedy RK, Bhatt YC, Mohnot P, editors. Aquatic weeds: problems, control and management. Udaipur: Himanshu Publications; 2005. p. 113-20.
[20] Singh RP, Mathur P. Investigation of variations in physico-chemical characteristics of a fresh water reservoir of Ajmer city, Rajasthan. Indian Journal of Environmental Sciences. 2005;9:57-61.
[21] Pandey DN, Gupta AK, Anderson DM. Rainwater harvesting as an adaptation to climate change. Current Science. 2003;85:46-59.
[22] Rathore MS, Reddy VR, Ramanathan S. Urban Water Supply in Rajasthan: Problems and Prospects. Economic and Political Weekly. 1994;29:2272-4.
[23] Sharma KC, Sharma R. Algal diversity in the littoral zone of a polluted shallow lake at Ajmer, Rajasthan. International Journal of Ecology & Environmental Sciences. 1992;18:139-46.
[24] Yatindra, Mathur BN. Studies on a new species of Myxidium (Protozoa: Myxozoa: Myxosporea) from a freshwater teleost fish Cirrhina reba (Ham). Uttar Pradesh Journal of Zoology. 1988;8:43-8.
[25] D'Rozario A. On four new species of cercariae. A contribution to Sewell's evolutionary scheme. Parasitology. 1939;31:285-98.
[26] Carpenter SR, Cole JJ, Pace ML, Batt R, Brock WA, Cline T, et al. Early warnings of regime shifts: A whole-ecosystem experiment. Science. 2011;332:1079-82.
[27] Davis J, Sim L, Chambers J. Multiple stressors and regime shifts in shallow aquatic ecosystems in antipodean landscapes. Freshwater Biology. 2010;55:5-18.
[28] Scheffer M, Carpenter S, Foley JA, Folke C, Walker B. Catastrophic shifts in ecosystems. Nature. 2001;413:591-6.
[29] Blindow I, Andersson G, Hargeby A, Johansson S. Long-term pattern of alternative stable states in two shallow eutrophic lakes. Freshwater Biology. 1993;30:159-67.
[30] Scheffer M, Carpenter SR. Catastrophic regime shifts in ecosystems: Linking theory to observation. Trends in Ecology and Evolution. 2003;18:648-56.
[31] Genkai-Kato M. Regime shifts: Catastrophic responses of ecosystems to human impacts. Ecological Research. 2007;22:214-9.
[32] Junk W, An S, Finlayson CM, Gopal B, Květ J, Mitchell S, et al. Current state of knowledge regarding the world’s wetlands and their future under global climate change: a synthesis. Aquat Sci. 2013;75:151-67.

[33] Gopal B. Future of wetlands in tropical and subtropical Asia, especially in the face of climate change. Aquat Sci. 2013;75:39-61.
[34] Reddy MS, Char NVV. Management of lakes in India. Lakes & Reservoirs: Research & Management. 2006;11:227-37.
[35] Pandey DN, Chaubey AC, Gupta AK, Vardhan H. Mine spoil restoration: A strategy combining rainwater harvesting and adaptation to random recurrence of droughts in Rajasthan. International Forestry Review. 2005;7:241-9.
[36] Swarnalatha K, Letha J, Ayoob S. An investigation into the heavy metal burden of Akkulam-Veli Lake in south India. Environmental Earth Sciences. 2012:1-12.
[37] Suresh G, Sutharsan P, Ramasamy V, Venkatachalapathy R. Assessment of spatial distribution and potential ecological risk of the heavy metals in relation to granulometric contents of Veeranam lake sediments, India. Ecotoxicology and Environmental Safety. 2012.
[38] Sheela AM, Letha J, Joseph S, Thomas J. Assessment of heavy metal contamination in coastal lake sediments associated with urbanization: Southern Kerala, India. Lakes and Reservoirs: Research and Management. 2012;17:97-112.
[39] Sheela AM, Letha J, Joseph S, Chacko M, Sanal kumar SP, Thomas J. Water quality assessment of a tropical coastal lake system using multivariate cluster, principal component and factor analysis. Lakes and Reservoirs: Research and Management. 2012;17:143-59.
[40] Sebastian G, Thomas M, Mathew TV, Meenakshi S. Some sedimentological aspects of vemband lake in Lerala, India. Pollution Research. 2012;31:261-6.
[41] Pushpangadan SB, Nair CR. Impact of environmental pollutants on microbial load (pathogens) in Akkulam-Veli Lake. Pollution Research. 2012;31:107-9.
[42] Paneer Selvam A, Laxmi Priya S, Banerjee K, Hariharan G, Purvaja R, Ramesh R. Heavy metal assessment using geochemical and statistical tools in the surface sediments of Vembanad Lake, Southwest Coast of India. Environmental Monitoring and Assessment. 2012;184:5899-915.
[43] Massar B, Dey S, Barua R, Dutta K. Microscopy and microanalysis of hematological parameters in common carp, Cyprinus carpio, inhabiting a polluted lake in North East India. Microscopy and Microanalysis. 2012;18:1077-87.
[44] Kra Essi KF, Agboue A, Amissa A, Yobou B, Trokourey A. Study of lakes waters pollution in the city of Yamoussoukro and their impact on industrial boiler. International Journal of Applied Engineering Research. 2012;7:535-48.
[45] Gandhimathi A, Meenambal T. Spatial prediction of heavy metal pollution for soils in Coimbatore, India based on ANN and kriging model. European Journal of Scientific Research. 2012;79:198-207.
[46] Das S, Unni B, Bhattacharjee M, Wann SB, Rao PG. Toxicological effects of arsenic exposure in a freshwater teleost fish, Channa punctatus. African Journal of Biotechnology. 2012;11:4447-54.
[47] Bhatnagar MK, Singh M, Bhatnagar P, Tripathp A. Physico-chemical analysis of some water samples in rewa city (M.P.), India. Pollution Research. 2012;31:213-5.
[48] Bhat MS, Ali M. Physico-chemical characteristics of bod dal basin of dal lake, Kashmir, India. Journal of Industrial Pollution Control. 2012;28:177-81.
[49] Reddy MV, Babu KS, Balaram V, Satyanarayanan M. Assessment of the effects of municipal sewage, immersed idols and boating on the heavy metal and other elemental pollution of surface water of the eutrophic Hussainsagar Lake (Hyderabad, India). Environmental Monitoring and Assessment. 2012;184:1991-2000.

[50] Najar IA, Khan AB. Assessment of water quality and identification of pollution sources of three lakes in Kashmir, India, using multivariate analysis. Environmental Earth Sciences. 2012;66:2367-78.
[51] Magarde V, Iqbal SA, Zaafarany I, Iqbal N. Pollution status with reference to microbiological aspects of Upper Lake, Bhopal, India. Journal of Pure and Applied Microbiology. 2012;6:903-11.
[52] Govil PK, Sorlie JE, Sujatha D, Krishna AK, Murthy NN, Mohan KR. Assessment of heavy metal pollution in lake sediments of Katedan Industrial Development Area, Hyderabad, India. Environmental Earth Sciences. 2012;66:121-8.
[53] Singare PU, Bhanage SV, Lokhande RS. Study on water pollution along the Kukshet Lakes of Nerul, Navi Mumbai, India with special reference to pollution due to heavy metals. International Journal of Global Environmental Issues. 2011;11:79-90.
[54] Najar IA, Khan AB. Assessment of pollution status of Khushalsar Lake, Kashmir, India, using multivariate stastistical techniques. Pollution Research. 2011;30:241-6.
[55] Zutshi B, Prasad SGR, Nagaraja R. Alteration in hematology of Labeo rohita under stress of pollution from Lakes of Bangalore, Karnataka, India. Environmental Monitoring and Assessment. 2010;168:11-9.
[56] Magarde V, Iqbal SA, Iqbal N. Pollution study of Upper Lake of Bhopal, India. Journal of Pure and Applied Microbiology. 2009;3:743-6.
[57] Jumbe AS, Nandini N, Tandon S. Legal aspects of surface water pollution in India: an overview of existing statutory frameworks in management of lake ecosystems. Proceedings of Taal2007: The 12th World Lake Conference2008. p. 1148.
[58] Dixit S, Tiwari S. Impact assessment of heavy metal pollution of Shahpura Lake, Bhopal, India. International Journal of Environmental Research. 2008;2:37-42.
[59] Padmanabha B, Belagali SL. Diversity indices of rotifers for the assesment of pollution in the lakes of Mysore city, India. Pollution Research. 2007;26:63-6.
[60] Karunasagar D, Balarama Krishna MV, Anjaneyulu Y, Arunachalam J. Studies of mercury pollution in a lake due to a thermometer factory situated in a tourist resort: Kodaikkanal, India. Environmental Pollution. 2006;143:153-8.
[61] Das BK. Environmental pollution impact on water and sediments of Kumaun lakes, Lesser Himalaya, India: A comparative study. Environmental Geology. 2005;49:230-9.
[62] Shrivastava P, Saxena A, Swarup A. Heavy metal pollution in a sewage-fed lake of Bhopal, (M. P.) India. Lakes and Reservoirs: Research and Management. 2003;8:1-4.
[63] Sharma RK, Rathore V. Pollution ecology with reference to commercially important fisheries prospect in a rural based water body: The Lake Sarsai Nawar, Etawah in U.P. (India). Pollution Research. 2000;19:641-4.
[64] Prakasam VR, Joseph ML. Water quality of Sasthamcotta lake, Kerala (India) in relation to primary productivity and pollution from anthropogenic sources. Journal of Environmental Biology. 2000;21:305-7.
[65] Govil PK, Reddy GLN, Gnaneswara Rao T. Environmental pollution in India: Heavy metals and radiogenic elements in Nacharam Lake. Journal of Environmental Health. 1999;61:23-8.
[66] Das BK. Environmental pollution of Udaisagar lake and impact of phosphate mine, Udaipur, Rajasthan, India. Environmental Geology. 1999;38:244-8.
[67] Ali MB, Tripathi RD, Rai UN, Pal A, Singh SP. Physico-chemical characteristics and pollution level of Lake Nainital (U.P., India): Role of macrophytes and phytoplankton in biomonitoring and phytoremediation of toxic metal ions. Chemosphere. 1999;39:2171-82.

[68] Gupta PK, Pant MC. Macrobenthos of Lake Naini Tal (U.P., India) with particular reference to pollution. Water, Air, and Soil Pollution. 1983;19:397-405.
[69] Pant MC, Gupta PK, Pande J. Aspects of water pollution in Lake Naini Tal, U.P., India. Environmental Conservation. 1981;8:113-7.
[70] Rao VVSG. Restoration of Urban Lakes in the NE Musi Basin, Hyderabad, India. In: Bengtsson L, Herschy R, Fairbridge R, editors. Encyclopedia of Lakes and Reservoirs: Springer Netherlands; 2012. p. 668-72.
[71] Sundararajan N, Sankaran S, Al-Hosni TK. Vertical electrical sounding (VES) and multi-electrode resistivity in environmental impact assessment studies over some selected lakes: a case study. Environmental Earth Sciences. 2011:1-15.
[72] Priya KL, Jennifer G, Thankam GL, Thankam SA, Mathew M. Monitoring the pollution intensity of wetlands of Coimbatore, Tamil Nadu, India. Nature Environment and Pollution Technology. 2011;10:447-54.
[73] Puri PJ, Yenkie MKN, Battalwar DG, Gandhare NV, Dhanorkar DB. Study and interpretation of physico-chemical characteristic of lake water quality in Nagpur city (India). Rasāyan Journal of Chemistry. 2010;3:800-10.
[74] Jain CK, Gurunadha Rao VVS, Prakash BA, Mahesh Kumar K, Yoshida M. Metal fractionation study on bed sediments of Hussainsagar Lake, Hyderabad, India. Environmental Monitoring and Assessment. 2010;166:57-67.
[75] Anu, Upadhyaya SK, Bajpai A. Impact of urbanization on lower lake of Bhopal (M.P.) India. Pollution Research. 2010;29:589-92.
[76] Yeung LWY, Yamashita N, Taniyasu S, Lam PKS, Sinha RK, Borole DV, et al. A survey of perfluorinated compounds in surface water and biota including dolphins from the Ganges River and in other waterbodies in India. Chemosphere. 2009;76:55-62.
[77] Magarde V, Iqbal SA, Pani S, Iqbal N. Impact of developmental activities on bio-diversity of a Central Indian wetland: Lesson learned. Biomedical and Pharmacology Journal. 2009;2:369-74.
[78] Zutshi B, Prasad SGR. Impact of pollution on fresh- and marine water resources - A review. Pollution Research. 2008;27:461-6.
[79] Rao EN. From poison ponds to pleasure spots: The restoration of Hyderabad lakes. In: Carpenter DO, editor.2008. p. 129-34.
[80] Jain CK, Malik DS, Yadav R. Metal fractionation study on bed sediments of Lake Nainital, Uttaranchal, India. Environmental Monitoring and Assessment. 2007;130:129-39.
[81] Kiran BR, Shashi Shekhar TR, Puttaiah ET, Shivaraj Y. Trace metal levels in the organs of finfish Oreochromis mossambicus (Peter) and relevant water of Jannapura Lake, India. Journal of Environmental Science and Engineering. 2006;48:15-20.
[82] Sujatha SD, Sathyanarayanan S, Satish PN, Nagaraju D. A sewage and sludge treated lake and its impact on the environment, Mysore, India. Environmental Geology. 2001;40:1209-13.
[83] Menon NN, Balchand AN, Menon NR. Hydrobiology of the Cochin backwater system - A review. Hydrobiologia. 2000;430:149-83.
[84] Unni PN, Nair SR. Environmental issues in Vembanad estuary due to salinity and flood control structures. Tampa, FL, USA: ASCE; 1995. p. 549-50.
[85] Kulshrestha SK. Conservation of lakes & wetlands in India. Growth, development and natural resource conservation. 1991:259-76.
[86] Singh J, Upadhyay SK, Pathak RK, Gupta V. Accumulation of heavy metals in soil and paddy crop (Oryza sativa), irrigated with water of Ramgarh Lake, Gorakhpur, UP, India. Toxicological and Environmental Chemistry. 2011;93:462-73.

[87] Sabale S, Jadhav V, Jadhav D, Mohite BS, Patil KJ. Lake contamination by accumulation of heavy metal ions in Eichhornia crassipes : A case study of Rankala Lake Kolhapur (India). Journal of Environmental Science and Engineering. 2010;52:155-6.
[88] Kamala Kannan S, Prabhu Dass Batvari B, Devarajan P, Periakali P, Krishnamoorthy R, Rajeshwara Rao N, et al. A preliminary study on herbal resources and their contamination with toxic heavy metals around pulicat lake, North Chennai, South east coast of India. Research Journal of Environmental Toxicology. 2010;4:178-84.
[89] Zachmann DW, Mohanti M, Treutler HC, Scharf B. Assessment of element distribution and heavy metal contamination in Chilika Lake sediments (India). Lakes and Reservoirs: Research and Management. 2009;14:105-25.
[90] Kamala-Kannan S, Prabhu Dass Batvari B, Lee KJ, Kannan N, Krishnamoorthy R, Shanthi K, et al. Assessment of heavy metals (Cd, Cr and Pb) in water, sediment and seaweed (Ulva lactuca) in the Pulicat Lake, South East India. Chemosphere. 2008;71:1233-40.
[91] Batvari BPD, Kamala-Kannan S, Shanthi K, Krishnamoorthy R, Lee KJ, Jayaprakash M. Heavy metals in two fish species (Carangoidel malabaricus and Belone stronglurus) from Pulicat Lake, North of Chennai, Southeast Coast of India. Environmental Monitoring and Assessment. 2008;145:167-75.
[92] Vardanyan LG, Ingole BS. Studies on heavy metal accumulation in aquatic macrophytes from Sevan (Armenia) and Carambolim (India) lake systems. Environment International. 2006;32:208-18.
[93] Amaraneni SR. Distribution of pesticides, PAHs and heavy metals in prawn ponds near Kolleru lake wetland, India. Environment International. 2006;32:294-302.
[94] Krishnakumar A, Sobha V, Padmalal D. Status of nutrients and heavy metals in the recently deposited sediments of Vellayani freshwater lake, Kerala, south west coast of India. Ecology, Environment and Conservation. 2005;11:235-40.
[95] Gupta SK, Dixit S, Tiwari S. Assessment of heavy metals in surface water of Lower lake, Bhopal, India. Pollution Research. 2005;24:805-8.
[96] Wilander A, Persson G. Recovery from eutrophication: Experiences of reduced phosphorus input to the four largest lakes of Sweden. Ambio. 2001;30:475-85.
[97] Wang H, Wang H. Mitigation of lake eutrophication: Loosen nitrogen control and focus on phosphorus abatement. Progress in Natural Science. 2009;19:1445-51.
[98] Vadeboncoeur Y, Jeppesen E, Vander Zanden MJ, Schierup HH, Christoffersen K, Lodge DM. From Greenland to green lakes: Cultural eutrophication and the loss of benthic pathways in lakes. Limnology and Oceanography. 2003;48:1408-18.
[99] Schelske CL, Stoermer EF, Conley DJ, Robbins JA, Glover RM. Early eutrophication in the lower great lakes: New evidence from biogenic silica in sediments. Science. 1983;222:320-2.
[100] Ryding SO, Rast W. The control of eutrophication of lakes and reservoirs. The control of eutrophication of lakes and reservoirs. 1989.
[101] Moss B. Engineering and biological approaches to the restoration from eutrophication of shallow lakes in which aquatic plant communities are important components. Hydrobiologia. 1990;200-201:367-77.
[102] Lau SSS, Lane SN. Biological and chemical factors influencing shallow lake eutrophication: A long-term study. Science of the Total Environment. 2002;288:167-81.
[103] Jørgensen SE. A eutrophication model for a lake. Ecological Modelling. 1976;2:147-65.

[104] Jin X, Xu Q, Huang C. Current status and future tendency of lake eutrophication in China. Science in China Series C, Life sciences / Chinese Academy of Sciences. 2005;48 Spec No:948-54.
[105] Hough RA, Fornwall MD, Negele BJ, Thompson RL, Putt DA. Plant community dynamics in a chain of lakes: principal factors in the decline of rooted macrophytes with eutrophication. Hydrobiologia. 1989;173:199-217.
[106] Havens KE, Aumen NG, James RT, Smith VH. Rapid ecological changes in a large subtropical lake undergoing cultural eutrophication. Ambio. 1996;25:150-5.
[107] Gulati RD, Van Donk E. Lakes in the Netherlands, their origin, eutrophication and restoration: State-of-the-art review. Hydrobiologia. 2002;478:73-106.
[108] Forsberg C, Ryding SO. Eutrophication parameters and trophic state indices in 30 Swedish waste-receiving lakes. Archiv fur Hydrobiologie. 1980;89:189-207.
[109] Feuchtmayr H, Moran R, Hatton K, Connor L, Heyes T, Moss B, et al. Global warming and eutrophication: Effects on water chemistry and autotrophic communities in experimental hypertrophic shallow lake mesocosms. Journal of Applied Ecology. 2009;46:713-23.
[110] Douglas MSV, Smol JP. Eutrophication and recovery in the high Arctic: Meretta Lake (Cornwallis Island, Nunavut, Canada) revisited. Hydrobiologia. 2000;431:193-204.
[111] Carpenter SR, Christensen DL, Cole JJ, Cottingham KL, He X, Hodgson JR, et al. Biological control of eutrophication in lakes. Environmental Science and Technology. 1995;29:784-6.
[112] Schindler DW, Hecky RE, Findlay DL, Stainton MP, Parker BR, Paterson MJ, et al. Eutrophication of lakes cannot be controlled by reducing nitrogen input: Results of a 37-year whole-ecosystem experiment. Proceedings of the National Academy of Sciences of the United States of America. 2008;105:11254-8.
[113] Carpenter SR, Ludwig D, Brock WA. Management of eutrophication for lakes subject to potentially irreversible change. Ecological Applications. 1999;9:751-71.
[114] Schindler DW. Eutrophication and recovery in experimental lakes: implications for lake management. Science. 1974;184:897-9.
[115] Qin B. Lake eutrophication: Control countermeasures and recycling exploitation. Ecological Engineering. 2009;35:1569-73.
[116] Smith VH, Schindler DW. Eutrophication science: where do we go from here? Trends in Ecology and Evolution. 2009;24:201-7.
[117] Conley DJ, Paerl HW, Howarth RW, Boesch DF, Seitzinger SP, Havens KE, et al. Controlling eutrophication: Nitrogen and phosphorus. Science. 2009;323:1014-5.
[118] Hinesly TD, Jones RL. Phosphorus in waters from sewage sludge amended lysimeters. Environmental Pollution. 1990;65:293-309.
[119] Khan F, Ansari A. Eutrophication: An ecological vision. Bot Rev. 2005;71:449-82.
[120] Hu MH, Ao YS, Yang XE, Li TQ. Treating eutrophic water for nutrient reduction using an aquatic macrophyte (Ipomoea aquatica Forsskal) in a deep flow technique system. Agricultural Water Management. 2008;95:607-15.
[121] Topcu A, Pulatsü S. Phosphorus fractions in sediment profiles of the eutrophic Lake Mogan, Turkey. Fresenius Environmental Bulletin. 2008;17:164-72.
[122] Ul Solim S, Wanganeo A. Excessive phosphorus loading to Dal Lake, India: Implications for managing shallow eutrophic lakes in urbanized watersheds. International Review of Hydrobiology. 2008;93:148-66.
[123] Schindler DW. The dilemma of controlling cultural eutrophication of lakes. Proceedings of the Royal Society B: Biological Sciences. 2012;279:4322-33.

[124] Solim SU, Wanganeo A. Factors influencing release of phosphorus from sediments in a high productive polymictic lake system. Water Science and Technology. 2009;60:1013-23.
[125] Karanam PV, Wani SP, Sahrawat KL, Jangawad LS. Economic evaluation of sediments as a source of plant nutrients. Current Science. 2008;95:1042-50.
[126] Søndergaard M, Jeppesen E, Lauridsen TL, Skov C, Van Nes EH, Roijackers R, et al. Lake restoration: Successes, failures and long-term effects. Journal of Applied Ecology. 2007;44:1095-105.
[127] Temporetti PF, Pedrozo FL. Phosphorus release rates from freshwater sediments affected by fish farming. Aquaculture Research. 2000;31:447-55.
[128] Turner BL, Kasperson RE, Matsone PA, McCarthy JJ, Corell RW, Christensene L, et al. A framework for vulnerability analysis in sustainability science. Proceedings of the National Academy of Sciences of the United States of America. 2003;100:8074-9.
[129] Turner BL. Vulnerability and resilience: Coalescing or paralleling approaches for sustainability science? Global Environmental Change. 2010;20:570-6.
[130] Pahl-Wostl C, Mostert E, Tabara D. The growing importance of social learning in water resources management and sustainability science. Ecology and Society. 2008;13.
[131] Kates RW, Clark WC, Corell R, Hall JM, Jaeger CC, Lowe I, et al. Sustainability science. Science. 2001;292:641-2.
[132] Kajikawa Y. Research core and framework of sustainability science. Sustainability Science. 2008;3:215-39.
[133] Clark WC, Dickson NM. Sustainability science: The emerging research program. Proceedings of the National Academy of Sciences of the United States of America. 2003;100:8059-61.
[134] Anderies JM, Rodriguez AA, Janssen MA, Cifdaloz O. Panaceas, uncertainty, and the robust control framework in sustainability science. Proceedings of the National Academy of Sciences of the United States of America. 2007;104:15194-9.
[135] Compendium of Pollution Control Acts, Rules - Central Pollution Control Board, New Delhi. http://www.cpcb.nic.in/NewItem_19_PollutionControlLaw.pdf.
[136] Sivaramakrishnan K. Environment, law, and democracy in India. Journal of Asian Studies. 2011;70:905-28.
[137] Saheb SU, Seshaiah S, Viswanath B. Environment and their legal issues in India. International Research Journal of Environment Sciences. 2012;1:44-51.
[138] Rajamani L. Public interest environmental litigation in India: Exploring issues of access, participation, equity, effectiveness and sustainability. Journal of Environmental Law. 2007;9:293-321.
[139] Amirante D. Environmental courts in comparative perspective: Preliminary reflections on the National Green Tribunal of India. Pace Envtl L Rev. 2011;29:441.
[140] Abraham CM. The Indian judiciary and the development of environmental law. South Asia Research. 1991;11:61-9.
[141] Nelivigi NS, Poojitha MG, Rosencranz A. The judiciary and the environment: recent trends and developments. Environmental Policy & Law. 1993;23:102-8.
[142] Rajamani L. The right to environmental protection in India: Many a slip between the cup and the lip? Review of European Community & International Environmental Law. 2007;16:274-86.
[143] Faure MG, Raja AV. Effectiveness of environmental public interest litigation in India: Determining the key variables. Fordham Environmental Law Review. 2010;21:239-94.
[144] Rosencranz A, Sahu G, Raghuvanshi V. Whither the National Environment Appellate Authority? Economic & Political Weekly. 2009;44:10-4.

[145] Zahawi RA, Augspurger CK. Tropical forest restoration: Tree islands as recruitment foci in degraded lands of Honduras. Ecological Applications. 2006;16:464-78.
[146] Zahawi RA. Instant trees: Using giant vegetative stakes in tropical forest restoration. Forest Ecology and Management. 2008;255:3013-6.
[147] Wunderle Jr JM. The role of animal seed dispersal in accelerating native forest regeneration on degraded tropical lands. Forest Ecology and Management. 1997;99:223-35.
[148] Parrotta JA, Turnbull JW, Jones N. Catalyzing native forest regeneration on degraded tropical lands. Forest Ecology and Management. 1997;99:1-7.
[149] Lamb D, Erskine PD, Parrotta JA. Restoration of degraded tropical forest landscapes. Science. 2005;310:1628-32.
[150] de Graff JV, Sidle RC, Ahmad R, Scatena FN. Recognizing the importance of tropical forests in limiting rainfall-induced debris flows. Environmental Earth Sciences. 2012;67:1225-35.
[151] Chazdon RL. Tropical forest recovery: Legacies of human impact and natural disturbances. Perspectives in Plant Ecology, Evolution and Systematics. 2003;6:51-71.
[152] Singh G, Rathod TR, Komara SS, Limba NK. Rainwater harvest influences habitat heterogeneity, nutrient build up and herbage biomass production in Aravalli Hills of Rajasthan, India. Tropical Ecology. 2012;54:73-88.
[153] Vieira DLM, Scariot A. Principles of natural regeneration of tropical dry forests for restoration. Restoration Ecology. 2006;14:11-20.
[154] Khurana E, Singh JS. Ecology of seed and seedling growth for conservation and restoration of tropical dry forest : A review. Environmental Conservation. 2001;28:39-52.
[155] Singh VS, Pandey DN, Prakash NP. What determines the success of joint forest management? Science-based lessons on sustainable governance of forests in India. Resources, Conservation and Recycling. 2011;56:126-33.
[156] Pandey DN. Ethnoforestry and sustainability science for JFM. In: Bahuguna VK, Mitra K, Capistrano D, Saigal S, editors. Root to Canopy: Regenerating Forests through Community-State Partnerships. New Delhi: Winrock International India/Commonwealth Forestry Association-India Chapter; 2004. p. 195-209.
[157] Pandey DN. Global climate change and carbon management in multifunctional forests. Current Science. 2002;83:593-602.
[158] Pandey DN. A bountiful harvest of rainwater. Science. 2001;293:1763.
[159] Pandey DN. Beyond vanishing woods: participatory survival options for wildlife, forests and people. Udaipur: Himanshu Publications; 1996.
[160] Ojasvi PR, Goyal RK, Gupta JP. The micro-catchment water harvesting technique for the plantation of jujube (Zizyphus mauritiana) in an agroforestry system under arid conditions. Agricultural Water Management. 1999;41:139-47.
[161] Singh G. Soil water dynamics, growth of Dendrocalamus strictus and herbage productivity influenced by rainwater harvesting in Aravalli hills of Rajasthan. Forest Ecology and Management. 2009;258:2519-28.
[162] Sheikh MI, Shah BH, Aleem A. Effect of rainwater harvesting methods on the establishment of tree species. Forest Ecology and Management. 1984;8:257-63.
[163] Singh G. Enhancing growth and biomass production of plantation and associated vegetation through rainwater harvesting in degraded hills in southern Rajasthan, India. New Forests. 2012;43:349-64.
[164] Pandey DN, Prakash NP. Sequential Restoration of Vegetation on Sand Dunes as an Adaptation to Climate Change in Thar Desert. RSPCB, Jaipur; 2013.

[165] Jat MK, Khare D, Garg PK, Shankar V. Remote sensing and GIS-based assessment of urbanisation and degradation of watershed health. Urban Water Journal. 2009;6:251-63.
[166] Dutta S, Pradhan R. Analysis of ground water quality of areas adjacent to Loco and Carriage workshops, Ajmer, Rajasthan. Ecology, Environment and Conservation. 2009;15:265-8.
[167] Verma M, Prakash B. Bacteriological analysis of ground water of Ajmer West, Rajasthan, India. Pollution Research. 2009;28:391-3.
[168] La Rosa D, Privitera R. Characterization of non-urbanized areas for land-use planning of agricultural and green infrastructure in urban contexts. Landscape and Urban Planning. 2013;109:94-106.
[169] Tzoulas K, Korpela K, Venn S, Yli-Pelkonen V, Kaźmierczak A, Niemela J, et al. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. Landscape and Urban Planning. 2007;81:167-78.
[170] Gill SE, Handley JF, Ennos AR, Pauleit S. Adapting Cities for Climate Change: The Role of the Green Infrastructure. Built Environment. 2007;33:115-33.
[171] Benedict MA, McMahon ET. Green infrastructure: smart conservation for the 21st century. Renewable Resources Journal. 2002;20:12-7.
[172] Cameron RWF, Blanuša T, Taylor JE, Salisbury A, Halstead AJ, Henricot B, et al. The domestic garden – Its contribution to urban green infrastructure. Urban Forestry & Urban Greening. 2012;11:129-37.
[173] Mell IC. Can green infrastructure promote urban sustainability? Proceedings of the Institution of Civil Engineers: Engineering Sustainability. 2009;162:23-34.
[174] La Greca P, La Rosa D, Martinico F, Privitera R. Agricultural and green infrastructures: The role of non-urbanised areas for eco-sustainable planning in a metropolitan region. Environmental Pollution. 2011;159:2193-202.
[175] Singh VS, Pandey DN. Sustainable housing: balancing environment with urban growth in India. 11th National Convention on "Sustainable Housing for Masses: Introspection and Way Forward". Vigyan Bhawan, New Delhi, , 7-8 December, 2012.2012.
[176] Singh VS, Pandey DN, Chaudhry P. Urban Forests and Open Green Spaces: Lessons for Jaipur, Rajasthan, India. RSPCB Occasional Paper No 1/2010. Jaipur, Rajasthan, India: Rajasthan State Pollution Control Board; 2010. p. pp. 23.
[177] Udawatta RP, Garrett HE, Kallenbach R. Agroforestry buffers for nonpoint source pollution reductions from agricultural watersheds. Journal of environmental quality. 2011;40:800-6.
[178] Udawatta R, Garrett H, Kallenbach R. Agroforestry and grass buffer effects on water quality in grazed pastures. Agroforestry Systems. 2010;79:81-7.
[179] Singh VS, Pandey DN. Multifunctional Agroforestry Systems in India: Science-Based Policy Options. RSPCB Occasional Paper No 4/2011. Jaipur, Rajasthan, India: Rajasthan State Pollution Control Board; 2011. p. 33.
[180] Pandey DN. Multifunctional agroforestry systems in India. Current Science. 2007;92:455-63.
[181] Pandey DN. Carbon sequestration in agroforestry systems. Climate Policy. 2002;2:367-77.
[182] Verma S, Chalka S, Sharma KC. An assessment of cumulative load of pollutants in ambient air of Ajmer, Rajasthan. Ecology, Environment and Conservation. 2009;15:277-82.
[183] Chalka S, Verma S, Sharma KC. Distribution of major air pollutants in urban environment of Ajmer, Rajasthan. Indian Journal of Environmental Sciences. 2006;10:107-11.

[184] Singh VS, Pandey DN, Gupta AK, Ravindranath NH. Climate Change Impacts, Mitigation and Adaptation: Science for Generating Policy Options in Rajasthan, India. RSPCB Occasional Paper No 2/2010. Jaipur, Rajasthan, India: Rajasthan State Pollution Control Board; 2010. p. 150.
[185] Pandey DN. Sacred Water and Sanctified Vegetation: Tanks and Trees in India. Paper presented at the conference of the International Association for the Study of Common Property (IASCP), in the Panel "Constituting the Riparian Commons". Bloomington, Indiana, USA, 31 May - 4 June2000.
[186] Jeppesen E, Meerhoff M, Jacobsen BA, Hansen RS, Søndergaard M, Jensen JP, et al. Restoration of shallow lakes by nutrient control and biomanipulation - The successful strategy varies with lake size and climate. Hydrobiologia. 2007;581:269-85.
[187] Pandey J, Verma A. The influence of catchment on chemical and biological characteristics of two freshwater tropical lakes of southern Rajasthan. Journal of Environmental Biology. 2004;25:81-7.
[188] Peterson SA. Lake restoration by sediment removal. Journal of the American Water Resources Association. 1982;18:423-36.
[189] Annadotter H, Cronberg G, Aagren R, Lundstedt B, Nilsson PÅ, Ströbeck S. Multiple techniques for lake restoration. Hydrobiologia. 1999;395:77-85.
[190] Qiu D, Wu Z, Liu B, Deng J, Fu G, He F. The restoration of aquatic macrophytes for improving water quality in a hypertrophic shallow lake in Hubei Province, China. Ecological Engineering. 2001;18:147-56.
[191] Gopal B, Sengupta M, Dalwani R, Srivastava SK. Conservation and Management of Lakes – An Indian Perspective. MoEF, Govt. of India, New Delhi; 2010.
[192] Hu L, Hu W, Deng J, Li Q, Gao F, Zhu J, et al. Nutrient removal in wetlands with different macrophyte structures in eastern Lake Taihu, China. Ecological Engineering. 2010;36:1725-32.
[193] Dutta A, Sharma K. Nutrient release potential of some macrophytes of a shallow lake of Ajmer, Rajasthan. Bulletin of the National Institute of Ecology. 2001;11:43-8.
[194] Rasul G. Policy instruments for promoting a green urban economy: the changing role of the state. In: Simpson R, Zimmermann M, editors. The Economy of Green Cities: A World Compendium on the Green Urban Economy: Springer Netherlands; 2013. p. 161-74.

Lake Anasagar, Ajmer
Abstracts of some published research

Charan, P. D., S. Renu and K. C. Sharma (2010). "**Gas chromatographie analysis of organochlorine pesticides in lake Anasagar of Ajmer, Rajasthan (India)**." Journal of Environmental Science and Engineering **52**(1): 37-40.

Anasagar is a perennial, shallow fresh water body which is degraded because of agricultural and other anthropogenic activities, such as input of detergent, sewage disposal, human settlement around the lake etc. In the lake waters as well as in the catchment area, pesticides are being used by the farmers which lead to contamination of water. Gas chromatographic analysis of 120 contaminated water samples collected from the lake was carried out. The organochlorine pesticides recorded in the samples were Heptachlor, ß-HCH, Y-HCH, Aldrin, DDT and Endosulfan. The average ranges of these pesticides were 0.0224ppm, 0.1035ppm, 0.0478ppm, 0.0041ppm, 0.1381ppm and 0.505 lppm, respectively. The study revealed that water of Anasagar is highly contaminated with these synthetic pesticides. Among these agrochemicals, the level of Endosulfan, DDT and Y-HCH were found to be significantly high in the lake. Therefore, the research efforts are needed to conserve the wetland as well as to minimise the impacts of agrochemicals on the lake ecosystem. The paper is also available at Charan, P. D., A. Patni and K. C. Sharma (2007). Pesticide contamination in lake anasagar of Ajmer, Rajasthan. Proceedings of Taal2007: The 12th World Lake Conference: 360-365. Available at http://wldb.ilec.or.jp/data/ilec/wlc12/B%20-%20Water%20Quality/B-33.pdf.

D'Rozario, A. (1939). "**On four new species of cercariae. A contribution to Sewell's evolutionary scheme**." Parasitology **31**(03): 285-298.

1. Two new species of Xiphidiocercariae have been described. These two forms have been designated as C. lühei and C. gopyjungi. 2. The flame-cell formula of C. lüheiis 2 × 3 × 3 = 18 and that of C. gopyjungi is 2 × 4 × 3 = 24. 3. It is shown that C. gopyjungi has the characters of both the subgroups Polyadena (Cort) and Daswan (Sewell), and the group Cercariae armatae is redefined. 4. Further, two new

species of furcocercous cercariae have been described. They have been designated as C. ajmeri and C. anasagari. 5. It has been pointed out that the types of excretory systems as met with in C. ajmeri and C. anasagari are of extreme importance from the evolutionary point of view and fill in gaps in Sewell's (1930) evolutionary scheme. 6. The latter two species have been listed in their proper position in Miller's (1926) scheme of classification of the furcocercous cercariae.

Dubey, S., V. K. Koli, C. Bhatnagar and M. Yaseen (2011). **Primary Productivity of Ana Sagar Lake, Ajmer, Rajasthan**. Proceedings of the Ninety Eighth Session of the Indian Science Congress, Chennai.

Primary productivity and physico-chemical parameters were estimated in Ana Sagar Lake, Ajmer from September 2007 to August 2008. The study indicated that Primary productivity of lake was high (GPP 1.93 to 6.24 gC/m3/day and NPP 0.72 to 4.99 gC/m3/day), which indicate that the lake was in eutrophic category. This productivity was also supported by phosphate (0.14 to 3.2 mg/l), nitrate (14.1 to 26.4 mg/l) and water temperature (16.4 to 28.3ºC).

GOR (2006). **Government of Rajasthan City Development Plan for Ajmer & Pushkar**.

This City Development Plan (CDP) has been prepared for the cities of Ajmer and Pushkar, as part of the initiative of the Government of Rajasthan to access funds from the Jawaharlal Nehru National Urban Renewal Mission (JNNURM). The City Development Plan consists of 3 Sections. Section I provides the background to the City Development Plan and is further broken into 3 parts. Part 1 covers the Trends in Urbanisation and Urban Planning as well as the status of the CDP under the JNNURM. Part 2 covers the rationale for selection of Ajmer-Pushkar as a single urban agglomeration and Part 3 covers the process adopted for the preparation of the CDP. Section II details the development plan for Ajmer, which includes the Vision for the city, development Objectives, sectoral strategies for achieving these objectives and projects to be implemented for executing the strategies. In addition, a Capital Investment Plan and a Financial Operating plan have also been prepared. Section III details the development plan for Pushkar and follows a similar structure as Section II

GOR (2009). **Environmental Management Guidelines and Action Plan of SWRPD for Water Sector in Rajasthan**, State Water Resources Planning Department, Sinchai Bhawan, J.L.N. Marg, Jaipur, Rajasthan.

Environmental Issues in Water Sector issues related to water sector are identified. These issues cover water quality, quantity, demand, extraction, water logging pesticides, forestry, health and impact of construction on water sector. A management plan, policy guidelines etc. are required to take care of these issues. Since these issues are looked after by various departments in the state therefore, an integrated planning of environmental management and related sector specific guidelines are required.

Jain, S., G. Sharma and Y.P.Mathur (2012). "**Effects of Pesticides on hormone and enzyme systems of aqua population: a view over Anasagar lake, Ajmer**." IOSR Journal Of Environmental Science, Toxicology And Food Technology **1**(5): 24-28.

Water contamination by pesticides because of the accumulation and distribution of contaminating substances in sediments of rivers, lakes, and ponds. Potential sources of this impact in water bodies include municipal sewage and agricultural runoff (pesticides and herbicides). The enzyme and hormone disrupting capabilities of pesticides and related chemicals are suspected to be some of the factors contributing to the decline of fish, amphibian and reptile populations of water bodies. In most cases the cause are assumed to result from man-made pollutants in the aquatic environment. The lake Anasagar is a perennial, shallow fresh wetland situated in the heart of Ajmer city. It is degraded because of anthropogenic activities including input of detergents, pesticides and other chemicals due to agricultural activities, sewage disposal and human settlement around the lake. A large area of the catchment of Lake Anasagar is being used for agriculture particularly Trapa bispinosa as the primary cash crop and vegetable crops such as Cauliflower, Tomato, Cabbage, Brinjal, Okra etc leading to input of organo chlorine pesticides in the lake. It was found that water of Anasagar is highly contaminated with these synthetic pesticides. The concentration of organo chlorine was higher in summers than in the rainy season. It has been indicated that many pesticides in the aquatic

environment are capable of disrupting the endocrine systems of aqua life. Some pesticides and related chemicals are persistent in the environment and are accumulated in the fatty tissue of organisms and increase in concentration as they move up through the food web. These chemicals are substances that can cause adverse effects by interfering in some way with the body's hormones or chemical messengers and even disrupting the sexual development of aqua population even at extremely low doses, reducing the cholinesterase activity of amphibians and reptiles, causing disease and reproductive failure in fish populations. Concern over the decline of amphibians globally has highlighted the importance of using this group as a bio indicator of environmental contamination and climate change.

Jat, M., D. Khare and P. Garg (2009). "**Urbanization and its impact on groundwater: a remote sensing and GIS-based assessment approach**." <u>The Environmentalist</u> **29**(1): 17-32.

The perils of unplanned urbanization and increasing pressure of human activities on hydro-geomorphologic system often result in modification of the existing recharge mechanism, which leads to many environmental consequences. In the present research, an attempt has been made to investigate the applicability of remote sensing and geographical information system (GIS) in dealing with spatial and temporal variability of dynamic phenomena, like urbanization and its impact on groundwater. This paper covers primarily, quantitative and qualitative impacts of urban growth on the behavior of aquifer in Ajmer city (India). Urban growth of the Ajmer city in last 17 years has been estimated from the satellite images. Database related to urbanization and groundwater has been created in GIS. Groundwater recharge has been computed using a water balance approach known as Water Level Fluctuation Methodology. Recharge estimation methodology has been implemented in GIS to introduce the spatial variability of hydro-geological characteristics. Further, temporal and spatial variations in groundwater quality and quantity have been correlated with urban growth using overlay analysis in GIS. The study reveals a general decline in water table and quality with urbanization. Further, remote sensing and GIS technologies have been found useful in assessment of spatial and temporal phenomena of urbanization and its impact on groundwater system.

Jat, M. K., P. K. Garg and D. Khare (2008). "**Monitoring and modelling of urban sprawl using remote sensing and GIS techniques**." International Journal of Applied Earth Observation and Geoinformation **10**(1): 26-43.

The concentration of people in densely populated urban areas, especially in developing countries, calls for the use of monitoring systems like remote sensing. Such systems along with spatial analysis techniques like digital image processing and geographical information system (GIS) can be used for the monitoring and planning purposes as these enable the reporting of overall sprawl at a detailed level. In the present work, urban sprawl of the Ajmer city (situated in Rajasthan State of India) has been studied at a mid scale level, over a period of 25 years (1977-2002), to extract the information related to sprawl, area of impervious surfaces and their spatial and temporal variability. Statistical classification approaches have been used for the classification of the remotely sensed images obtained from various sensors viz. Landsat MSS, TM, ETM+ and IRS LISS-III. Urban sprawl and its spatial and temporal characteristics have been derived from the classified satellite images. The Shannon's entropy and landscape metrics (patchiness and map density) have been computed in terms of spatial phenomenon, in order to quantify the urban form (impervious area). Further, multivariate statistical techniques have been used to establish the relationship between the urban sprawl and its causative factors. Results reveal that land development (160.8%) in Ajmer is more than three times the population growth (50.1%). Shannon's entropy and landscape metrics has revealed the spatial distribution of the urban sprawl over a period of last 25 years.

Khare, P. and N. Chaudary (2010). **Remote sensing and GI system in environmental sampling: Case study of Anasagar lake (Rajasthan) India**, LAP LAMBERT Academic Publishing (June 4, 2010)

Environmental threats to Anasagar wetland include pollution, eutrophication, encroachment,siltation, weed infestation, unplanned, aquaculture practices etc.There are causing serious problems for the area and are proving detrimental to the growth of the system: it is noted that, while dissolved oxygen content was low, the conductivity values indicating presence of pollutants was found to be high. Both the

parameters are unsafe for aquatic life. Pollution is being caused from garbage, waste, sewage, detergents,fertilizers etc. from run off processes. This nutrient rich water result in explosive growth of Azolla, Hydrilla,Potamogetion, Vallisneria, etc. Ceratophyllium is well-adapted macrophytes to water rich in inorganic Nitrogen. Trapa is cultivated as a source of food. Pesticides have broadly contiminated natural water resources, which gain entry into the biota of the area where it is represented in a toxic form. With the occurrence of total dried phase during summer in Ana agar truckloads of basin area soil is being taken out after digging the bed. This results in the loss of rich storage of nutrients from the bottom habitat.

Koli, V. K. and M. M. Ranga (2011). "**Physicochemical status and primary productivity of Ana Sagar Lake, Ajmer (Rajasthan), India**." Universal Journal of Environmental Research and Technology **1**(3): 286-292.

Primary productivity and physico-chemical parameters were estimated in Ana Sagar Lake, Ajmer from September 2007 to August 2008. GPP value ranged between 1.93 and 6.24 gC/m2/day, NPP ranged between 0.72 and 4.99 gC/m2/day and Community respiration ranged from 0.26 to 3.6 gC/m2/day. Water temperature varied from 16.4°C to 31.2°C. pH and transparency ranged between 6.7 and 10.2 and 34 cm and 65 cm respectively. Variation in dissolved oxygen (DO) was from 6.7 to 10.7 mg/l. Biological oxygen demand (BOD) and alkalinity varied from 9.2 to 25.2 mg/l and 176 to 264 mg/l. Concentration of nutrients viz. chloride (18.5 to 32.4 mg/l), nitrate (12.9 to 26.4 mg/l) and phosphate (1.2 to 3.2 mg/l) also varied independently. Primary productivity and physico-chemical values of the lake were found high, mainly due to sewage discharged, industrial effluents and the agricultural runoff by surrounding city population. High values of productivity and nutrients also exposed its eutrophic condition.

Mathur, P., P. Sangeeta, S. Kriti, N. Neelima and S. Anand (2009). "**Assessment of physico-chemical properties of Anasagar Lake of Ajmer (India)**." Journal of Environmental Research and Development **4**(3): 780-786.

There are three lakes in Ajmer of which Anasagar is the biggest and has the largest catchment area. The gorgeous man-made Anasagar Lake is situated to the north of the city

of Ajmer. The state of Rajasthan is well known for its desert area and water scarcity. It is situated at 74°38′-74°42′E and 26°25′-26°29′N. The catchment area of lake is 70.55 sq. km, and its circumference is 12.88 sq. km. Sampling of physiochemical factor from various sites on the surface water from Anasagar Lake of Ajmer city was carried out. The aim was to determine the water quality of the lake by studying the physical parameters including temperature, turbidity and electrical conductivity and chemical parameters which include pH, alkalinity, dissolved oxygen, total hardness, chloride, phosphate, conductivity, total dissolved solid, sodium potassium and chemical oxygen demand.

Pandey, D. N., A. K. Gupta and D. M. Anderson (2003). "**Rainwater harvesting as an adaptation to climate change**." Current Science **85**(1): 46-59.

Extreme climate events such as aridity, drought, flood, cyclone and stormy rainfall are expected to leave an impact on human society. They are also expected to generate widespread response to adapt and mitigate the sufferings associated with these extremes. Societal and cultural responses to prolonged drought include population dislocation, cultural separation, habitation abandonment, and societal collapse. A typical response to local aridity is the human migration to safer and productive areas. However, climate and culture can interact in numerous ways. We hypothesize that people may resort to modify dwelling environments by adapting new strategies to optimize the utility of available water by harvesting rain rather than migrating to newer areas. We review recent palaeoclimatological evidence for climate change during the Holocene, and match those data with archaeological and historical records to test our 'climate change-rainwater harvest' hypothesis. We find correlation between heightened historical human efforts for construction of rainwater harvesting structures across regions in response to abrupt climate fluctuations, like aridity and drought. Historical societal adaptations to climate fluctuations may provide insights on potential responses of modern societies to future climate change that has a bearing on water resources, food production and management of natural systems.

Praveen, M., P. Sangeeta, S. Kriti and K. Yati (2010). "**Identification and classification of some freshwater**

invertebrates in Anasagar lake of Ajmer." Current World Environment **5**(1): 137-141.

"Limnology" a new interdisciplinary science with multifarious dimensions has emerged which deals with the study of structural and functional attributes of the lentic fresh water environment and problems associated with them. Limnology has immense and universal significance for the citizen of today, all around the world. Streams, rivers, wetlands and lakes are home for many small animals called macro invertebrates. The term macro invertebrates describe those animals that have no back bone and can be seen with naked eyes. This study includes analysis of identification of invertebrates in Anasagar Lake in Ajmer (Raj.). The methodology employed involves collection and identification of invertebrates with the help of various equipments and tools. The result has been presented in form of a key of freshwater invertebrates of Anasagar Lake of Ajmer.

Rathore, M. S., V. R. Reddy and S. Ramanathan (1994). "**Urban Water Supply in Rajasthan: Problems and Prospects**." Economic and Political Weekly **29**(35): 2272-2274.

The growing problems in providing adequate drinking water to urban populations is a consequence of the lack of long-term planning and inefficient management of urban water usage. Ajmer city is situated almost in the centre of Rajasthan.It lies on the foothills of Aravalli Range. The city is situated in a valley rather than a basin, which it is said was once the bed of Sagaramati river. During the British rule when it became the military headquarters of the British government in this region. The history of modern drinking water supply system started with the British efforts to construct a lake called Foysagar in 1892 which was completed in 1907. After that several projects were taken up but the supply was never adequate to meet the growing water demand of increasing population pressure. The city population increased at the rate of 0.68 per cent during 1981 -91 and 2.12 per cent over 1971-91 The relative low growth of the city is attributed to the water scarcity problem. The shift from surface water systems to ground water supply systems resulted in the neglect of local water bodies or the lakes. Consequently, the ground water recharge capacity in and around the city went down. The massive deforestation in the Aravalli mountains on the city boundary and the catchment areas of the water bodies added to the problem.

It was argued that the three lakes, namely, Anasagar, Foysagar and Pushkar, must be saved from encroachment and maintained at all costs so that the huge investment made in installing large number of handpumps in the city can function. Further, new schemes taken up to solve the city water supply problems, particularly the Bisalpur Project, should be examined and efforts be made to supply water at an early date. There is an urgent need to undertake a large-scale afforestation programme and also measures be taken to check encroachments on the forest land. And, ground water survey of Ajmer city be taken up at an early date to identify the water potential areas and also to know the limitedness of the existing handpumps.

Sharma, A., M. M. Ranga and P. C. Sharma (2010). "**Water Quality Status of Historical Gundolav Lake at Kishangarh as a Primary Data for Sustainable Management**." South Asian Journal of Tourism and Heritage **3**(2): 149-158.

Gundolav Lake is a part of historical, cultural, economical, and recreational life of Kishangarh. It is facing multifold pressure due to urbanization, domestic and industrial waste discharge, bathing and washing, agricultural practices and wetland encroachment. Different study stations at Gundolav Lake exhibited seasonal and inter-site variations in physic-chemical parameters and zooplankton composition. Nala site (Station IV) was found major source point for nutrient entry showing peculiarly high BOD (49.42 mg/l), COD (74.18 mg/l), chloride (282.75 mg/l), sulphate (277.20 mg/l), nitrate (4.32 mg/l), phosphate (12.27 mg/l) and low DO content (3.68 mg/l) signify nutrient enriched status of the lake, favoring high productivity. The eutrophic condition of the lake is clearly indicated by the presence of pollution-indicator species, viz. protozoans (Paramoecium caudatum, Oxytricha ovalis, O. oblongatus, Holophyra simplex and Cyclidium glaucoma) Rotifers (Brachionus calcyflorus, B. forficula, Keratella tropica and K. procurva) and copepods (Neodiaptomus schmackari, Mesocyclops leuckarti and M. hyalinus). Dominance of protozoan and rotiferan communities indicates water quality deterioration and onset of eutrophication at alarming rate.

Sharma, K., C. Chouhan, P. Charan and M. Nag (2009). "**Water quality and restoration practices of lake Budha Pushkar - a**

threatened water body of Ajmer, Rajasthan." Ecoscan **3**(1-2): 53-58.

Lake Budha Pushkar, a threatened water body situated in the Pushkar gap of Aravallis was studied for its water quality and possible restoration practices. The Water quality parameters indicates that values of TDS (1171.20 mg/L), Total Alkalinity (775.0 mg/L), Total Hardness (338.90 mg/L), Calcium Hardness (2640.0 mg/L), Total Solids (2990.0 mg/L), TSS (24480.0 mg/L) are comparatively high. Sediment was analyzed for its use as fertilizer. It has a high content of Macro (NPK) along with (OM) and micronutrients Fe (39.60 ppm), Mn (18.78 ppm), Cu (2.38 ppm), Zn (3.24 ppm), As maximum values and 3-6 times higher than the soils of the area. The maximum values of nitrates and phosphates were 1.53 mg/L and 2.90 mg/L, respectively. Two major causes of its degradation are high rate of sedimentation through sand-fall from nearby sand dunes and agricultural activities at about half of the peripheral area of water body. Agricultural activities have led to high input of N and P fertilizers along with pesticides being used by the farmers. Jal Chetna (campaigh for awareness of water) through public participation launched by the Government proved successful in restoration of lakes.

Sharma, K. C., P. D. Charan and M. Nag. "**An Integrated Restoration Plan for Lake Anasagar: A Threatened Water Body of Ajmer, Rajasthan, India.**" Available at http://wldb.ilec.or.jp/data/ilec/WLC13_Papers/others/23.pdf

The Lake Anasagar is a threatened water body of Ajmer city of Rajasthan. Once the most beautiful lake in North-West part of British India is now extremely polluted because of anthropogenic activities like sewage disposal, cloth washing and agricultural activities. The lake area is being encroached for housing which has reduced water spread. Besides use of chemical fertilizers (-NO3 and -PO4) in the lake corridor, pesticides are used by farmers for aquaculture and cultivation of other crops. Study showed that soil contaminants such as β-HCH, γ-HCH, α-HCH and δ-HCH (> 400 mg/kg) added into the lake have further polluted the lake to a greater extent. The physicochemical characteristics of lake water show hypereutrophic condition. The sedimentation also reduces the water bearing capacity of the lake. An integrated restoration plan proposed for the lake includes catchment area development and lake area

development checking soil erosion, establishment of sewage treatment plant (STP), leasing of peripheral land for green trade units and constructing a circular road for recreation of tourists. An eco-architectural plan for lake area development for sustainability is also proposed which may be applicable to similar lakes in urban areas of Rajasthan.

Sharma, K. C. and R. Sharma (1992). "**Algal diversity in the littoral zone of a polluted shallow lake at Ajmer, Rajasthan**." International Journal of Ecology & Environmental Sciences **18**(2-3): 139-146.

Algal diversity in the littoral zone of Anasagar, a polluted shallow man-made lake influenced by various anthropogenic activities was studied. A total of 123 species belonging to 60 genera were recorded. Sewage-affected site was more conducive to luxuriant growth of algae. Species such as Achnanthes hungarica, Ankistrodesmus falcatus, Chlorella vulgaris, Chlorococcum infusionum, species of Navicula and Oscillatoria, Pandorina morum, Pediastrum tetras, Scenedesmus quadricauda and Stigeoclonium tenue were pollution indicator species. -from Authors

Sharma, V., R. Kumawat, D. Meena, D. Yadav and K. Sharma (2012). "**Record of Tailed Jay Butterfly Graphium agamemnon (Linnaeus, 1758)(Lepidoptera, Papilionidae) from central Aravalli foothills, Ajmer, Rajasthan, India**." Journal on New Biological Reports **1**(1): 17-20.

The first photographic record of the Tailed jay (Graphium agamemnon) from central Aravalli foothills of Ajmer, Rajasthan, India is presented in this paper. On the evening of 26 December, 2011 at around 17.30 hrs during the regular field surveys at the wetlands of central Aravalli foothills of Ajmer we photographed two individuals of butterflies with glittering green coloration and with moderate body size, these were sighted on the vegetation nearby the wetland - Anasagar, which is situated at eastern side of foothills of central Aravalli mountain ranges. At the near by area we found 13 individuals of the same species. Each individual was photographed for further identification process with the help of High Resolution Digital Cameras (Sony DX 50 and Canon D70) and the identification was confirmed by using various field guides (Wynther-Blyth, 1957; Kunte, 2000 and 2001; Kehimkar, 2008).

Singh, R. P. and P. Mathur (2005). "**Investigation of variations in physico-chemical characteristics of a fresh water reservoir of Ajmer city, Rajasthan**." Indian Journal of Environmental Sciences **9**(1): 57-61.

The present study deals with the physico-chemical studies of an ancient but famous fresh water lake 'Ana Sagar' Ajmer, Rajasthan. The parameters selected for the present piece of work were water temperature, pH, dissolved oxygen, transparency, conductivity, total dissolved solids, alkalinity, phosphorus as phosphate, total hardness and nitrates. Data were collected over a period of six months (Nov. 2000 to April 2001). The result obtained in the present investigation showed that this lake was highly polluted, its water was extremely alkaline and the nitrate and phosphates were high in comparison to standard limits (as of an eutrophic lake).

Singh, R. P. and P. Mathur (2005). **Studies on a polluted lentic waterbody (Anasagar Lake) of Ajmer, with special reference to its physicochemical and biological status**. Aquatic weeds: problems, control and management. S. M. Mathur, A. N. Mathur, R. K. Trivedy, Y. C. Bhatt and P. Mohnot. Udaipur, Himanshu Publications**:** 113-120.

The pollution of Anasagar Lake, in Ajmer Rajasthan, India, was studied from September 2002 to February 2003. This lake was highly alkaline, rich in nutrients, and eutrophic in nature. Aquatic weeds, such as Typha, Ipomoea, Azolla, Vallisneria, Trapa and Potamogeton species, were present in this lake in large quantities and were also a cause of concern with regard to sewage pollution. The presence of algae, other aquatic species, and alterations in physicochemical parameters can be the major reasons of pollution of this water body. Biological invasion has also created an alarming condition in this aquatic ecosystem. The main species found in this lake, which also contributed to pollution, were Prosopis chilensis and Lantana species.

Yatindra and B. N. Mathur (1988). "**Studies on a new species of Myxidium (Protozoa: Myxozoa: Myxosporea) from a freshwater teleost fish Cirrhina reba (Ham)**." Uttar Pradesh Journal of Zoology **8**(1): 43-48.

Myxidium molnari sp. nov., from the gall-bladder of C. reba collected from Ana Sagar, Ajmer, India is described. A table with comparative morphometric characteristics of all the Myxidium spp. reported from the fishes of India is also given.