TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

21.3

The Wetlands Diversity

Editors

Doru Bănăduc & Angela Curtean-Bănăduc

Sibiu – Romania
2019

TRANSYLVANIAN REVIEW OF SYSTEMATICAL AND ECOLOGICAL RESEARCH

21.3

The Wetlands Diversity

Editors

Doru Bănăduc & Angela Curtean-Bănăduc

"*Lucian Blaga*" University of Sibiu,
Faculty of Sciences,
Department of Ecology and Environment Protection

Sarasota Bay Foundation

International Association for Danube Research

"Lucian Blaga" University of Sibiu

Ecotur Sibiu N.G.O.

Broward College, Fort Lauderdale

ESENIAS East and South European network for Invasive Alien Species

Sibiu – Romania
2019

Scientifical Reviewers

John Robert AKEROYD
Sherkin Island Marine Station,
Sherkin Island – Ireland.

Valerio BARTOLUCCI
Broward College,
Fort Lauderdale, Florida – United States of America.

Doru BĂNĂDUC
"Lucian Blaga" University of Sibiu,
Sibiu – Romania.

Alexandru BURCEA
"Lucian Blaga" University of Sibiu,
Sibiu – Romania.

Kevin CIANFAGLIONE
Camerino University,
Camerino – Italy.

Angela CURTEAN-BĂNĂDUC
"Lucian Blaga" University of Sibiu,
Sibiu – Romania.

Constantin DRĂGULESCU
"Lucian Blaga" University of Sibiu,
Sibiu – Romania.

Nicolae GĂLDEAN
Ecological University of Bucharest,
Bucharest – Romania

Marian-Traian GOMOIU
Romanian Academy,
Bucharest – Romania

Mike JOY
Institute for Governance and Policy Studies,
Rutherford House, Pipitea Campus – New Zealand.

Sanda MAICAN
Romanian Academy Institute of Biology,
Bucharest – Romania.

Harcharan Singh RUMANA
Govind Sustainability Solution,
Delhi – India.

Pablo del MONTE
Centro Interdisciplinario de Ciencias Marinas del IPN,
La Paz – México.

Erika SCHNEIDER-BINDER
Karlsruhe University, Institute for Waters and River Basin Management,
Rastatt – Germay.

David SERRANO
Broward College,
Fort Lauderdale, Florida – United States of America.

Teodora TRICHKOVA
Bulgarian Academy of Sciences, Institute of Zoology,
Sofia – Bulgaria.

Editorial Assistants

IN MEMORIAM

Ernst Heinrich Philipp August Haeckel
(1834 – 1919)

Ernst Heinrich Philipp August Haeckel, the eminent German zoologist and evolutionist who was one of the period's most enthusiastic advocates of Darwinism, was born on 16 February 1834 in Potsdam, and died on 9 August 1919 in Jenna. He projected and proposed original ideas on the evolutionary descent of humans and he asserted that phylogeny is briefly and partially repeated in the process of ontogeny ("ontogeny recapitulates phylogeny").

Haeckel grew up in Merseburg. He studied in Würzburg and in Berlin University, where one of his professors, Johannes Müller, began to take him on expeditions to the North Sea coasts and to kindle his interest in sea organisms.

This contact with marine biology directed Haeckel's interests towards biology, but initially he took a medical degree, to satisfy his family's plans for him, at Berlin in 1857. For a while he practiced medicine; and travelled in Italy, where he painted and even considered art as a path. At Messina he researched Radiolaria one-celled protozoans.

The direction of Haeckel's interest was induced by reading Charles Darwin's On the Origin of Species by Means of Natural Selection. Meanwhile, in 1861 he obtained a dissertation in zoology at Jena University. In 1862 he was appointed associate professor of zoology, and that year, when he published his Radiolaria monograph, he asserted his understanding and acceptance of Darwin's theory of evolution. Since then he began to be a strong supporter of Darwinism, and he started lecturing to wide lay audiences on the theory of descent. For Haeckel, this was only the starting point, with effects and results to be sought further. In 1865 he was appointed full professor in Jena University, where he remained in charge until his retirement in 1909.

Haeckel's best-known published works were: Generelle Morphologie der Organismen (General Morphology of Organisms) and Die Perigenesis der Plastidule (The Generation of Waves in Small Vital Particles).

Haeckel brought debate to substantial and valuable biological questions. His gastraea theory, tracing multicellular animals to a theoretical two-layered ancestor, aroused both analysis and deliberations. His attraction to systematization along evolutionary lines drive to his very important improvements in the knowledge related to some invertebrate taxa such as radiolaria, medusa, siphonophores, and sponges.

Gathering and building collections, Haeckel founded the Phyletic Museum in Jena and also the Ernst Haeckel Haus; the latter contains his books and archives, and it cares for many other memorabilia of his extraordinary life and prestigious professional work.

The centenary of Haeckel reminds us of his lifelong devotion to natural sciences in a heroic stage of the history of the theory of evolution, a beautiful and remarkable life under the signs of art-like science.

The Editors

CONTENTS

Preface

In a global environment in which the climate changes are observed from few decades no more only through scientific studies but also through day by day life experiences of average people which feel and understand allready the presence of the medium and long-term significant change in the “average weather” all over the world, the most comon key words which reflect the general concern are: heating, desertification, rationalisation and surviwing.

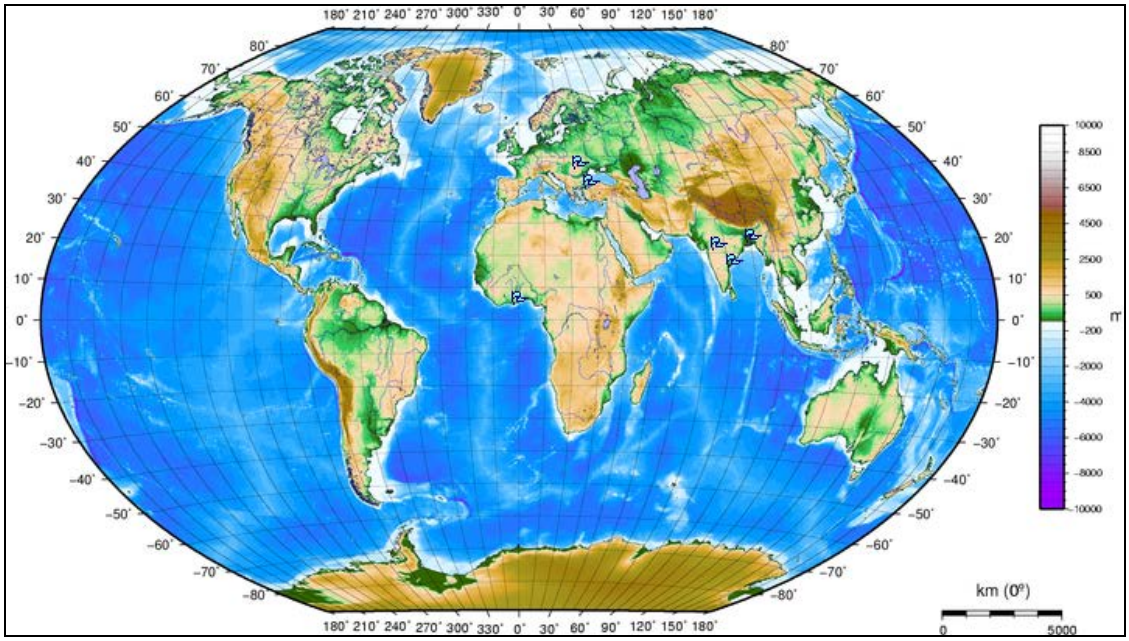
The causes, effects, trends and possibilities of human society to positively intervene to slow down this process or to adapt to it involve a huge variety of aproacess and efforts.

With the fact in mind that these aproaces and efforts shuld be based on genuine scientific understanding, the editors of the *Transylvanian Review of Systematical and Ecological Research* series launch three annual volumes dedicated to the wetlands, volumes resulted mainly as a results of the *Aquatic Biodiversity International Conference*, Sibiu/Romania, 2007-2019.

The therm wetland is used here in the acceptance of the Convention on Wetlands, signed in Ramsar, in 1971, for the conservation and wise use of wetlands and their resources. **Marine/Coastal Wetlands** – Permanent shallow marine waters in most cases less than six metres deep at low tide, includes sea bays and straits; Marine subtidal aquatic beds, includes kelp beds, sea-grass beds, tropical marine meadows; Coral reefs; Rocky marine shores, includes rocky offshore islands, sea cliffs; Sand, shingle or pebble shores, includes sand bars, spits and sandy islets, includes dune systems and humid dune slacks; Estuarine waters, permanent water of estuaries and estuarine systems of deltas; Intertidal mud, sand or salt flats; Intertidal marshes, includes salt marshes, salt meadows, saltings, raised salt marshes, includes tidal brackish and freshwater marshes; Intertidal forested wetlands, includes mangrove swamps, nipah swamps and tidal freshwater swamp forests; Coastal brackish/saline lagoons, brackish to saline lagoons with at least one relatively narrow connection to the sea; Coastal freshwater lagoons, includes freshwater delta lagoons; Karst and other subterranean hydrological systems, marine/coastal. **Inland Wetlands** – Permanent inland deltas; Permanent rivers/streams/creeks, includes waterfalls; Seasonal/intermittent/irregular rivers/streams/creeks; Permanent freshwater lakes (over eight ha), includes large oxbow lakes; Seasonal/intermittent freshwater lakes (over eight ha), includes floodplain lakes; Permanent saline/brackish/alkaline lakes; Seasonal/intermittent saline/brackish/alkaline lakes and flats; Permanent saline/brackish/alkaline marshes/pools; Seasonal/intermittent saline/brackish/alkaline marshes/pools; Permanent freshwater marshes/pools, ponds (below eight ha), marshes and swamps on inorganic soils, with emergent vegetation water-logged for at least most of the growing season; Seasonal/intermittent freshwater marshes/pools on inorganic soils, includes sloughs, potholes, seasonally flooded meadows, sedge marshes; Non-forested peatlands, includes shrub or open bogs, swamps, fens; Alpine wetlands, includes alpine meadows, temporary waters from snowmelt; Tundra wetlands, includes tundra pools, temporary waters from snowmelt; Shrub-dominated wetlands, shrub swamps, shrub-dominated freshwater marshes, shrub carr, alder thicket on inorganic soils; Freshwater, tree-dominated wetlands; includes freshwater swamp forests, seasonally flooded forests, wooded swamps on inorganic soils; Forested peatlands; peatswamp forests; Freshwater springs, oases; Geothermal wetlands; Karst and other subterranean hydrological systems, inland. **Human-made wetlands –** Aquaculture (e. g., fish/shrimp) ponds; Ponds; includes farm ponds, stock ponds, small tanks; (generally below eight ha); Irrigated land, includes irrigation channels and rice fields; Seasonally flooded agricultural land (including intensively managed or grazed wet meadow or pasture); Salt exploitation sites, salt pans, salines, etc.; Water storage areas, reservoirs/barrages/dams/impoundments (generally over eight ha); Excavations; gravel/brick/clay pits; borrow pits, mining pools; Wastewater treatment areas, sewage farms, settling ponds, oxidation basins, etc.; Canals and drainage channels, ditches; Karst and other subterranean hydrological systems, human-made.

The editors of the *Transylvanian Review of Systematical and Ecological Research* started and continue the annual sub-series (*Wetlands Diversity*) as an international scientific debate platform for the wetlands conservation, and not to take in the last moment, some last heavenly "images" of a perishing world …

This volume included variated original researches from diverse wetlands around the world.



The subject areas (▱) for the published studies in this volume.

No doubt that this new data will develop knowledge and understanding of the ecological status of the wetlands and will continue to evolve.

Acknowledgements

The editors would like to express their sincere gratitude to the authors and the scientific reviewers whose work made the appearance of this volume possible.

The Editors

Editorial Office:

"Lucian Blaga" University of Sibiu, Faculty of Sciences, Department of Ecology and Environment Protection, Dr. Ion Rațiu Street 5-7, Sibiu, Sibiu County, Romania, RO-550012, Angela Curtean-Bănăduc (ad.banaduc@yahoo.com, angela.banaduc@ulbsibiu.ro)

(ISSN-L 1841 – 7051; online ISSN 2344 – 3219)

USING DYNAMIC LIGHT SCATTERING FOR MONITORING THE SIZE OF THE SUSPENDED PARTICLES IN WASTEWATER

Dan CHICEA * and *Silviu Mihai REI* **

* "Lucian Blaga" University of Sibiu, Faculty of Sciences, Dr. Ion Raţiu Street 5-7, Sibiu, Sibiu County, Romania, RO-550012, dan.chicea@ulbsibiu.ro
** "Lucian Blaga" University of Sibiu, Faculty of Sciences, Research Center for the Physics of Complex Systems, Dr. Ion Raţiu Street 5-7, Sibiu, Sibiu County, Romania, RO-550012/Continental Automotive Systems, Salzburg Street 8, Sibiu, Sibiu County, Romania, RO-550018, silviu.rei@continental-corporation.com

DOI: 10.2478/trser-2019-0015

KEYWORDS: wastewater, coherent light scattering, Dynamic Light Scattering (DLS), artificial neural network.

ABSTRACT

A coherent light scattering experiment on wastewater samples extracted from several stages of water processing within a wastewater processing plant was carried out. The samples were allowed to sediment while they were the subject of a Dynamic Light Scattering (DLS) measurement. The recorded time series were processed using an Artificial Neural Network based DLS procedure to produce the average diameter of the particles in suspension. The method, using a single physical procedure for monitoring the variation of the average diameter in time, indicates the dominant type of suspensions in water.

ZUSAMMENFASSUNG: Verwendung der dynamischen lichtverwertung zur überwachung der grösse der abhängigen teilchen im abwasser.

Es wurde ein kohärentes Lichtstreuungsexperiment an Abwasserproben durchgeführt, die aus mehreren Stufen der Wasseraufbereitung innerhalb einer Abwasseraufbereitungsanlage entnommen wurden. Die Proben konnten sich sedimentieren, während sie einer dynamischen Lichtstreuungsmessung (DLS) unterzogen wurden. Die aufgezeichneten Zeitreihen wurden unter Verwendung eines DLS-Verfahrens auf Basis eines künstlichen neuronalen Netzwerks verarbeitet, um den durchschnittlichen Durchmesser der in Suspension befindlichen Teilchen zu erzeugen. Das Verfahren, bei dem ein einziges physikalisches Verfahren zur Überwachung der zeitlichen Änderung des durchschnittlichen Durchmessers verwendet wird, zeigt den vorherrschenden Typ von Suspensionen in Wasser an.

REZUMAT: Folosirea împrăştierii dinamice a luminii pentru monitorizarea dimensiunii medii a particulelor aflate în suspensie în apa reziduală.

A fost efectuat un experiment de împrăștiere a luminii coerente pe probe de apă reziduală prelevate din diferite locații ale unei stații de tratare a apei reziduale. Probele au fost lăsate să se sedimenteze, timp în care au fost subiectul unui experiment de împrăștiere dinamică a luminii. Seriile temporale înregistrate au fost prelucrate folosind un procedeu simplificat de dnamică a împrăştierii luminii asistat de o rețea artificială neuronală care a determinat dimensiunea medie a particulelor în suspensie. Metoda care folosește un singur procedeu fizic, oferă informații despre tipul particulelor din suspensie.

INTRODUCTION

Wastewater is one of the predominant environmental problems, due to the input of different substances (Oprean and Olosutean, 2011). The waste water treatment is one of the significant main elements in maintaining the quality of a wide variety of aquatic habitats and ecosystems in the present human society circumstances; the substance types and their concentrations in some effluents are main problems in the matter, leading to the alteration of oxygen balances, eutrophication, and major modifications in wildlife composition, inducing a threat to many aquatic species (Ansari et al., 2010; Gjyli and Mukli, 2009; Khoshnood and Khoshnood, 2015; Khuram et al., 2019; Wedyan et al., 2019).

A proper treatment of such wastewater pollutants including those in suspended form cannot be obtained in the absence of specific identification methods, including the size of suspended particles in wastewater. This identification is important in choosing specific-adapted wastewater treatment methods. Developing such an identification method is the main goal of the present study.

Any natural water, also the wastewater, is partially opaque. The partial opacity is caused by the particles suspended in it, which scatter and absorb light. This physical property is called turbidity (*, 2002). Some of the particles in suspension consist of sand, clay, silt, plankton, algae, micro-organisms, as in natural water in ponds and rivers (**, 2006). Wastewater can also contain human feces and urine, mixed with used toilet paper, in which case the wastewater is named blackwater (Tilley et al., 2014). Wastewater can also contain washing water, in which case it is known as greywater or sullage (Tilley et al., 2014) or manufactured liquids from domestic sources. Wastewater is ussualy treated in a wastewater treatment plant and released into a receiving water body, typically a river.

The parameter that describes the fact that water is not fully transparent, is called turbidity and is related to the total amount of suspended material in water (*, 2002). As stated in previous work (Chicea, 2013a, b) turbidity is not a measure of the concentration or of the size of the particles. Moreover, measuring and knowing turbidity does not provide good knowledge regarding the size and the type of particles. As already stated (Chicea, 2013a, b), a good knowledge of the size and the type of the suspended particles is important.

If the suspended particles scatter light in an elastic manner, there are no changes produced in water, but if the particles absorb light, this causes a temperature increase in turbid water. Under the same light exposure turbid water is warmer than less turbid (less opaque) water. Water temperature is a tremendously important parameter in an ecosystem. Gumpinger et al. (2010) stated that water temperature is considered one of the most essential regulating parameters in aquatic ecosystems. Moreover, because of the intensive interrelations with other physical and chemical parameters, water temperature has a high indicative value when considering the general condition of a river ecosystem (Gumpinger et al., 2010).

The work presented here is a continuation of the previous work (Chicea, 2013a, b; Chicea and Chicea, 2015) aiming to assess the type of suspension in natural water (organic or inorganic) using a combination of two physical procedures: sedimentation and Dynamic Light Scattering (DLS hereafter). The novelty consists in making the time series processing much faster by using an Artificial Neural Network (ANN hereafter) and details and results are presented in the following sections.

MATERIAL AND METHODS

Particles sedimentation

When a particle is suspended in a fluid, as a suspension particle in natural or wastewater is, it is subject to the action of three forces: gravity, buoyant force and the Stokes drag, if the motion of the particle takes place in the laminar regime (Chicea, 2008). Details on the three forces have been extensively presented in (Chicea and Chicea, 2015) in the first four equations and in the first two figures. They will therefore not be repeated here.

If the density of the particle, ρ, is different from the density of the fluid, ρ_0, the particle will start moving and the velocity v will increase. As the velocity increases, so does the Stokes drag, up to the point that makes the sum of the three forces null, as illustrated in figure 1 and equation 4 (Chicea and Chicea 2015). The limit velocity of falling is reached and kept constant thereafter. The limit velocity v_l is given by equation (1), where R is the radius of the particle, g is the gravitational acceleration and η is the coefficient of dynamic viscosity of the fluid.

$$v_l = \frac{2(\rho-\rho_0)R^2 g}{9\eta} \tag{1}$$

If the density of the particle, ρ, is bigger than ρ_0, v_l is oriented downwards; if ρ is smaller than ρ_0, v_l is oriented upwards, and if they are equal the particle is in static equilibrium.

The limit velocity can be used to assess the type of the particles that are still suspended in the fluid after a certain time from the beginning of the experiment, if we have a procedure to measure the diameter of the particles, such as DLS for instance. For this purpose, we can consider a cuvette with the suspension as in figure 2 (Chicea and Chicea, 2015). All the particles that were located above the mark at the beginning of the experiment (hereafter at time 0) will fall below the laser beam level in time t if they have a velocity bigger than $v_m(t)$, given by equation (2):

$$v_m(t) = \frac{L}{t} \tag{2}$$

This means that at time t, only the particles having a velocity smaller than $v_m(t)$ in equation (6), are remaining in suspension, above the line and, hence a diameter smaller than d_{max} found by inverting equation (2):

$$d_{max} = 2 \cdot R_{max} = \sqrt{\frac{9\eta v_m}{2(\rho-\rho_0)g}} \tag{3}$$

A plot of the d_{max} versus time, considering L = one cm, as was used in the work described here, and the suspensions to be silt or sand, with a density ρ = 2,600 kg/m^3, is presented in figure 3 (Chicea and Chicea, 2015) and is therefore not repeated here.

These considerations allow us to assess the type of suspensions in water, together with another complimentary procedure to measure the diameter of the particles at time t, which is the ANN assisted DLS procedure that is described in the following subsection. The conclusions of (Chicea and Chicea, 2015) highlight that if particles are silt and sand, the diameter in the beam area will monotonously decrease in time; if the diameter suddenly increases it is an indication that the silt and sand has sedimented and only organic particles and bacteria remained in the beam area and if the diameter remains constant the suspension consists of organic particles mainly.

The reference DLS procedure

DLS is an optical procedure used for assessing the size of the particles in suspension (Clark, 1970; Berne and Pecora, 2000; Chicea, 2010). When coherent light crosses a medium having scattering centers (SC) an in-uniformly illuminated image is obtained, called the speckle image, as explained in a report of previous work on this subject (Chicea, 2013a, b; Chicea and Chicea, 2015). The image is not static but changes in time giving the aspect of "boiling speckles" (Goodman, 1984; Briers, 2001).

As the SCs are moving, the image presents intensity fluctuations in each location. If we place a detector in a certain location, the time variations of the intensity are recorded and a time series is the result. The schematic of the experimental setup is the same as in (Chicea and Chicea, 2015) except that the scattering angle was chosen to be 90°.

The power spectrum of the intensity of the light scattered by particles in suspension can be linked to the probability density function (Clark, 1970; Tscharnuter, 2000). This link between the PDF and the power spectrum is a consequence of the translation of the relative motion of the scattering particles into phase differences of the scattered light. By subtracting the average intensity from the recorded time series and calculating the square of the intensity we obtain the power time series. The Fourier transform of the power time series is the power spectrum.

We can compare the spectrum numerically computed from the experimental data with the theoretically expected spectrum, which is the Lorentzian line S(f) (4), (Clark et all, 1970, Chicea and Rei, 2018). S(f) has two free parameters a_0 and a_1 and is fit to the power spectrum using a least square minimization procedure. Once the fit is completed, the diameter of the SCs can be assessed as the double of the radius R.

$$S(f) = a_0 \frac{a_1}{(2\pi f)^2 + a1^2} \tag{4}$$

The radius can be derived as a function of the fitted parameter a_1 and other known quantities using (5) and further details are presented (Chicea, 2017; Chicea and Rei, 2018).

$$R = \frac{2k_B TK^2}{6\pi\eta a_1} \tag{5}$$

The wavelength was 633 nm, the light source was a He-Ne laser and the power was 10 mW. The scattering angle θ was chosen to be 90°, different from the value of 4°58'11" which was used in Chicea and Chicea (2015). Consequently, the data acquisition rate was changed to 16 kHz, and this combination increased the accuracy of the diameter measurement considerably. This DLS procedure based on fitting the Lorentzian line to the PSD to determine the average diameter was considered the reference procedure and for testing and validating the ANN based DLS, which is presented briefly in the next subsection.

ANN based DLS time series processing

For each particle size there is a corresponding Lorentzian line, therefore we can naturally conclude that solving the particle size problem for a range of sizes is equivalent to finding the function for fitting the power spectrum of the recorded time series. The function we selected as input for the neural network is the autocorrelation function of the time series recorded.

$$R_x(t) \equiv lim_{T\to\infty} \frac{1}{T} \int_0^\infty x(t)x(t+\tau)dt \tag{6}$$

The problem can be reduced to fitting the autocorrelation function of the time series, rather than fitting the Lorentzian line, simply because the PSD and the autocorrelation are not independent of each other, according to the Wiener-Khinchin Theorem (Weisstein, 2018).

The alternative of using the autocorrelation to be fitted is an advance, as compared to the reference method. Due to sensors calibration, a time series can have various amplitudes, for the same particle size, when measurements are taken with different equipment or a different calibration. This will be reflected in the power spectral density, in the amplitudes corresponding to various frequencies. The autocorrelation function creates a cleaner input for the neural network and does not depend on the amplitudes, but on how fast the time series decorrelates. And this, reflected in the correlation time, is connected to the particle size, a connection which can be revealed by a properly trained and designed neural network. Our analysis which follows will be based on an algorithm for mono-disperse systems of particles. When using the normalized autocorrelation function, scaling the PSD is no longer required, because the function will be normed to one and decay to zero when time increases.

The schematic of the ANN based DLS time series processing is presented in figure 1. The Matlab package was used in generating and training the ANN which was an ANN for fitting type, having three layers, as previously described. The first (input) layer had 350 neurons, the hidden layer had 26 neurons and the third (output) layer had one neuron, as the output is the average diameter. Details on designing the ANN, on generating the set of training data and on testing the performance of the procedure are extensively presented in (Chicea and Rei, 2018). Overall, the ANN based DLS time series processing procedure proved to be thousands of times faster than the reference DLS procedure, once the time series is recorded. The results presented in the corresponding section were done using the ANN based procedure described in this subsection.

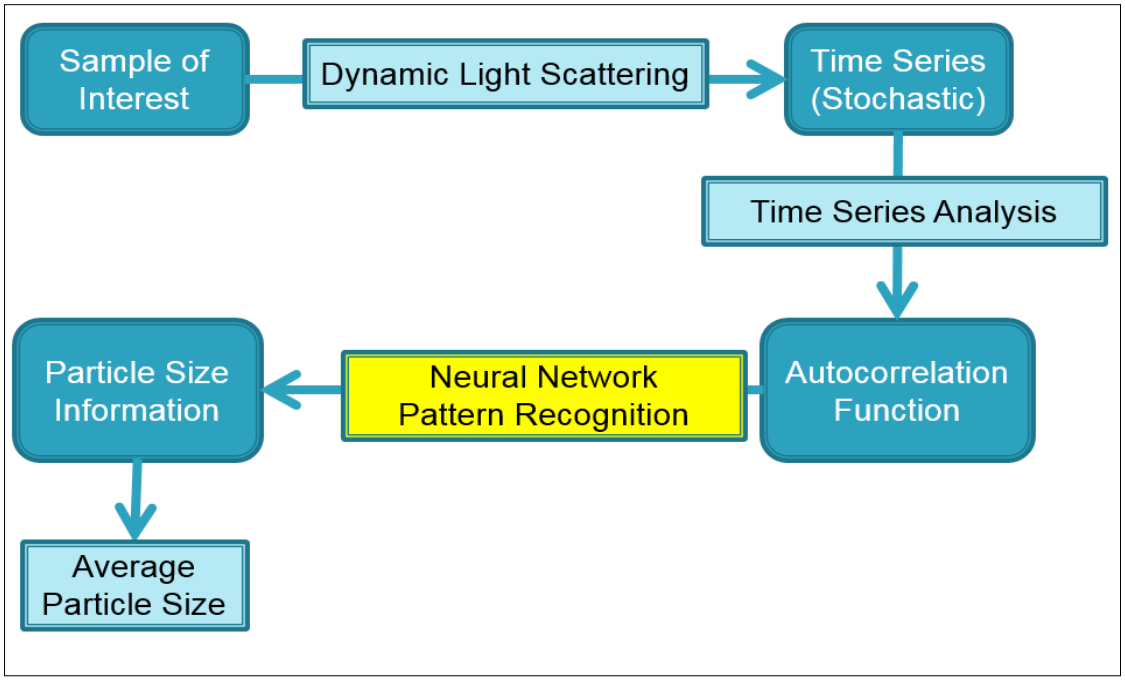


Figure 1: The schematic of the ANN based DLS time series processing.

The ANN that was used in time series processing for the work reported here is different from the ANN used in (Chicea and Rei, 2018). The number of neurons in the layers was the same, but the set of training data was considerably bigger, covering the diameter range 10-3,000 nm. The diameters computed using the ANN were compared with the diameters computed using the reference DLS method described in the previous subsection and were found to be accurate within 2% in the training range. The diameters were less accurate outside the training area that is within 15% for diameters of 5,000 nm. We should note that the reference DLS method is not precise for diameters bigger than 3,000 nm, therefore the diameters computed with the ANN, which are bigger that 3,000 nm, should be viewed as half-quantitative assessment rather than a precise measurement.

Experimental procedure and data processing

Wastewater samples from several locations within the wastewater processing plant at Mohu, Sibiu (the plant, hereafter) were taken and each one was placed in the circular cuvette having a diameter of 0.8 cm. Figure 3 illustrates the schematic of the plant and the location of sampling water.

At location one, the untreated water was used for measurement. At location two, water which went through the screen grit chamber and aeration tank, active sludge was used for measurements. At location three the water which went through final sedimentation was used for measurements. Samples of water from the three mentioned locations were taken and measurements for a short duration (five minutes) and a long duration (10 hours) were made. For the short duration, time series were recorded every 10 seconds. For the long time duration, time series were recorded every 20 minutes.

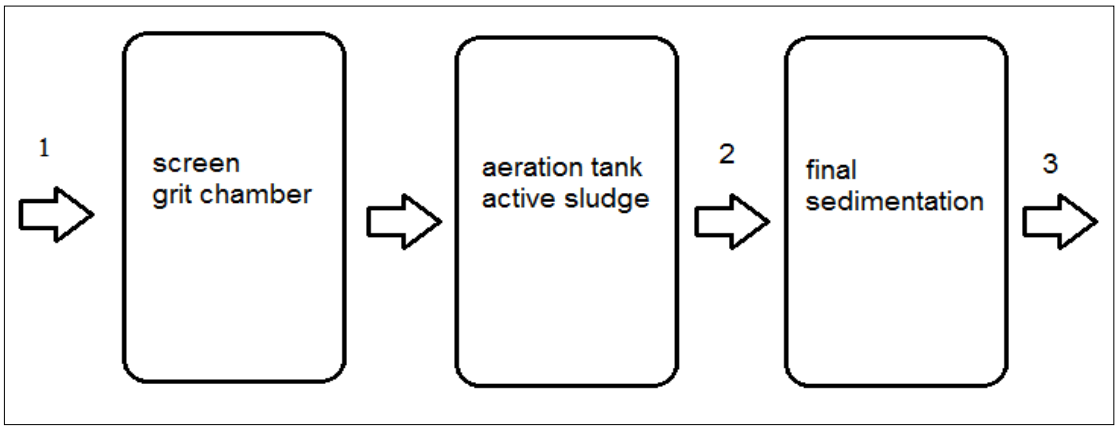


Figure 2: The schematic of the plant and the location of sampling water.

RESULTS AND DISCUSSION

Figure 3 reveals the average particle size estimated during different stages of wastewater processing. The wastewater at input, sampled at location one, contains sand, silt and organic suspensions. The average diameter estimated was 4,700 nm. It is worth noting that the input water is already pre-filtered so that the big particles have been removed. After sedimentation, only the organic particles remained in the aeration tank. After about seven – eight hours average time spent in the aeration tank with aerobic bacteria, the size of the remaining particles were about 660 nm. This is visible in the measurement at location two. At location three, the water exits the sedimentation tank having smaller particles of with an average diameter of 550 nm.

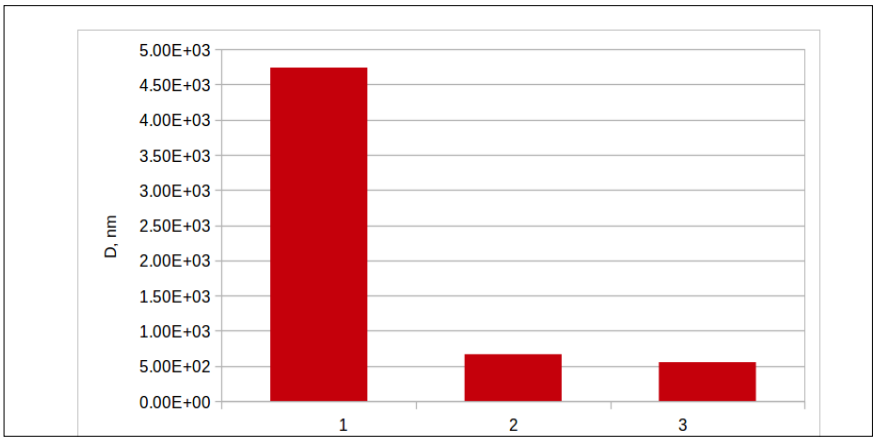


Figure 3: Medium size of suspended particles during different stages of wastewater processing.

At location one, the short time monitoring shows a fast sedimentation of the inorganic particles which initially dominate the measurement as they are in much higher numbers. As soon as their numbers decrease, the organic particles, which do not sediment, as they have a density equal to the water density, start to dominate the measurement (Fig. 4).

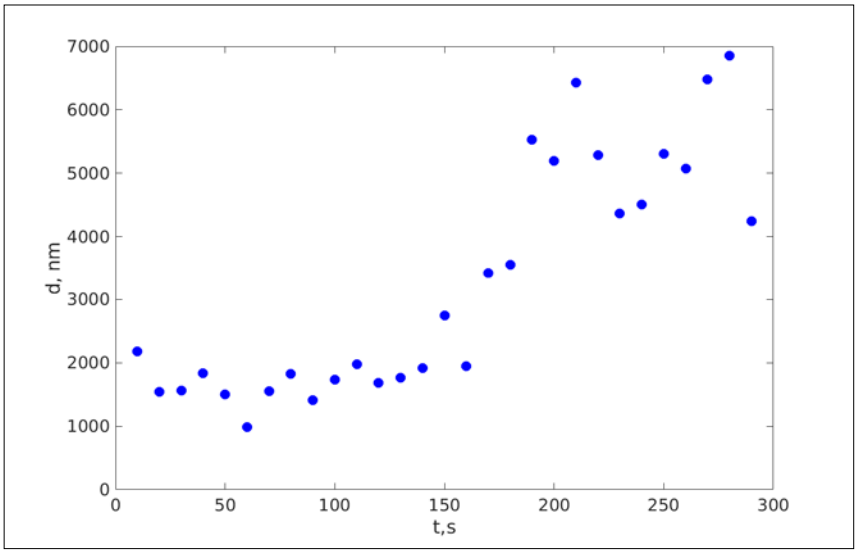


Figure 4: The short time variation of the average diameter of the suspended particles in time from treated water samples at the exit of the plant, in location one.

This is the reason for the jump from low particle size value to a higher value in about 150 seconds. In the long time monitoring at location one the organic particles remain in the water, which makes sense as the water did not undergo the stages of the treatment meant to reduce the organic content. At location two, the short time monitoring reveals that there are inorganic particles that dominate the measurement, most likely particles which were not filtered

out and were moved in the water movement through tanks. In the long time monitoring it can be seen that these particles sediment and the size tend to decrease slowly. This is consistent with the treatment stage which involves mixing the water with active sludge which has small particles and bacteria in higher concentration.

Figure 5 illustrates the variation of the average diameter of the suspended particles in time from treated water samples at the exit of the plant, in location three.

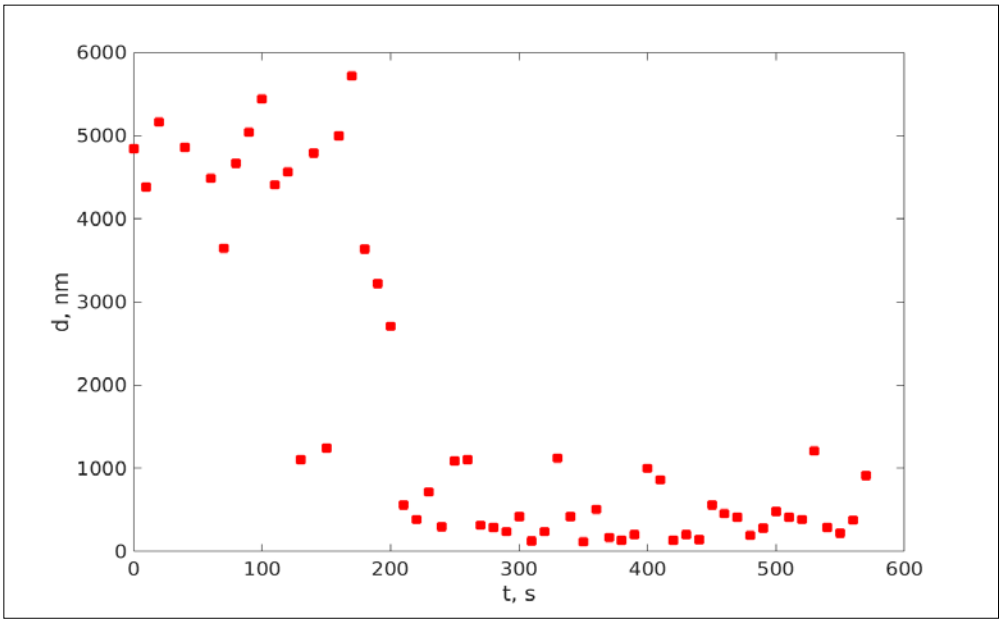


Figure 5: The short time variation of the average diameter of the suspended particles in time from treated water samples at the exit of the plant, in location three.

At location three, the exit of the plant, there is a smaller amount of particles but with a mixture of sizes in the low range. The evolution of sizes can be explained noting that the measurement takes place for the particles in the scattering volume, in the way of the laser beam. The result is consistent with particles which are organic but have a density slightly smaller than water. As time passed, particles drifted towards surface. Smaller particles drifted also but with a smaller velocity. In the end, a small number of organic particles with big diameters still remain in wastewater after processing.

CONCLUSIONS

Using the combination of DLS with sedimentation is a simple and reliable tool that can be used in describing the type of suspension in natural water. The combined DLS – sedimentation procedure outputs the average diameter of the particles and the type of particles that can be found in suspension, without requiring calibration. The novel procedure described in this work is a traditional DLS with the time series processing performed with an ANN. The ANN is designed and trained just once, using a big set of input data of autocorrelations in this case, with known diameters. The process of generating the training data and of training the ANN is laborious and time consuming, but this process is performed just once. Processing the autocorrelations later on using the ANN is thousands of times faster and much less computation intensive (Chicea and Rei, 2018), therefore it can be exported to a light computing platform like a tablet or smart-phone, making thus the DLS particle seizer much faster and more portable.

ACKNOWLEDGEMENTS

We are especially indebted to Ms. Maier and Ms. Filip from Apa-Canal Sibiu S. A. for their direct help and fruitful discussions. The work presented in this article was in part financed from "Lucian Blaga" University of Sibiu research grants LBUS-IRG-2017-03.

REFERENCES

1. Ansari A. A., Gill S. S. and Khan F. A., 2000 – Eutrophication: threat to aquatic ecosystems, in Ansari A., Singh Gill S., Lanza G. and Rast W. (eds), Eutrophication: causes, consequences and control, Springer, Dordrecht, DOI: https://doi.org/10.1007/978-90-481-9625-8_7, ISBN 978-90-481-9624-1.
2. Berne B. J. and Pecora R., 2000 – Dynamic Light Scattering: with applications to chemistry, biology and physics, Dover Publications, 10-23.
3. Briers J. D., 2001 – Laser Doppler, speckle and related techniques for blood perfusion mapping and imaging, *Physiological Measurement*, 22, 35-66.
4. Chicea D., 2008 – Coherent Light Scattering on nanofluids – *Computer Simulation Results Applied Optics*, 47, 10, 1434-1442.
5. Chicea D., 2010 – Nanoparticles and nanoparticle aggregates sizing by DLS and AFM, *Journal of Optoelectronics and Advanced Materials*, 4, 9, 1310-1315.
6. Chicea D., 2013a – Estimating particle concentration in natural water by speckle size measurement, *Proceedings of 11th International Conference on Environment, Ecosystems and Development (EED'13)*, Braşov, Romania, June 1-3, 151-161.
7. Chicea D., 2013b – Estimating particle concentration in natural water by speckle contrast, *Transylvanian Review of Systematical and Ecological Research*, 15.1, 2, 1-10.
8. Chicea D. and Chicea L. M., 2015 – Profiling suspensions in natural water by a simplified dynamic light scattering procedure and sedimentation, *Transylvanian Review of Systematical and Ecological Research*, 17.2, 1-10.
9. Chicea D., 2017 – Using neural networks for Dynamic Light Scattering time series processing, *Measurement Science and Technology*, 28, 5, 055206.
10. Chicea D. and Rei S. M., 2018 – A fast artificial neural network approach for Dynamic Light Scattering time series processing, *Measurement Science and Technology*, 29, 105201, 15, https://doi.org/10.1088/1361-6501/aad937.
11. Clark N. A., Lunacek J. H. and Benedek G. B., 1970 – A study of brownian motion using light scattering, *American Journal of Physics*, 38, 575-585.
12. Gjyli L. and Mukli L., 2009 – Assessment of water microbiologic pollution in Durres's Harbour basin (Albania), *Transylvanian Review of Systematical and Ecological Research*, 8, The Wetlands Diversity, 169-184.
13. Goodman J. W., 1984 – Statistical properties of laser speckle patterns, in Laser speckle and related phenomena, 9, in *Topics in Applied Physics*, Dainty J. C., Edit., Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 9-75.
14. Gumpinger C., Höfler S., Berg K. and Scheder C., 2010 – Water temperature as an applicable parameter with a high indicative value for the general condition of a river-ecosystem, drawing on the example of the river Trattnach in Upper Austria, *Transylvanian Review of Systematical and Ecological Research*, 10, The Wetlands Diversity, 1-14.
15. Khoshnood Z. and Khoshnood R., 2015 – Effect of industrial wastewater on fish in Karoon River, *Transylvanian Review of Systematical and Ecological Research*, 17.1, The Wetlands Diversity, 109-120.

16. Khuram I., Muhammad Z., Ahmad N., Ullah R. and Barinova S., 2019 – Green and Charophyte algae in bioindication of water quality of Shah Alam River (District Peshawar, Pakistan), *Transylvanian Review of Systematical and Ecological Research*, 21.1, The Wetlands Diversity, 1-16.
17. Oprean L. and Olosutean H., 2011 – A new perspective on McKinney's wastewater model, *Transylvanian Review of Systematical and Ecological Research*, 12, The Wetlands Diversity, 181-202.
18. Tilley E., Ulrich L., Lüthi C., Reymond P. and Zurbrügg C., 2014 – Compendium of sanitation systems and technologies – (2nd revised edition), Swiss Federal Institute of Aquatic Science and Technology (Eawag), Duebendorf, Switzerland, ISBN 978-3-906484-57-0, 7-14.
19. Tscharnuter W., 2000 – in Encyclopedia of Analytical Chemistry, Meyers R. A. (ed.), John Wiley and Sons Ltd., 5469-5485.
20. Weisstein E. W. 2018 – Wiener-Khinchin theorem, from MathWorld – A Wolfram Web Resource, http://mathworld.wolfram.com/Wiener-KhinchinTheorem.html.
21. Wedyan M. A., Qnais E., Altaif K. and Al-Tawaha R., 2019 – Characteristics of dissolved organic nitrogen in municipal and biological nitrogen removal wastewater treatment plants in Jordan, *Transylvanian Review of Systematical and Ecological Research*, 21.2, The Wetlands Diversity, 1-12.
22. *, 2002 – Waterwatch Australia National Technical Manual, Module 4, Waterwatch Australia Steering Committee, Environment Australia, ISBN 0-6425-4856-0, 19-21.
23. **, 2006 – National Soil Survey Handbook part 618, Soil properties and qualities, United States Department of Agriculture – Natural Resource Conservation Service, 42-55.

WATER, SANITATION AND ITS IMPACT ON ENVIRONMENT AND HUMAN BEING – A CASE STUDY

Harcharan Singh RUMANA * and *Ramesh Chandra SHARMA* **

* Govind Sustainability Solution Pvt. Ltd. Unit 17-18, CSC. Pkt-E, Mayur, Vihar, Ph-II, Delhi 91, India, IN-110091, hsrumana@gmail.com
** Desert Medicine Research Centre (ICMR), New Pali Road, Jodhpur, Rajasthan, India, IN-342005, rcsharma@hotmail.com

DOI: 10.2478/trser-2019-0016

KEYWORDS: drinking water quality, microbial contamination, human health, India.

ABSTRACT

The present study was carried out to assess the drinking water quality, hygiene and human health existing in the city of Jodhpur. About 89.8% of houses use household drinking water from supply, and the remaining 10.2% houses depend on public taps or other water sources. Similar results for sanitation and hygiene observed as 97% of houses did not have any garbage disposal facility and in all 10.6% did not have easy access to a sanitary facility. The results of physical and chemical parameters of ground water were above the drinking water standards, whereas in the case of household drinking water were within standard limits. The presence of total coliform, faecal coliform and faecal streptococci were showing water contamination which may be the cause of significant prevalence 5.0% ($p < 0.001$) of gastrointestinal infections.

ZUSAMMENFASSUNG: Wasser, Gesundheitspflege und ihre Auswirkungen auf die Umwelt und die Menschen – eine Fallstudie.

Vorliegende Untersuchung wurde durchgeführt, um die Qualität des Trinkwassers sowie von Hygiene und Gesundheit der in Jodhpur, lebenden Menschen zu bewerten. Etwa 89.8% der Haushalte benutzen Trinkwasser aus der Wasserversorgung, während die verbleibenden 10.2% von öffentlichen Wasserhähnen oder anderen nicht etablierten Wasserquellen abhängig sind. Ähnliche, für die Gesundheitsversorgung und Hygiene festgestellte Ergebnisse belegen, dass 97% der Haushalte keine Einrichtungen für Abfallbeseitigung und insgesamt 10.6% der Haushalte keinen leichten Zugang zu Sanitäranlagen haben. Die Ergebnisse von physikalischen und chemischen Parametern des Grundwassers liegen höher als die Trinkwasserstandardwerte, während sie im Falle des Haushalt Trinkwassers innerhalb der Standardgrenzen liegen. Das Vorhandensein der Gesamtkolibakterien, der Fäkalkolibakterien und Fäkal Streptokokken zeigen die Wasserkontaminierung an, die gegebenenfalls die Ursache einer bemerkenswerten Prävalenz von 5.0% ($p < 0.001$) gastrointestinaler Infektionen sind.

REZUMAT: Apa, igiena și impactul lor asupra mediului și a populației – studiu de caz.

Acest studiu a evaluat calitatea apei potabile, a igienei și sănătății populației în orașul Jodhpur. Aproape 89.8% din gospodării folosesc apa potabilă de la rețeaua de alimentare cu apă, 10.2% de la robinete publice sau alte surse. Rezultate privind îngrijirea sănătății și igiena, arată că 97% dintre gospodării nu au facilități pentru deșeurile menajere și 10.6% nu au acces ușor la facilități sanitare. Valorile parametrilor fizici și chimici a apei freatice sunt mai mari decât standardele admise pentru apa potabilă, iar în cazul apei potabile a gospodăriilor aceste valori sunt între limitele standardului. Prezența colibacililor totali, a celor fecali și a streptococilor fecali, indică o contaminare a apei, care probabil este cauza prevalenței de 5.0% ($p < 0.001$) a infecțiilor gastro-intestinale.

INTRODUCTION

The needs of safe water supply, sanitation and hygiene are all unable to keep pace with urban growth followed by poor housing, poor drainage and garbage accumulation causes serious pollution problems. It finally has adverse effects on the health of people (Hutton et al., 2007; WHO, 2007; Kumar et al., 2011). The problem is aggravated due to the discharge of industrial effluents containing toxic pollutants, city sewage and overproduction of solid waste, which are the main cause of most waterborne diseases (CPCB, 2009). Toxic substances such as arsenic, lead, cadmium, nitrates, pesticides, etc., also enter the household drinking water supply at many points before reaching the tap, are also a matter of concern (Morris, 1995). Lack of hygiene further aggravates the problem. The magnitude of waterborne diseases such as cholera, diarrhoea, hepatitis, typhoid, amoebic, and bacillary dysentery are very high throughout the world (WHO, 2005). Nearly half the world's population does not have access to safe water through a household connection or a yard tap from a piped distribution system and live without sanitation (WHO/UNICE, 2000). In developing countries, over 90% of all diarrhoeal deaths occur in children under five years. Improving the drinking water quality, and providing enough water, for both personal and domestic hygiene are keys to prevention and control of diarrhoeal diseases (Fewtrell et al., 2005).

Water is one of the most priceless resource of Earth and under constant and variate anthropogenic impact (Vörösmarty et al., 2000; Flörke et al., 2013; Haddeland et al., 2013; Hutton and Chase, 2017). The needs of safe water supply, sanitation and hygiene are all unable to keep pace with urban growth followed by poor housing, poor drainage and garbage accumulation, and cause serious pollution problems (Mara, 2003; Hutton and Haller, 2004; Hutton et al., 2007; Gjyli and Mukli, 2009; Mara et al., 2010). It finally has adverse effects on the health of people (Ahern et al., 2005; Gerba, 2009; Kumar et al., 2011; Lim et al., 2012; Benova et al., 2014; Pepper et al., 2015).

The urban population has increased in India three and half times (UN, 2001), from 17.28% (1951) to 28% (2001). Clean drinking water facility through taps is available to only 35% of urban households and 18% of rural households in India as per the records of Registrar General and Census Commissioner of India 2001. Other residents use improper water sources like wells, ponds, and rivers. Lack of water, sanitation, and hygiene results in the loss of 0.4 million lives annually in India (WHO, 2007).

In the west sector of Rajasthan, which contain a sector of the Thar Desert, the situation evolves in a bad one due to a deficiency of secure water for drinking. Jodhpur area (Rajasthan, India) includes over one million residents with 2.1% annual human population increase as per census 2001. It has over 10,000 industrial sites, which induce pollution and influence the water quality. The studied locality has a complex system of pipelines for water supply and sewerage fluids, which does not support all the needs of the inhabitants and require numerous restorations. There is scarce available information in the present in India, concerning the drinking water pollution and its negative human's health effects. Thus, this study was developed to evaluate the significance of water pollution, sanitation problem, occurrence and predominance of diseases that may guide in planning and managing intervention activities.

Increasing urban population from about 869,403 to 972,259 and industries from 8,468 to 10,585 during the last five years, caused concern for increasing water pollution. The studied city has incomplete and inadequately maintained sewerage and water distribution system.

MATERIAL AND METHODS

Study area. Jodhpur the Sun City is placed in a dry region in the west of Rajasthan, where economic advancement was registered as very important since the last decade. Jodhpur has developed into the second biggest city of Rajasthan area and an outstanding centre both for industry and education. It is placed at latitude 26°18'N, longitude 73°04'E and at an elevation of 230 m above m.s.l. and cover a total area of 70 km^2. Placed at the margin of the Thar Desert the researched surface where there is acute dryness with very hot summers, with temperatures around 45°C, with numerous dust storms and moderate temperature in winter. The annual ordinary rainfall is 31.0 mm. Jodhpur continue to be one of the fastest developing cities in India.

Water sampling sites. The city has 60 wards with different landscapes (Fig. 1). Public Health Engineering Department (PHED) treats this water in waterworks and then supply the city for drinking purpose. Water samples were collected from following major categories of sites. Category one: the household drinking water samples were collected from twelve randomly selected sites in the city as shown in figure 1. Category two: similarly groundwater samples from open wells, step wells, tube wells and hand pumps were also collected from the twelve sites (Fig. 1). Category three: there are three main reservoirs of raw water in the city, Kailana, Takhat Sagar, and Balsamand. These reservoirs receive water continuously from the Rajiv Gandhi Canal. These water sources also receive runoff water from the adjoining watersheds during rains. Category four: waterworks water samples were also collected for comparative study. The main water works for drinking water supply to the city is set up at Kaylana Lake, Chopasani Road. The other one is at Balsamand Lake, which supplies water to a very small population of the city in its north. Samples were collected since 2004 to 2005, covering all seasons.

Collection of water sample. Water samples of various potable water sources as household drinking water and ground waters (open wells, tube wells, hand pumps, etc.) were collected in screw-capped, clean, sterile, 2.5-litre inert plastic containers (PVC bottles) from the selected sites. Immediately after collection of samples, bottles were put in an icebox and were transported to the laboratory. Samples are stored at 4°C to avoid any changes in their physical, chemical, and biochemical characteristics. For the microbial investigations samples were collected separately in sterile 500 mL bottles and analyzed within 30 hours.

Water analysis. Water quality was determined for physical, chemical, and bacteriological characteristics. Parameters measured for water pollution studies include pH, temperature, turbidity, conductivity and total dissolved solids (TDS), alkalinity, hardness, chlorides, fluorides, nitrates, phosphates, and sulphates for chemical, lead, cadmium, iron, dissolved oxygen, biological oxygen demand-BOD, total coliforms (TC), faecal coliform (FC) and faecal streptococci (FS). The levels of heavy metals were determined by acid digestion methods using Atomic Absorption Spectrophotometer (Perkin-Elmer Model 2380) and air-acetylene flame. The bacteriological investigation was carried out by the membrane filtration method. Direct plating and estimation of coliform densities were done. The coliform density was reported as membrane filtration count per 100 mL. The standard methodology was followed for water pollution assessment (APHA, 1992, 1998).

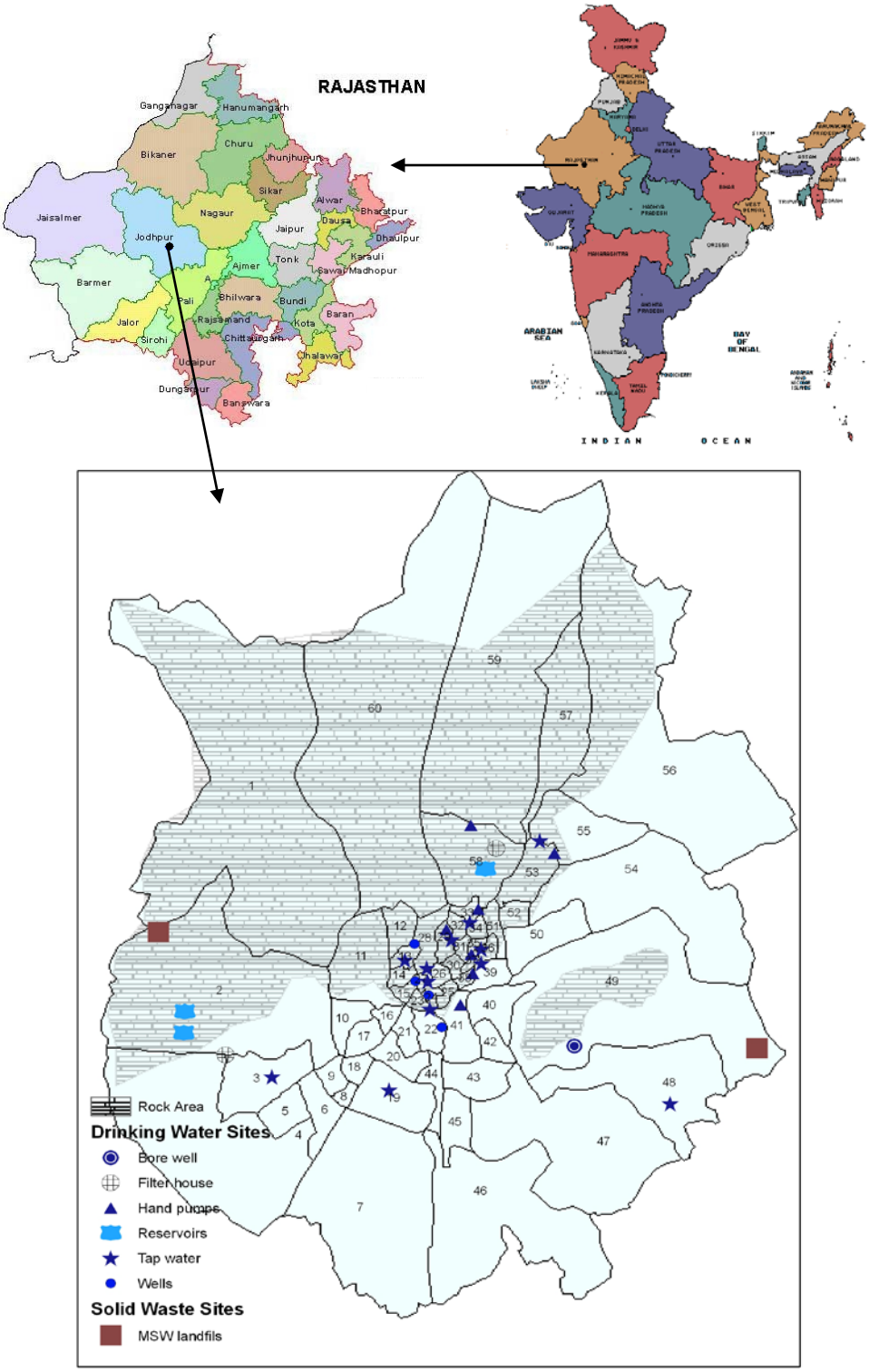


Figure 1: Ward map showing the drinking water pollution and solid wastes study sites in Jodhpur, Rajasthan, India.

Sanitation issue. The most common method of disposal of municipal solid wastes in the city is by deposition in landfills. There are two dumping places in the city for municipal solid wastes. The main dumping ground for Municipal Solid Waste (MSW) is situated in the western part of the city near the Kaylana Reservoir. The municipal solid waste dumping area is spread over a large area of about 200 acres of lands in the western part of the city on a hilly and stony bed. The samples have been collected from the sites on a random basis to take an unbiased representative sample. Two main landfills or disposal sites have been selected for the present study (Fig. 1). For taking the solid and hazardous wastes samples from the selected sites, a one-two m diameter deep ditch was made with an area of about two m^2 from the surface of the landfills. The samples were analysed using standard methods as described in Laboratory Manual for Soil and Water Testing Methods (Ghosh et al., 1983).

Health survey. A human population cross-sectional health analysis was accomplished in the city. A sample size of 10,000 was taken to find out the prevalence of morbidity circumstances with a prevalence of 1% or over, with a 10% standard error. The samples were dispersed to 60 wards of Jodhpur. Data on local water-associated health problems as per the schedule at household level were collected. The information about the number of humans treated at OPD and wards of four teaching hospitals of Jodhpur regarding gastrointestinal illnesses and cancer were collected from office of Principal Dr. S. N. Medical College, Jodhpur. Exhaustive investigation of information about health and illnesses and their link with diverse water pollution has been achieved using Epi Info 2000 software.

RESULTS

Water quality. A total of 165 representative water samples were collected from different localities of the city. Out of 165 water samples, 123 were from household drinking water, six from the outlet of waterworks, nine from surface water sources and 36 from ground waters (open wells, step wells, hand pumps and tube wells) were collected. They were examined for physical, chemical, and bacteriological parameters and results of annual average water quality with the number of samples above the drinking water standards are described in tables 1-2. Drinking water samples collected from waterworks showed most of the parameters were within acceptable limits. Very few samples from household drinking water were reported outside the standards for their physical and chemical factors (Tab. 2). Only a few colonies of total coliform, faecal coliform and faecal streptococci bacteria were present. The results of water samples collected from surface waters (reservoirs/lakes) for most of physical and chemical parameters were found within the range of drinking water standards except turbidity (Tab. 1). The growth of all three types of colonies of bacteria as total colilfom, faecal coliform and faecal streptococci in these untreated water samples were observed (Tabs. 1-2).

Groundwater is also used for drinking as well as other activities such as bathing, washing, cleaning, etc. The results of physical, chemical, and bacteriological characteristics of groundwater samples are given in table 1. The parameters such as conductivity, total dissolved solids, total hardness, nitrates, alkalinity, dissolved oxygen, total coliform, faecal coliform, and fecal streptococci in groundwater samples were found above the acceptable standard limits. The annual average level of these parameters was also found above the acceptable standards. The results of metal analysis show that lead, iron, and cadmium in all water samples were present in traces or below the detectable limit. The growth of colonies of total coliform, faecal coliform and fecal streptococci bacteria were found in all type of water samples.

Table 1: Annual average values of physical-chemical and bacteriological characteristics of different water sources (2004-2005); * values in mg/l; ** bacterial colonies as counts/ 100 ml; Turb. – turbidity (NTU), cond. (µS/cm), Hard. – hardness, Res. Cl* – Residual Cl*.

Parameters	Acceptable limit	Drinking water N = 123	Filter plant N = 6	Raw waters N = 9	Open/step wells N = 23	Hand pumps/bore wells N = 23
pH	6.5 - 8.5	7.6 + 0.34	7.4 + 0.3	7.6 + 0.26	7.6 + 0.23	7.5 + 0.3
Turb.	< 5.0	1.2 + 0.93	1.7 + 1.5	18.4 + 14.4	0.8 + 1.05	3.3 + 3.9
Cond.	< 600	256.6+118.58	450.7 + 302.0	425.3+267.17	1079.1+341.6	1820.2+988.9
TDS*	< 500	139.9 + 59.31	153.0 + 20.3	207.1 + 69.6	702.1+196.28	1256.8+670.9
Hard.*	< 300	95.2 + 22.12	132.5 + 32.7	143.9 + 52.6	270.8 + 43.35	393.2 + 230.6
Res. Cl*	< 0.20	0.1 + 0.04	0.2 + 0.1	0.1 + 0.04	0.1 + 0.03	0.1 + 0.0
T. (°C)	NA	25.1 + 7.62	24.7 + 5.0	24.6 + 6.89	25.1 + 2.21	25.1 + 2.0
Cl*	< 250	32.7 + 8.24	39.9 + 23.9	43.8 + 49.52	93.9 + 38.08	209.5 + 110.8
F*	< 1.0	0.1 + 0.10	0.7 + 0.6	0.7 + 0.58	0.2 + 0.12	0.7 + 0.4
NO_3*	< 45	9.3 + 11.89	5.1 + 2.8	6.4 + 4.09	124.6 + 57.72	296.1 + 167.9
SO_4*	< 200	39.8 + 29.01	49.0 + 22.3	73.2 + 35.37	146.3 + 69.67	202.3 + 127.4
Alk.*	< 200	97.3 + 44.70	87.9 + 44.0	132.1 + 39.80	272.2+102.67	302.6 + 124.5
DO*	> 7.5	6.0 + 1.01	5.5 + 0.8	5.3 + 0.77	4.4 + 2.02	4.5 + 1.8
BOD*	< 2.0	1.0 + 0.51	0.9 + 0.6	1.0 + 0.97	1.1 + 0.75	1.1 + 0.6
Pb*	< 0.05	0.0 + 0.00	0.0 + 0.00	0.0 + 0.00	0.0 + 0.00	0.0 + 0.0
Fe*	< 0.30	0.1 + 0.08	0.2 + 0.10	0.2 + 0.09	0.2 + 0.21	0.2 + 0.2
Cd*	< 0.01	0.0 + 0.05	0.0 + 0.00	0.0 + 0.00	0.0 + 0.00	0.0 + 0.0

Table 2: Number of water samples outside the acceptable standard (2004-2005); *Values are in mg/l; **Bacterial colonies as counts/100 mL.

Parameters	Acceptable limit	Filter house N = 6	Drinking tap water				Raw water sources N = 9	Open/step well (N = 9)	Hand pumps/ bore wells (N = 23)
			Winter N = 47	Summer N = 40	Monsoon N = 36	Annual N = 123			
pH	6.5 - 8.5	0	0	8	2	10	1	0.0	1.0
Turb.	< 5.0	0	0	0	1	1	7	0.0	3.0
Cond.	< 600	0	2	2	0	4	2	9.0	22.0
TDS*	< 500	0	1	0	0	1	0	8.0	22.0
Hard.*	< 300	0	0	0	0	0	0	3.0	15.0
Res. Cl*	< 0.20	0	0	0	0	0	0	0.0	0.0
T. (°C)	NA	0	0	0	0	0	0	0.0	0.0
Cl*	< 250	0	0	0	0	0	0	0.0	8.0
F*	< 1.0	0	0	0	0	0	3	0.0	5.0
NO_3*	< 45	0	2	0	0	2	0	9.0	22.0
SO_4*	< 200	0	0	0	0	0	0	1.0	12.0
Alk.*	< 200	0	1	0	0	1	0	7.0	19.0
DO*	> 7.5	0	47	40	36	123	8	9.0	21.0
BOD*	< 2.0	0	1	0	1	2	1	2.0	1.0
TC**	0.0	6	34	38	35	107	8	7.0	22.0
FC**	0.0	0	18	25	26	69	7	6.0	15.0
FS**	0.0	0	14	16	21	51	7	6.0	9.0

Sanitation issue. Removal of waste is a main problem of worry. Municipal Corporation gathers wastes and transports to the disposal sites, which are commonly a low-lying surface on the periphery of the city. The data about it was obtained from Jodhpur Municipal Corporation. Jodhpur Municipal Corporation gathers city solid wastes in open trucks, which cannot compress the wastes. About 30-35 trucks, of 10 tons each, of solid wastes are gathered and transported to the dumping areas. The principal dumping area is located near Badli in the western part of the city. This is located in the basin area of Kaylana, the main water reservoir of Jodhpur. The city solid waste dumping field is spread over a broad area of about 200 acres in the western side of the city on hilly and stony substrata. The main dumping area is under the expanding state of motorized machinery for compacting and levelling the wastes, and covering the top level with soil before finally compacting it. Solid waste fragments were sampled from these landfills, and separated into its contents. The principal elements were minerals, coal, vegetables, paper, glass, rags, wood, plastics, iron, rubber, dust, etc., which may be rich in toxic chemicals and also pathogens. The organic matter was isolated. The percentage fractions of each element of municipal solid wastes samples are presented in table 3.

Table 3: Percentage and average weight of municipal solid waste fractions.

Components	Average (n = 12)	
	Weight in grams	%
Minerals and building materials (mixed)	1,661.4	33.2
Polythene bags and plastics (mixed)	136.2	2.7
Glasses and porcelains (mixed)	130.3	2.6
Fibers (textile and a part of waste wood)	112.3	2.3
Metal: iron (mixed)	73.5	1.5
Total compostable material	1,280	25.6
Fine soil	1,606.3	32.1
Total weight	5,000	100.0

Health Assessment

Health survey was conducted in 1,600 houses in the city, which included 9,287 individuals (46.2% females and 53.8% males). Out of 9,287 individuals, 81.1% were Hindus, 18.2% were Muslims, 0.5% were Sikhs and 0.2% were Christians. Based on their housing details, 2.9% of individuals were slum dwellers (lowest income group), 46.7% lived in low-income settlement, 47.3% in middle-income settlement and 3% lived in posh colonies (high-income settlement). Educational status of the population shows that 24.0% population (17.4% males and 31.7% females) was illiterate and 76% literate. Most houses (97%) did not have any garbage disposal facility, and garbage from these houses was dumped on roadsides or open plots. It was found that toilets were not available in 5.9% houses and these residents practiced open field defecation, whereas 0.1% individuals depended on common toilets meant for a group of families, 1.3% on dry pits and 3.3% on public toilets. In all 10.6% of houses in the city did not have easy access to sanitary facilities. Tap water supply was available to 85.6% population (89.8% houses), and the remaining 14.4% population (10.2% house) depended on public taps/tankers, hand pumps, reservoirs, bore wells and open wells.

The percent prevalence of different environmental related diseases such as gastrointestinal diseases, diabetes mellitus and skin diseases are described in tables 4-6. The prevalence of gastrointestinal infections was 5.0% (Tab. 4). It was 4.9% in males and 4.7% of females. Of all 1.2% had abdominal pain, 0.4% loss of appetite, 0.8% hyperacidity, 0.3% diarrhoea, 0.3% dysentery, 0.7% gastritis, 0.3% hepatitis, 0.6% jaundice and 0.4% has typhoid. In the survey, 2.1% males and 2.2% of females have shown a history of diabetes (Tab. 5). Percent prevalence of skin diseases was 4.1% (Tab. 6). Prevalence of various skin diseases such as allergic manifestation, fungal infections, dermatitis, leucoderma and patch of discolouration were 3.0, 0.3, 0.8, 0.2, and 0.3% respectively.

Table 4: Percent prevalence of gastrointestinal diseases in Jodhpur.

Age-group	Sex	Number examined (n)	Percent prevalence of									
			Abd. pain	Loss of appetite	Hyper-acidity	Diarrhoea	Dysentery	Gastritis	Hepatitis	Jaundice	Typhoid	Total
0-1	M	42	2.4	0.0	0.0	2.4	0.0	0.0	0.0	2.4	0.0	7.2
	F	31	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	M + F	73	1.4	0.0	0.0	1.4	0.0	0.0	0.0	1.4	0.0	4.2
1-5	M	305	0.3	0.7	0.0	2.3	1.0	2.3	0.0	1.3	0.0	7.9
	F	258	0.4	0.0	0.4	1.2	0.8	1.6	0.0	0.8	0.4	5.6
	M + F	563	0.4	0.4	0.2	1.8	0.9	2.0	0.0	1.1	0.2	7.0
5-14	M	967	1.4	0.3	0.2	0.4	0.7	0.6	0.1	1.0	0.4	5.1
	F	802	2.1	0.4	0.0	0.4	0.5	0.6	0.2	0.5	0.6	5.3
	M + F	1,769	2.0	0.3	0.1	0.4	0.6	0.6	0.2	0.8	0.5	5.5
15-44	M	2,581	0.9	0.2	0.6	0.1	0.3	0.7	0.3	0.8	0.4	4.3
	F	2,226	1.1	0.6	0.9	0.2	0.1	0.4	0.3	0.2	0.4	4.2
	M + F	4,807	1.0	0.4	0.7	0.1	0.2	0.6	0.3	0.5	0.4	4.2
45-59	M	695	0.7	0.3	1.7	0.0	0.4	0.8	0.6	0.3	0.4	5.2
	F	561	2.0	0.4	3.2	0.2	0.0	0.4	0.2	0.4	0.4	7.2
	M + F	1,256	1.3	0.3	2.4	0.1	0.2	0.7	0.4	0.3	0.4	6.1
60 +	M	403	0.0	1.2	0.2	0.0	0.2	0.7	1.0	0.2	0.0	3.5
	F	416	1.0	0.0	1.7	1.0	0.5	0.0	0.2	0.2	0.0	4.6
	M + F	819	0.6	0.6	1.0	0.5	0.4	0.4	0.6	0.2	0.0	4.3
All ages	M	4,993	0.9	0.4	0.6	0.3	0.4	0.8	0.3	0.8	0.4	4.9
	F	4,294	1.4	0.4	1.0	0.3	0.2	0.5	0.2	0.3	0.4	4.7
	M + F	9,287	1.2	0.4	0.8	0.3	0.3	0.7	0.3	0.6	0.4	5.0

Table 5: Percent prevalence of known diabetics in Jodhpur.

Age-group	Sex	Number examined (n)	Percent prevalence of known diabetics
5-14	M	967	0.1
	F	802	0.1
	M + F	1,769	0.1
15-44	M	2,581	0.6
	F	2,226	0.7
	M + F	4,807	0.6
45-59	M	695	5.6
	F	561	5.7
	M + F	1,256	5.7
60 +	M	403	12.4
	F	416	11.3
	M + F	819	11.8
All ages	M	4,993	2.1
	F	4,294	2.2
	M + F	9,287	2.2

Table 6: Percent prevalence of skin diseases in Jodhpur.

Age group (years)		Number examined (n)	Percent prevalence of					
			Allergy	Fungal infections	Dermatitis	Leuco-derma	Patch decolouration	Total
0-1		73	0.0	0.0	1.4	0.0	0.0	1.4
1-5		563	2.7	0.4	0.2	0.0	0.0	3.3
5-14		1,769	3.5	0.2	0.3	0.1	0.1	4.2
15-44		4,807	2.4	0.3	0.4	0.1	0.4	3.6
45-59		1,256	3.5	0.5	0.1	0.1	0.7	4.9
60 +		819	3.4	0.1	0.4	0.6	0.1	4.6
All ages	4,993	2.8	0.3	0.3	0.0	0.4	3.8	–
	4,294	3.1	0.3	0.3	0.3	0.3	4.3	–
	9,287	3.0	0.3	0.3	0.2	0.3	4.1	–

Table 7: Number of Gastroenteritis diseases and cancer patients.

Teaching hospitals Jodhpur	Year		
	2002	2003	2004
Infections of GIT	43,813	39,740	47,700
Malignancies of GIT	302	300	300

Secondary data for gastrointestinal infections, gastrointestinal malignancies and leukaemia were also collected from all teaching hospitals of the city and is shown in table 7. The numbers of cases of gastrointestinal diseases were showing an increasing trend. However, there was not any trend observed for the number of cases of gastrointestinal cancer (oesophagus, stomach, and intestine) no change was observed for gastrointestinal malignancies (Fig. 2). Leukaemia also did not show an increasing trend.

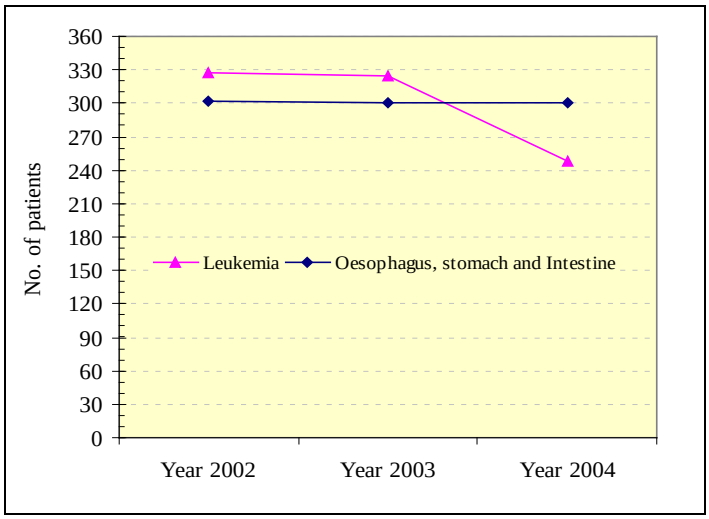


Figure 2: Number of gastrointestinal malignancies at teaching hospitals.

DISCUSSION

The absence of faecal coliform and faecal streptococci in chlorinated water at filter house outlet samples and presence of FC in 69 samples (56%) and FS in 51 (42%) samples of household drinking water (Tabs. 1-2) indicates contamination of water during its flow in the supply network. The residual chlorine level was found between 0.2-0.4 ppm in outlet waters of waterworks, ideally, which should be about 0.7 ppm. It was concluded from the work of Tavakoli et al. (2005) that total chlorine levels of less than 0.71 mg/l in water supply systems could not provide the recommended safety levels. They have reported that *Aeromonas hydrophila* was get inactivated in < 100 minutes time at chlorine levels of 0.11 mg/l to 0.90 mg/l; whereas. *Escherichia coli* were able to tolerate 0.30 mg/l chlorine for > 1,000 minutes while *Enterococcus faecalis* and *Salmonella typhi* survived at total chlorine concentration of 0.50 mg/l for 100 minutes. The higher number of counts of total coliform also indicates chances of other bacterial contamination. Diarrhoeal diseases, jaundice and hepatitis, were observed at low levels in all age groups indicating that most of the water quality is improving except a few sites (on site-specific contamination). During the present study 5.0% prevalence of gastrointestinal diseases might be due to water pollution (Tabs. 1-2). Of all 1.2% had abdominal pain, 0.3% diarrhoea, 0.3% dysentery, 0.7% gastritis, 0.6% jaundice, 0.4% typhoid, 0.3% hepatitis, and 0.4% had typhoid. Almost similar results was observed at Bikaner City in North-West Rajathan where 15.5% of the population and 44.5% of families suffered from one or more common water-borne diseases including amoebiasis, diarrhoea (5.4%), dysentery, jaundice and typhoid (Saxena and Chhabra, 2004). The presence of total coliform, faecal coliform and faecal streptococci in household drinking water may be due to leakage of pipes, mixing of sewer wastewater with supply lines particularly in narrow and tight roads, or storage endpoints as tanks or earthen/brass vessels (mutkas) in households. Another factor responsible for it is intermittent water supply on alternate days, which also encourage bacterial growth in pipelines. Similar observations for drinking water were also reported by George et al. (2006) in Lebanon where intermittent water supply systems exist. The causes of pollution can also be predicted on the basis of the ratio of FC/FS (Tab. 8). It was inferred from the FC/FS ratio that household drinking water contamination is due to human pollution (Gerba, 2000; Gerba and Pepper, 2006; Gerba, 2009; Hass et al., 2014).

Table 8: FC/FS ratio in all water samples and type of pollution (2004-2005) (*Gerba, 2000; 2009; 2015).

Water source	FC/FS	FC/FS*	Pollution source*	Water source	FC/FS
Drinking water N = 123	4.3	> 4.0	Human pollution	Drinking water N = 123	4.3
Filter plant N = 6	1.4	2.0-4.0	Human waste in mixed pollution	Filter plant N = 6	1.4
Raw water N = 9	0.7	< 0.7	Animal pollution	Raw water N = 9	0.7
Open/ step wells N = 9	0.9	0.7-2.0	Animal waste in mixed pollution	Open/ step wells N = 9	0.9
Hand pumps/ bore wells N = 23	7.3	> 4.0	Human pollution	Hand pumps/ bore wells N = 23	7.3

The results of household drinking water quality showed that all physical and chemical parameters were within the range of ICMR/WHO drinking water standards (Tabs. 1-2). Same is true for water samples of surface water sources and waterworks (Tab. 1).

Household drinking water supply was available to 85.6% population (89.8% houses), and the remaining 14.4% population (10.2% houses) depended on public taps or other improper water sources such as tankers, hand pumps, reservoirs, tube wells and open wells. The presence of total coliform, faecal coliform and faecal streptococci in all groundwater samples except the samples collected from the tube well indicates pollution in the groundwater aquifer in Jodhpur City. It indicates that groundwater contamination is also has link with seepage and leachate from sewerage, industrial effluents, industrial hazardous wastes, landfills and agricultural runoff. The same is not be the cause of higher concentration of nitrates, sulphates, chlorides, total hardness (calcium and magnesium), conductivity, and total dissolved solids as it is occurring naturally in a large area of western Rajasthan. Higher concentration of chloride content of water may also indicate possible pollution from human sewerage, animal manure or industrial wastes (APHA, 1998; CPCB, 2009). The higher concentrations of total dissolved solids (TDS) may cause adverse taste effects as highly mineralized water may also deteriorate domestic plumbing and appliances (APHA, 1998; CPCB, 2009). The presence of higher concentration of above-mentioned parameters also favours the bacterial contamination. Some studies carried out by Kumar et al. (2006) on drinking water drawn from hand pumps and tube wells at different locations in district Bathinda, Punjab had revealed a higher concentration of sodium, potassium, calcium, magnesium, chlorine and total hardness along with the pH value and conductivity of the water. Similar, observations of contaminations of drinking water drawn either from surface waters or groundwater by leaching from the soil were made by Holt (2000), and Reimann and Banks (2004).

Groundwater samples from open wells/hand pumps and tube wells showed high levels of nitrates (124.6 mg/l, 296.1 mg/l; Tab. 1). It was three-six times higher than the acceptable standard given by the World Health Organization (2005, 2007, 2008). Groundwater NO^-_3 contamination in shallow unconfined aquifers in Jodhpur is occurring naturally through the use of industrial effluents and city sewerage for irrigation and land application of animal manures and inorganic, commercial fertilizers also increase its level through the leaching process. Many studies have documented the relationship between agricultural activities and NO^-_3 leaching in shallow aquifers (Power and Schepers, 1989; Spalding and Exner, 1993; Stuart et al., 1994; Puckett et al., 1999; Nolan and Stoner, 2000; Gupta et al., 2000; Nolan, 2001; Sandor et al., 2001; Kumar et al., 2002; Robert et al., 2003). The present results of the high level of nitrates in groundwater of Jodhpur City are also in line with the findings of major parts of Churu, Alwar, Bharatpur, Jalore, Jaipur, Sikar, Tonk, and Jhunjhunu districts of Rajasthan which are also inherited by nitrate-rich ground waters (Kumar et al., 2002). They have classified nitrate toxicity into five water quality zones, namely, safe, mild, moderately problematic, highly problematic and dangerous with a view of health effects. The groundwater nitrate has much increased in the last years, and the demonstration of endogenous nitration among highly exposed subjects raises the concern of elevated cancer risk. The high-level groundwater nitrates may be one of the causes of gastrointestinal cancers in the city, which have been observed (Tab. 7). Similar results regarding gastric cancers and its association of nitrate content were observed by Sandor et al. (2001) in a small area of inequalities. In the present study, history of diabetes was given by 2.1% of males and 2.2% of females but was not found among groundwater water users in Jodhpur (Tab. 5). Kostraba et al. (1992) have suggested that even low-level nitrate exposure through drinking water may play a role in the etiology of Insulin Dependent Diabetes Mellitus (IDDM).

Metals like lead, cadmium, and iron in household drinking water samples from supply during the study period were detected within the limit (Tab. 1). This can be inferred from the absence of heavy metal pollution in surface waters and water works outlets that it is potable and good for consumption. The presence of metals in household drinking water indicates pollution at endpoints that may be due to leakage of supply pipelines or storage tanks at household levels. Similar reports of Alam and Sadiq (1989) on metal contamination of drinking water in Dhahran found that copper, iron, and zinc in the drinking water increased during its transportation which was related to the length and material of distribution pipes and the concentration of copper and zinc were increased during overnight storage of water in the appliances. The absence of metals indicates ground waters that they may be absent in leachate or seepage from landfills, city sewer lines, hazardous waste effluent. Almost similar results were reported from Delhi region by Dixit et al. (2003) for drinking waters drawn from tube wells and surface waters where marginally high levels of manganese, copper, selenium, and cadmium than Indian Standards (IS) specification regulated for drinking water. The levels of iron, nickel, lead, and zinc were within limits (final water supply of four treatment plants; Dixit et al., 2003).

The main dumping ground for MSW is situated in the western part of the city. The percent fractions of the main components of municipal solid waste samples such as minerals and building material (29.25%), glasses and porcelains (3.3%), polythene bags, rubbers and plastics (3.8%), fibers (textile and a part of waste wood, papers, vegetable matter, etc.) (3%), metals with iron (2.2%), compostable material (26.0%), and fine soil with ash (32.5%) were found during the present study (Tab. 3). Similarly percent fractions of municipal solid wastes reported in 40 cities by Bhinde and Sundaresan (1983) and 23 mega cities by EPTRI (1995) and were compared with the present status of MS in Jodhpur City. The difference lies in the

presence of stones and building material (29.2%), which seems to be absent in other cities in India. This may be due to the presence of sandstone quarries and mineral extractions industries in the city. The other important fraction was the presence of a lower amount of compostable matter and fine ash/soils as compared to other cities (Bhinde and Sundaresan, 1983; EPTRI, 1995). Present findings for plastics, fibbers (rags), glasses, and metals are almost the same as reported by EPTRI (1995) in mega cities. Bhinde and Subdersan (1983) has reported that the urban population generate 374 g/capita/day of solid wastes whereas later on EPTRI (1995) has estimated about 456 g/capita/day of solid waste. According to their findings, it can be estimated that in Jodhpur the total amount of MSW generated per day will be between 374 to 456 tons per day. Each of urban residents generates 350-1,000 g solid wastes every day (Upadhyay et al., 2005). The high amount of non-degradable (9.3%) and slow degradable fractions is a matter of public health concern. About 0.3% of the population was facing pollution problem due to solid wastes in their surroundings in Jodhpur City. Most houses (97%) did not have any garbage disposal facility, and garbage from these houses was dumped on roadsides or open plots. It was found that toilets were not available in 5.9% houses and these residents practiced open field defecation, whereas 0.1% individuals depended on common toilets meant for a group of families, 1.3% on dry pits and 3.3% on public toilets. In all 10.6% of houses in the city did not have easy access to sanitary facilities. All these might be the main cause of the significant prevalence (4.1%, $p < 0.001$) of skin disease. The poor sanitary facility, personal hygiene and lack of safe drinking water may cause health problems in the near future at a much larger scale due to the presence of contaminants, toxic metals and other pathogens.

CONCLUSIONS

The human health is adversely affected by the pollution of water and bad sanitation, which is more marked in developing countries like India. Presence of faecal coliform in 56% and faecal streptococci in 42% water samples, indicating the microbial contamination (human pollution). The study indicates that low levels of diarrhoeal diseases (diarrhoea 0.3%, dysentery 0.3%, and gastritis 0.7%), jaundice (0.6%), hepatitis (0.3%), and typhoid (0.4%) the improving health condition in all age groups. Except for a few sites all water samples from surface water, waterworks outlets and household drinking water as stored in tanks or earthenware vessels were found potable as their physical and chemical quality are concerned. Nitrates were three-six times higher in all groundwater samples (124.6 mg/l and 296.1 mg/l respectively) than the drinking water standards given by WHO (2008). They can be the cause of elevated gastrointestinal cancer and diabetes mellitus. Electric conductivity, nitrate, pH, chloride, calcium, sulphate, magnesium, cadmium, iron and lead were measured, all of these not exceed the drinking water standards but reveal pollution at endpoints that may be due to leakage of pipelines or storage tanks. Thus, increasing demand for safe drinking water may cause health problems in the near future at a much larger scale.

ACKNOWLEDGEMENTS

We are thankful to the Ministry of Environment and Forests, Government of India for sponsoring the project “Environmental Health Study in Jodhpur”.

REFERENCES

1. Ahern M., Kovats R., Wilkinson P., Few R. and Matthies F., 2005 – Global health impacts of floods: Epidemiologic Evidence, *Epidemiologic Reviews*, 27, 1, 36-46.
2. Alam I. A. and Sadiq M., 1989 – Metal contamination of drinking water from corrosion of distribution pipes, *Environmental Pollution*, 57, 167-178.
3. Benova L., Cumming O. and Campbell O., 2014 – Systematic review and meta-analysis: association between water and sanitation environment and maternal mortality, *Tropical Medicine and International Health*, 19, 4, 368-387.
4. Bhinde A. D. and Sundaresan B. B., 1983 – Solid waste management in developing countries, New Delhi, Indian National Scientific Documentation Centre, 222.
5. Central Pollution Control Board (CPCB), 2009 – Status of water quality in India, *Monitoring of Indian Aquatic Resources Series*, Minars/2009-2010, New Delhi.
6. Dixit R. C., Verma S. R., Nitnaware V. and Thacker N. P., 2003 – Heavy metals contamination in surface and groundwater supply of a city, *Indian Journal of Environmental Health*, 45, 107-112.
7. Eaton A. D., Clesceri L. S., Greenberg A. E., Greenberg A. E. and Franson M. A. H. 1998 – Standard methods: for the examination of water and wastewater, 20th edition, American Public Health Association, Washington DC, 1220.
8. EPTRI 1995 – Status of solid waste disposal in Metropolis Hyderabad, Hyderabad, Environmental Protection Training and Research Institute, 46.
9. Fewtrell L., Kaufmann R. B., Kay D., Enanoria W., Haller L. and Colford J. M. Jr. 2005 – Water, sanitation, and hygiene interventions to reduce diarrhoea in less developed countries: a systematic review and meta-analysis, *Lancet Infectious Diseas*, 5, 42-52.
10. Flörke M., Kynast E., Bärlund I., Eisner S., Wimmer E. and Alcamo J., 2013 – Domestic and industrial water uses of the past 60 years as a mirror of socio-economic development: A global simulation study, *Global Environmental Change*, 23, 1, 144-156, https://Doi.Org/10.1016/J.Gloenvcha.2012.10.018.
11. George M. and Ayoub L. M., 2006 – Impact of intermittent water supply on water quality in Lebanon, *International Journal of Environment and Pollution*, 26, 379-397.
12. Gerba C. P., 2000 – Indicator Organisms, 491-503, in Environmental Microbiology, Maier R. M., Pepper I. L. and Gerba C. P., (eds), Academic Press, San Diego, CA, 585.
13. Gerba C. P. and Pepper I. L., 2006 – Microbial contaminants, in Environmental and Pollution Science, 2nd edition, Pepper I. L., Gerba C. P. and Brusseau M. L. (eds), Academic Press, San Diego, CA, 144-169.
14. Gerba C. P., 2009 – Environmentally transmitted pathogens, 445-484, in Environmental Microbiology (2nd edition), Maier R. M., Pepper I. L. and Gerba C. P., (eds), Elsevier Academic Press, 589.
15. Gerba C. P., 2015 – Indicator microorganisms, VI, Water and foodborne pathogens, Chapter 23, 551-564, in Environmental microbiology, 3rd edition, Pepper I. L., Gerba C. P. and Gentry T. J., (eds), Elsevier Press, 728.
16. Ghosh A. B., Bajaj J. C., Hasan R. and Singh D., 1983 – Soil and water testing methods: a laboratory manual, IARI, New Delhi, 31-36.
17. Gjyli L. and Mukli L., 2009 – Assessment of water microbiologic pollution in Durres's marine harbour basin (Albania), *Transylvanian Review of Systematical and Ecological Research*, 8, The Wetlands Diversity, 169-184.
18. Greenberg A. E., Clesceri L. S. and Laton A. D. (eds) 1992 – Standard methods: for the examination of water and wastewater, 18th edition, American Public Health Association, Washington DC, ISBN-10: 0875532071, 1100.
19. Gupta S. K., Gupta R. C., Gupta A. B., Seth A. K., Bassin J. K. and Gupta A. 2000 – Recurrent acute respiratory tract infections in areas with high nitrate concentrations in drinking water, *Environ Health Perspect*, 108, 363-366.
20. Haas C. N., Rose J. B. and Gerba C. P., 2014 – Quantitative microbial risk assessment, 2nd edition, Wiley Blackwell, ISBN 9781118910030, 427.

21. Haddeland I., Biemans H., Eisner S., Fekete B., Florke M., Hanasaki N., Heinke J., Ludwig F., Schewe J., Stacke T., Wada Y. and Wisser D., 2013 – A global multi-model view on water balance alterations caused by human interventions versus climate change, *Proceedings of the National Academy of Sciences*, submitted.
22. Holt M. S., 2000 – Sources of chemical contaminants and routes into the freshwater environment, *Food Chemical Toxicology Journal*, 38, 1 supplement S, 21-27.
23. Hutton G. and Haller H., 2004 – Evaluation of the costs and benefits of water and sanitation improvements at global level, Geneva, World Health Organization, 87, WHO/SDE/WSH/0404.
24. Hutton G., Haller L. and Bartram J., 2007 – Economic and health effects of increasing coverage of lowcost household drinking-water supply and sanitation interventions to countries off-track to meet MDG target 10, Geneva, World Health Organization, 68.
25. Hutton G. and Chase C., 2017 – Water supply, sanitation and hygiene, in Injury prevention and environmental health, disease control priorities, 3rd edition, 7, World Bank Group, 171-198.
26. Kostraba J. N., Gay E. C., Rewers M. and Hamman R. F., 1992 – Nitrate levels in community drinking waters and risk of IDDM, An ecological analysis, *Diabetes Care*, 15, 11, 1505-1508.
27. Kumar S., Gupta A. B. and Gupta S., 2002 – Need for revision of nitrates standards for drinking water: a case study of Rajasthan, *Indian Journal of Environmental Health*, 44, 168-172.
28. Kumar M., Singh S. and Mahajan R. K., 2006 – Mahajan Rk., trace level determination of U, Zn, Cd, Pb, Cu in drinking water samples, *Environmental Monitoring Assessment*, 112, 283-292.
29. Kumar G. S., Kar S. S. and Jain A., 2011 – Health and environmental sanitation in India: issues for prioritizing control strategies, *Indian Journal of Occupational and Environmental Medicine*, 2011 September-December., 15, 3, 93-96, Doi: 10.4103/0019-5278.93196.
30. Lim S. S., Vos T., Flaxman A. D., Danaei G., Shibuya K., Adair-Rohani H., Amann M., Anderson H. R., Andrews K. G., Aryee M., Atkinson C., Bacchus L. J., Bahalim A. N., Balakrishnan K., Balmes J., Barker-Collo S., Baxter A., Bell M. L., Blore J. D., Blyth F., Bonner C., Borges G., Bourne R., Boussinesq M., Brauer M., Brooks P., Bruce N. G., Brunekreef B., Bryan-Hancock C., Bucello C., Buchbinder R., Bull F., Burnett R. T., Byers T. E., Calabria B., Carapetis J., Carnahan E., Chafe Z., Charlson F., Chen H, Chen J. S., Cheng A. T., Child J. C., Cohen A., Colson K. E., Cowie B. C., Darby S., Darling S., Davis A., Degenhardt L., Dentener F., Des Jarlais D. C., Devries K., Dherani M., Ding E. L., Dorsey E. R., Driscoll T., Edmond K., Ali S. E., Engell R. E., Erwin P. J., Fahimi S., Falder G., Farzadfar F., Ferrari A., Finucane M. M., Flaxman S., Fowkes F. G., Freedman G., Freeman M. K., Gakidou E., Ghosh S., Giovannucci E., Gmel G., Graham K., Grainger R., Grant B., Gunnell D., Gutierrez H. R., Hall W., Hoek H. W., Hogan A., Hosgood H. D. 3rd, Hoy D., Hu H., Hubbell B. J., Hutchings S. J., Ibeanusi S. E., Jacklyn G. L., Jasrasaria R., Jonas J. B., Kan H., Kanis J. A., Kassebaum N., Kawakami N., Khang Y. H., Khatibzadeh S., Khoo J. P., Kok C., Laden F., Lalloo R., Lan Q., Lathlean T., Leasher J. L., Leigh J., Li Y., Lin J. K., Lipshultz S. E., London S., Lozano R., Lu Y., Mak J., Malekzadeh R., Mallinger L., Marcenes W., March L., Marks R., Martin R., McGale P., McGrath J., Mehta S., Mensah G. A., Merriman T. R., Micha R., Michaud C., Mishra V., Mohd Hanafiah K., Mokdad A. A., Morawska L., Mozaffarian D., Murphy T., Naghavi M., Neal B., Nelson P. K., Nolla J. M., Norman R., Olives C., Omer S. B., Orchard J., Osborne R., Ostro B., Page A., Pandey K. D., Parry C. D., Passmore E., Patra J., Pearce N., Pelizzari P. M., Petzold M., Phillips M. R., Pope D., Pope C. A. 3rd, Powles J., Rao M., Razavi H., Rehfuess E. A., Rehm J. T., Ritz B., Rivara F. P., Roberts T., Robinson C., Rodriguez-Portales J. A., Romieu I., Room R., Rosenfeld L. C., Roy A., Rushton L., Salomon J. A., Sampson U., Sanchez-Riera L., Sanman E., Sapkota A., Seedat S., Shi P., Shield K., Shivakoti R., Singh G. M., Sleet D. A., Smith E., Smith K. R., Stapelberg N. J., Steenland K., Stöckl H., Stovner L. J., Straif K., Straney L., Thurston G. D., Tran J. H., Van Dingenen R., van Donkelaar A., Veerman J. L., Vijayakumar L., Weintraub R., Weissman M. M., White R. A., Whiteford H., Wiersma S. T., Wilkinson J. D.,

Williams H. C., Williams W., Wilson N., Woolf A. D., Yip P., Zielinski J. M., Lopez A. D., Murray C. J., Ezzati M., Al Mazroa M. A. and Memish Z. A., 2012 – A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the global burden of disease study 2010, *The Lancet*, 380, 9859, 2224-2260.

31. Mitchell R. J., Babcock S. R., Gelinas S., Nanus L. and Stasney D. E., 2003 – Nitrate distributions and source identification in the Abbotsford-Sumas Aquifer, *Northwestern Washington State Journal of Environmental Quality*, 32, 789-800.
32. Morris R. D., 1995 – Drinking water and cancer, *Environ Health Perspectives*, 103, supplement 8, 225-232.
33. Nolan B. T., 2001 – Relating nitrogen sources and aquifer susceptibility to nitrate in shallow ground waters of the United States, *Ground Water*, 39, 290-299.
34. Nolan B. T. and J. D. Stoner, 2000 – Nutrients in ground waters of the conterminous United States, 1992-1995, *Environmental Science and Technology*, 34, 1156-1165.
35. Power J. F. and Schepers J. S., 1989 – Nitrate contamination of groundwater in North America, *Agriculture Ecosystems and Environment*, 26, 165-187.
36. Puckett L. J., Crowley T. K., Lorenz D. L. and Stoner J. D., 1999 – Estimation of nitrate contamination of an agro-ecosystem outwash aquifer using a nitrogen mass-balance approach, *Journal of Environmental Quality*, 28, 2015-2025.
37. Registrar General and Census Commissioner of India 2001 – Provisional Population Totals, Census of India, Paper 1, New Delhi.
38. Reimann C. and Banks D., 2004 – Setting action levels for drinking water: are we protecting our health or our economy (or our backs!)?, *Science of the Total Environment*, 332, 13-21.
39. Sandor J., Kiss I., Farkas O. and Ember I., 2001 – Association between gastric cancer mortality and nitrate content of drinking water: ecological study on small area inequalities, *European Journal of Epidemiology*, 17, 443-447.
40. Saxena M. M. and Chhabra C., 2004 – A status survey of common water-borne diseases in desert city Bikaner (NW Rajasthan, India), *Journal of Communication Disorders*, 36, 53-59.
41. Spalding R. F. and Exner M. E., 1993 – Occurrence of nitrate in ground water – A review, *Journal of Environmental Quality*, 22, 392-402.
42. Stuart M. A., Rich F. J. and Bishop G. A., 1994 – Survey of nitrate contamination in shallow domestic wells of the inner coastal plain of Georgia, *Ground Water*, 33, 284-290.
43. Tavakoli A., Yazdani R., Shahmansouri M. R. and Isfahani B. N., 2005 – Chlorine residual efficiency in inactivating bacteria from secondary contamination, in Isfahan, 2002, *Eastern Mediterranean Health Journal*, 11, 3, 425-434.
44. United Nations 2001 – World population prospects: The 2000 Revision, United Nations, Population Division, Department of Economic and Social Affairs, New York, 59.
45. Upadhyay V. P., Rajeswar P. M., Ajay S. and Khazan S., 2005 – Eco Tools for Urban Waste Management in India, *Journal of Human Ecology*, 18, 253-269.
46. Vörösmarty C. J., Green P., Salisbury J. and Lammers R. B., 2000 – Global water resources: Vulnerability from climate change and population growth, *Science*, 289, 284-288.
47. World Health Organization, 2005 – Weekly Epidemiological Record, 3 June 2005, 80th Year/3 Juin 2005, 80e Année No. 22, 80, 193-200.
48. World Health Organization (WHO), 2007 – Guidelines for drinking-water quality, Incorporation first addendum, 1, Recommendations, 3rd edition, WHO, Geneva.
49. World Health Organization, 2008 – Guidelines for drinking-water quality, 3rd edition incorporating the first and second addenda, 1, Recommendations; WHO Press, Geneva, 515.
50. WHO/UNICEF 2000 – Global water supply and sanitation assessment, report, Geneva, WHO and UNICEF, www.who.org and www.unicef.org.
51. Zhao H. X., Mold M. D., Stenhouse E. A., Bird S. C., Wright D. E., Demaine A. G. and Millward B. A., 2001 – Drinking water composition and childhood-onset Type 1 diabetes mellitus in Devon and Cornwall, England, Diabet Medicine, 18, 709-717.

POLLINATION ECOLOGY CHARACTERISTICS OF *BARRINGTONIA RACEMOSA* (L.) SPRENG. (LECYTHIDACEAE)

*Jacob Solomon Raju ALURI *, Suvarna Raju PALATHOTI **, Dileepu Kumar BANISETTI **** and *Sravan Kumar SAMAREDDY **

* Andhra University, Department of Environmental Sciences, Visakhapatnam, India, IN-530003, solomonraju@gmail.com, sravankumarsamareddy@gmail.com
** International College of Engineering and Management, Department of Health and Safety Environmental Management, P. O. Box 2511, Pc 111, Muscat, Sultanate of Oman, raju@icem.edu.om
*** M. R. College (autonomous), Department of Botany, Vizianagaram, India, IN-535002, dillepbanisetti14@gmail.com

DOI: 10.2478/trser-2019-0017

KEYWORDS: *Barringtonia racemosa*, hanging racemes, late evening anthesis, hawk moth pollination, indehiscent fruits.

ABSTRACT

Barringtonia racemosa is an evergreen mangrove associate. It is an year-round bloomer that produces attractive pinkish-white flowers on long, hanging racemes. The flowers open during evening-night time during which only hawk moths swiftly visit them for nectar collection effecting both self- and cross-pollination. Fruits are large, single-seeded, indehiscent and buoyant, and disperse in the direction of tidal or ocean currents. Seeds are exposed only when fruits rot; when anchored in the muddy substratum, they germinate within two or three weeks to produce new plants.

ZUSAMMENFASSUNG: Charakteristische Merkmale zur Bestäubungsökologie von *Barringtonia racemosa* (L.) Spreng. (Lecythidaceae).

Barringtonia racemosa ist eine immergrüne Art der Mangrovengesellschaft. Sie blüht ganzjährig, wobei ihre attratktiven rosa-weißen Blüten lange, hängende Rispen bilden. Die Blüten öffnen sich zu Abend- und Nachtszeiten während denen sie nur flüchtig von Schwärmern zum Nektar saugen besucht werden und dabei Selbst- und auch Fremdbestäubung bewirken. Die Früchte sind groß, eingrifflig, geschlossen, schwimmfähig und verteilen sich in Richtung der Gezeiten- oder Ozeanströmungen. Die Samen werden nur dann freigelegt, wenn die Früchte sich zersetzen; wenn sie sich im schlammigen Substrat verankern, keimen sie innerhalb von zwei bis drei Wochen, wobei sich neue Pflanzen entwickeln.

REZUMAT: Caracteristicile ecologiei polenizării la *Barringtonia racemosa* (L.) Spreng. (Lecythidaceae).

Barringtonia racemosa este un component al mangrovelor sempervirescente. Înflorește de-a lungul întregului an, producând flori atractive, roz-alburii, pendente în raceme lungi. Florile se deschid seara-noaptea când doar molia-șoim le vizitează grăbit pentru colectare de nectar, efectuând atât autopolenizarea cât și polenizarea încrucișată. Fructele sunt mari, monoloculare, cu o singură sămânță, indehiscente, plutitoare și dispersate în direcția curenților marini sau oceanici. Semințele sunt etalate/eliberate doar la putrezirea fructelor; dacă se fixează în substratul mâlos, ele germinează în timp de două-trei săptămâni producând noi plante.

INTRODUCTION

Mangrove forests are an important coastal resource and vital to the socio-economic development of coastal people. The mangroves are sources of highly valued commercial products and fishery resources and also as sites for developing a burgeoning eco-tourism (Kathiresan and Bingham, 2001; Sabai and Sisitka, 2013).

The importance of pollination ecology in other ecosystems is often widely known but there is little information on pollination and pollinators of mangroves in India and other parts of the world. Since the reproduction of mangroves depends on their pollination mode and pollinating agents, it is essential to study pollination ecology of mangroves to take measures for their restoration (Tomlinson, 1986; Mitra et al., 2014).

Tanaka (2004) reported that *Barringtonia* is a genus of 56 species with a wide distribution in the tropics from eastern Africa to northern Australia. The genus name commemorates Daines Barrington, an 18th century botanist, jurist and antiquary. Prance (2012) revised the genus and recognized 69 species. He noted that this genus has three distinct areas of species diversity, namely the Malay Peninsula, Borneo, and New Guinea. But, of all the species recognized, only three of them, *B. asiatica*, *B. acutangula* and *B. racemosa* are extremely widespread and occur in lowlands near the sea or beside streams and dispersed by water. Of these, *B. racemosa* is a widespread in the mangrove forests of India. The specific name refers to the long racemes on which the pedicellate flowers are borne (Chantaranothai, 1995).

Tanaka (2004) reported that records of pollinators of *Barringtonia* genus are sparse. Start and Marshall (1976) documented that *Barringtonia* sp. is pollinated by Mariana fruit bat, *Pteropus mariannus* in West Malaysia. Marshall (1983) noted that *B. racemosa* is pollinated by bats. He also mentioned that *B. acutangula* with shaving-brush type floral characteristics is probably pollinated by bats. Kato (1999) suggested that *B. racemosa* may be pollinated by bats in Japan. However, he noted that pollinators of this species have not been observed so far. Tanaka (2004) reported that *B. racemosa* is visited for nectar by four moth species, *Asota heliconia riukiuana, Milionia basalis pyreri, Nevrina procopia* and *Erasmia pulchella fritzei* in Iriomote Island, Japan. Of these, the first three visited the flowers only once while the last one visited twice during the observation period. Based on his field study, he stated that *B. racemosa* is probably pollinated by moths because its flowers were not visited by any other animals, including bats. Further, he attributed fruit-set in this species to the foraging activity of visiting moths.

Chantaranothai (1995) reported that *B. racemosa* is a coastal species that flourishes well under humid and moist conditions. It is distributed along tropical and sub-tropical coasts in South Africa, Mozambique, Madagascar, India, Sri Lanka, Malaysia, Thailand, Laos, southern China, northern Australia, coastal Taiwan, the Ryukyu Islands and Polynesian Islands. Boo Chich et al. (2006) noted that *B. racemosa* is rare in the wild and occurs in damp places in mangroves, tidal rivers, sandy and rocky shores and freshwater swamps in Singapore. Keng et al. (1998) reported that *B. racemosa* is listed as Critically Endangered on the Red List of threatened plants of Singapore. In India, it is distributed on the west coast from Konkan southwards through Karnataka, Kerala, Tamil Nadu, Sundarbans, and in the Andamans. Mahanti and Kumar (2017) reported that *B. racemosa* is a common and major species in the estuary situated adjacent to Poovar Island, the formation of which is a natural wonder because the lake, river, sea and beach meet the land. Arun et al. (2011) reported that *B. racemosa* is distributed in the Mangrove Reserve Forest in East Godavari District, Andhra Pradesh, India. The present study also found that this species occurs in this mangrove forest but it is a very rare one growing landward of the Coringa Estuary. Rajith et al. (2010) noted that this species is

used in India as firewood and for its root decoction to stop bleeding during the post-delivery period. Pauku (2006) mentioned that *B. racemosa* is used as a good living fence and for treating venereal diseases in the Solomon Islands. Boo Chich et al. (2006) documented that *B. racemosa* is used for different purposes in Singapore. The powder of all parts of this plant is used as fish poison while the extract of these parts is an insecticide. The bark and root possess high tannin content and hence are used as tanning agents. This species is often cultivated as an ornamental tree in parks, gardens and along roadsides because its red and white flowers borne on long, hanging flowering shoots are attractive and provide aesthetic appeal (Umaru et al., 2018). Despite the importance of *B. racemosa* in traditional medicine and as a constituent of landward species of mangrove forest throughout its distribution range, there is a paucity of information on the pollination ecology of this species. Therefore, the present study was made to provide floral biology and pollination of this species as this information is important to know its sexual system, pollination syndrome, pollinators and fruiting aspects.

MATERIAL AND METHODS

Barringtonia racemosa (L.) Spreng. (Lecythidaceae) occurring in Godavari Coringa mangrove forest (16°30'-17°00'N and 82°10'-80°23'E) located in Andhra Pradesh, India, was used for the study of floral biology and pollination aspects during June 2017 to July 2018. The morphological characters of flowers were recorded using 30 flowers collected at random. Flower-opening schedule was recorded based on ten days of field observations. Ten mature buds on five plans were used to record the time and mode of anther dehiscence. 25 mature buds were collected into a Petri dish and used subsequently to count the number of pollen grains per anther. The standard procedure given in Dafni et al. (2005) was used for calculating the pollen output per anther. Ten flowers were used to measure the average volume of nectar produced per flower and it was noted in µl. Hand Sugar Refractometer was used to record sugar concentration in the nectar. The commencement and cessation of stigma receptivity was tested with H_2O_2 as given in Dafni et al. (2005). The insect species visiting the flowers were observed during day time from early evening to late night on different days in different months for the probing behaviour, forage collected, contact with sex organs that result in pollination and inter-plant foraging activity. Fruiting aspects such as fruit and seed characters, fruit dispersal and seed germination were observed in the field.

RESULTS

Barringtonia racemosa is commonly called "Powder-puff Mangrove Associate". It is a medium-sized tree that grows in the landward side or edges of estuaries of mangrove forest (Fig. 1a). It is a medium-sized tree species propagated by seed and stem cuttings. The bark is silvery and smooth at the early growth stage and slowly develops fissures as it ages. The leaves are large and borne alternately, clustered at the ends of branches and appearing as in rosette-form. The midribs and branching veins are conspicuous on both sides of the leaves (Fig. 1b). Flowering occurs year-long without any concentrated flowering at any time of the year. However, the flowering is relatively sparse during the dry season when the plant sheds leaves for a short period. The flowers are produced on long hanging and pendulous racemes of almost one meter length; they open basipetally (Figs. 1c, 2a, b). They are short-stalked, large (35-45 mm long and 71 to 89 mm wide) and bisexual. The calyx is fused at the base and separated towards apex into four greenish pink sepals. The corolla consists of four elliptic free whitish

petals but basally attached to the staminal tube. The stamens are numerous, long, white to pinkish and arranged in five-six whorls of which the innermost whorl is without anthers and all other whorls are with basifixed fertile anthers; they collectively form a large central mass extending into up to 40 mm diameter. The ovary is globular, two-four loculed and each locule contains one-two ovules. The style is simple, filiform, 20-50 mm long and tipped with obtuse stigma. A part of the style and the obtuse stigma extends beyond the height of stamens of all whorls from bud stage and during the entire life of the flower.

Figure 1: *Barringtonia racemosa*; a. Habitat; b. Foliage, c; Flowering phase; d. Fruiting phase.

The mature buds are pinkish-red and split open in the early evening to expose the huge mass of stamens in pink and white sprays and show full bloom during night time (Figs. 2c, d). At that time, they produce a pungent sweet odour which persists until the next day, remain open all night and the staminal mass falls off on the early evening of the next day. In a full grown raceme, almost half of the mature buds bloomed simultaneously. A flower produces 3.5 ± 1.2 µl of nectar with 23-29% sugar concentration. With so many flowers opening at inflorescence level on the same day, individual plants secrete ample volume of nectar. The anther dehiscence occurs by longitudinal slits during flower-opening period and the stigma attains receptivity about an hour after complete flower-opening and ceases before sunrise on the following day. The pollen output varied from 659 to 980 grains per anther. With so many anthers at flower and inflorescence level dehiscing on the same day, individual plants supply huge amount of pollen for pollination. After the shedding of petals and staminal mass in individual flowers, the ants such as *Camponotus* sp. and *Oecophylla* sp. crowded at the flowers seeking nectar at the base of the corolla, but their role in pollination was found to be ruled out because the flowers were devoid of staminal mass. After the fall of petals and staminal mass from the flowers that opened on the previous day, the next batch of mature buds began to open gradually in the late evening and bloomed completely during which they were not crowded by ants.

Figure 2: *Barringtonia racemosa*; a. Hanging inflorescence in bud phase; b. Inflorescence in flowering phase; c-d. Close-up view of flowers; e. Fruits in development phase; f. Fully developed fruits.

As soon as the mature buds opened, they were foraged for nectar by the hawk moths *Agrius convolvuli* L., *Macroglossum sitiene* Walker, *M. gyrans* Walker, *Nephele hespera* Fabr. and *Hippotion rosetta* Swinhoe. They visited the flowers very swiftly usually from base to top and occasionally from top to base. They hovered at the flowers, inserted the proboscis and obtained nectar in one to two seconds. In so doing, their proboscis, head and underside of wings contacted the stigma and stamens and this contact facilitated pollen transfer from the stamens to the moths and from moths to the stigma resulting in pollination. As they were swift fliers, they foraged numerous flowers on different racemes on different plants in quest of more nectar and thereby promoted the rate of cross-pollination. The foraging activity of moths ceased after 21:00 h. The flowers were not visited by any other animals later in the night and also on the next day, before the fall of the staminal mass.

The fruit is a tetragonous, 30-65 mm long indehiscent drupe tapering at the base and truncate at the apex (Fig. 1d). It is green initially and reddish when ripe but crowned by the persistent calyx. Each fruit contains a single 20-35 mm long aromatic seed surrounded by spongy and fibrous flesh (Figs. 2e, f). It floats and disperses by ocean currents for several months. After dispersal, the seed gradually gets exposed by rotting of fruit material, anchors in the substratum when soil is exposed and germinate within two-three weeks. The root appears from the calyx end and the shoot appears from the other end of the fruit. The seedling slowly grows to produce a new plant.

DISCUSSION

The genus *Barringtonia* is a mangrove associate and distributed towards landward estuaries. It is an important species in estuaries due to its preference for humid and damp areas (Kabir et al., 2014). In the present study also, it is found growing in the landward Coringa Mangrove Forest but it has become very rare due to land use changes along the landward side of this forest. It is an evergreen tree species but displays a leafless state for a brief period during the dry season. But, it is a year-long bloomer and its pinkish-white flowers borne on long racemes are quite attractive from a very long distance; this species with its long flowering racemes add aesthetic appeal to the entire estuarine area.

Bat- and moth-pollinated plant species have been reported to have similar floral characteristics. Night-time blooming, brush-like or bell-shaped flowers with a strong fruity, soar or musty odour and large quantity of dilute nectar constitute bat-floral syndrome while night-time blooming, narrow-deep shaped flowers with strong or semi-strong aromatic odour and semi-large quantity of dilute nectar constitute moth-floral syndrome (Kato, 1993; Proctor et al., 1996). In *Barringtonia racemosa* the flower moths and bats in South Africa (Strey, 1976). In the present study, *B. racemosa* has been found to display night-time blooming, long and brush-like flowers on long hanging racemes, strong sweet odour emitted from the flowers upon anthesis and moderate quantity of semi-dilute nectar which collectively suggest moth-floral syndrome. In line with this, the flowers have been pollinated exclusively by hawk moths during late evening and early night period. As the moths are swift fliers, they forage numerous flowers on different plants, the foraging behaviour of which promotes cross-pollination rate. In Iriomote Island of Japan also, *B. racemosa* has been reported to be foraged and probably pollinated only by moths (Tanaka, 2004). The present study does not agree with the report by Marshall (1983) that *B. racemosa* is bat-pollinated. However, further studies are required throughout the distribution range of this species to define its pollinator classes according to their availability in respective mangrove habitats in different geographic regions. Thus, Tanaka (2004) expressed that bats are extinct on the Iriomote Island of Japan and this could be the reason for the absence of foraging visits of bats on *B. racemosa* on this island. In the present study area also, roosts of bats occur neither in the vicinity of the mangrove forest nor far away from the forest on land. Therefore, it is not unreasonable to suggest that *B. racemosa* with floral characteristics adapted for bat pollination is not pollinated by bats because of non-availability of bats in the area. Therefore, *B. racemosa* is pollinated by moths or bats depending on their availability in the habitat.

It is important to note that the stamens are well exposed from the flowers of *B. racemosa*. But, the humid habitat is not conducive for making the pollen dry to powdery form for their easy dispersal by wind. Further, the basifixed arrangement of the anthers also does not facilitate for free movement of anthers to liberate pollen into the air. Hence, wind-pollination in this species can be totally ruled out. Apart from this, the pollen of *B. racemosa* is an important source for pollen-collecting bees such as honey bees and carpenter bees as each flower and raceme provides ample pollen. However, bee foraging activity was not observed on the flowers at the study area.

Strey (1976) reported that in *B. racemosa*, the flowers, after shedding petals and stamens are crowded with ants due to the presence of nectar around the ovary. In the present study also, *Camponotus* and *Oecophylla* ants crowd the flowers and racemes after shedding the petals and stamens, and feed on the left-over nectar around the ovary. Their feeding activity has no role in pollination but their presence may deter insects that cause harm to the ovary.

Van Wyk and Van Wyk (1997) reported that *B. racemosa* produces fruits with a single seed which is enclosed by spongy and fibrous flesh. In the present study also, it was found that this species produces fruits with a single aromatic seed enclosed by spongy and fibrous material which provides them buoyancy and allows them to disperse in tidal water. Since the fruits are indehiscent, the seed remains inside and germinates only when the fruit rots and settles in the muddy substratum. After the seed anchors in the substratum, it germinates within two-three weeks and gradually produces a new plant.

CONCLUSIONS

Barringtonia racemosa is an evergreen mangrove associate species. It flowers year-long and produces attractive pinkish-white flowers on hanging racemes. It is exclusively pollinated by hawk moths. Fruits are single-seeded, indehiscent and buoyant. They are dispersed by ocean currents and seeds upon rotting of fruits germinate within a short time to produce new plants. This tree species is valued for traditional medicine and as an ornamental due to its attractive flowers. It is suggested that its habitat should be enhanced with hawk moth larval host plant species in order to promote fruit set rate, especially through cross-pollination in this species.

ACKNOWLEDGEMENTS

We thank Dr. Venkata Ramana K., Young Scientist, DST-SERB, Dr. Prasada Rao C., Guest Faculty, Department of Botany, Andhra University, Visakhapatnam, for field assistance in mangrove forest.

REFERENCES

1. Arun P. R., Murugeşan M. and Nikhil Raj P. P., 2011 – Impacts of proposed seismic survey operations on the avifauna and wildlife of reserve forest areas of KG basin project of oil India Limited, Salim Ali Centre for Ornithology and Natural History, Coimbatore, 39.
2. Boo Chich M., Kartini O.-H. and Ou-Yang C. L., 2006 – 1001 Gardens plants in Singapore, National Parks Board, Singapore, 501.
3. Chantaranothai P., 1995 – Barringtonia (Lecythidaceae) in Thailand, *Kew Bulletin*, 50, 677-694.
4. Dafni A., Kevan P. G. and Husband B. C., 2005 – Practical Pollination Biology, Enviroquest Limited, Ontario, 90.
5. Kabir Z. K. M., Rahman M. S., Islam R. M., Paul P. K., Rahman S., Jahan R. and Rahmatullah M., 2014 – A review on a mangrove species from the Sunderbans, Bangladesh, Barringtonia racemosa (L.) Roxb., *Amerian-Eurasian Journal of Sustainable Agriculture*, 7, 356-372.
6. Kathiresan K. and Biningham B. L., 2001 – Biology of mangroves and mangrove ecosystems, *Advances in Marine Biology*, 40, 81-251.
7. Kato M., 1993 – Emergence of pollinators and evolution of bees, in Animals attracted by flowers, Inoue T. and Kato M. (eds), Heibonsha Limited, Tokyo, 33-78.
8. Kato M., 1999 – Symbiosis of plants and animals at night, in Natural history of flowers, Ohara M. (ed.), Hokkaido University Press, Sapporo, 74-88.
9. Keng H., Chin S. C. and Tan H. T. W., 1998 – The Concise Flora of Singapore: Monocotyledons, 2, NUS Press, Singapore, 215.
10. Mahanti P. and Kumar S., 2017 – Major biodiversity of Poovar Beach along the Neyaar River: a tourism destination of Kerala, India, *International Research Journal of Environmental Sciences*, 6, 72-75.
11. Marshall A. G., 1983 – Bats, flowers and fruit: evolutionary relationships in the Old World, *Biological Journal of Linnean Society*, 20, 115-135.
12. Mitra B., Biswas O., Roy S. and Chakraborti U., 2014 – Pollinators of mangroves in the perspective of Indian Sunderbans, *ENVIS Newsletter*, 21, 6-10.
13. Pauku R. L., 2006 – Species profiles for Pacific Island Agroforestry, 19, www.traditionaltree.org
14. Prance G. T., 2012 – A Revision of Barringtonia (Lecythidaceae), *Allertonia*, 12, 1-161.
15. Proctor M., Yeo P. and Lack A., 1996 – The natural history of pollination, Harper Collins Publishers, London, 479.
16. Rajith N. P., Navas M., Thaha A. M., Manju M. J., Anish N., Rajasekharan S. and George V., 2010 – A study on traditional mother care plants of rural communities of South Kerala, *Indian Journal of Traditional Knowledge*, 9, 203-208.
17. Sabai D. and Sisitka H., 2013 – Analysing learning at the interface of scientific and traditional ecological knowledge in a mangrove ecosystem restoration scenario in the eastern coast of Tanzania, *Transylvanian Review of Systematical and Ecological Research*, 15.2, 185-210.
18. Start A. N. and Marshall A. G., 1976 – Nectarivorous bats as pollinators of trees in West Malaysia, in Variation, breeding and conservation of tropical forest trees, Burley J. and Styles B. T. (eds), Academic Press, London, 141-150.
19. Strey R. G., 1976 – Barringtonia racemosa, *The Flowering Plants of Africa*, 43, 1706.
20. Tanaka N., 2004 – Pollination of Barringtonia racemosa (Lecythidaceae) by moths on Iriomote Island, Japan, *Annals of the Tsukuba Botanical Garden*, 23, 17-20.
21. Tomlinson P. B., 1986 – The botany of mangroves, Cambridge University Press, New York, 419.
22. Umaru I. H., Ahmed F. B., Umaru H. A. and Umaru K. I., 2018 – Barringtonia racemosa: phytochemical, pharmacological, biotechnological, botanical, traditional use and agronomical aspects, *World Journal of Pharmacy and Pharmceutical Sciences*, 7, 78-121.
23. Van Wyk A. E. and Van Wyk P., 1997 – Field guide to the trees of southern Africa, Struik, Cape Town, 732.

IS *PENICULUS FISTULA FISTULA* NORDMANN, 1832 REPORTED ON *CORYPHAENA HIPPURUS* LINNAEUS, 1758 FROM TURKEY? UPDATED DATA WITH FURTHER COMMENTS AND CONSIDERATIONS

Ahmet ÖKTENER *and *Murat ŞİRİN* **

* Sheep Research Institute, Department of Fisheries, Çanakkele Street 7 km, Bandırma, Balıkesir, Turkey, TR-10200, ahmetoktener@yahoo.com, mothocya@hotmail.com

DOI: 10.2478/trser-2019-0018

KEYWORDS: *Peniculus fistula*, *Mullus*, *Coryphaena*, Marmara Sea, checklist, host.

ABSTRACT

53 striped surmullet, *Mullus surmuletus* Linnaeus, 1758 (Teleostei, Mullidae), were collected from the Marmara Sea, Turkey and examined for metazoan parasites in July 2017. The parasitic copepod, *Peniculus fistula fistula* Nordmann, 1832 (Pennellidae), was collected from all the hosts, both on fins and body surface. This is the second report of this copepod in Turkish marine waters. Although *Peniculus fistula fistula* was reported for the first time on *Coryphaena hippurus* Linnaeus, 1758 by Öktener (2008), there was an indefiniteness and doubt about the occurrence of this parasite. This study aimed to confirm occurrence of *Peniculus fistula fistula* in Turkey and to present revised host list with comments.

ZUSAMMENFASSUNG: Ist der an *Coryphaena hippurus festgestellte* Linnaeus, 1758 Ruderfußkrebs *Peniculum fistula fistula* Nordmann, 1832 aus der Türkei? Aktualisierte Angaben mit weiteren Kommentaren und Betrachtungen.

53 Steifenbarben *Mullus surmuletus* Linnaeus, 1758 (Teleostei, Mullidae) wurden aus dem Marmara Meer, Türkei gesammelt und im Juli 2017 auf Vorkommen metazoischer Parasiten untersucht. Der parasitäre Ruderfußkrebs *Peniculus fistula fistula* Nordmann, 1832 (Pennellidae, Copepoda) wurde von allen Wirtstieren, sowohl von den Kiemen, als auch von der Körperoberfläche gesammelt. Vorliegender Bericht ist der zweite betreffend das Vorkommen dieser Copepoden Art in marinen Gewässern der Türkei. Obwohl *Peniculus fistula fistula* zum erstenmal von Öktener (2008) an *Coryphaena hippurus* Linnaeus, 1758 gemeldet wurde, gab es eine Unbestimmtheit und Zweifel betreffend das Vorkommen dieses Parasiten. Vorliegende Untersuchung ist darauf ausgerichtet, das Vorkommen von *Peniculus fistula fistula* in der Türkei zu bestätigen und eine revidierte Liste der Wirte mit Kommentaren vorzulegen.

REZUMAT: Copepodul *Peniculum fistula fistula* Nordmann, 1832 semnalat pe *Coryphaena hippurus* Linnaeus, 1758 este din Turcia? Date actualizate cu comentarii și considerații.

53 de pești din specia *Mullus surmuletus* Linnaeus, 1758 (Teleostei, Mullidae) au fost colectați în luna iulie 2017 din Marea Marmara, Turcia și examinați în vederea identificării de paraziți metazoici. Copepodul parazitar *Peniculus fistula fistula* Nordmann, 1832 (Pennellidae, Copepoda) a fost colectat pe toate speciile gazdă atât de pe înotătoare, cât și de pe suprafața corpului. Prezentul raport este al doilea referitor la prezența acestui copepod în apele marine ale Turciei. Cu toate că *Peniculus fistula fistula* a fost semnalat pentru prima dată de Öktener (2008) pe *Coryphaena hippurus* Linnaeus, 1758 a existat o nedumerire și dubii asupra prezenței acestui parazit. Prezentul studiu are obiectivul de a confirma existența speciei *Peniculus fistula fistula* în Turcia și a prezenta o listă revizuită și comentată a gazdelor.

INTRODUCTION

In Turkey, the total length of the sea coast is 8,333 km, including the Black Sea, the Mediterranean Sea, the Aegean Sea and the Marmara Sea (Kılıç, 1999). The Marmara Sea being an unique inland sea displays the transitional environment between the Black Sea and the Mediterranean Sea (Bănăduc et al., 2016). Bilecenoğlu et al. (2014) indicated the fish species diversity according to Turkish seas as follows: the Aegean Sea 449 sp.; Turkish Mediterranean Sea coasts 441 sp.; Marmara Sea 257 sp.; Turkish Black Sea coasts 154 sp. There are limited studies on the parasitic copepods of fish in the Marmara Sea.

The striped surmullet, *Mullus surmuletus* Linnaeus, 1758 (Perciformes, Mullidae) is a fish species of important commercial value, distributed in Eastern Atlantic, the Mediterranean Sea and the Black Sea. It is a carnivorous fish that feeds mainly on benthic organisms such as shrimps and amphipods, polychaetes, molluscs, and benthic fishes. It is a demersal and oceanodromous fish. (Froese and Pauly, 2017)

Members of Pennellidae (Copepoda, Siphonostomatoida) are parasitic copepods of marine fish and cetaceans. The genus *Peniculus* Nordmann, 1832 (Pennellidae) includes 11 nominal species. The species of the genus penetrate often the fins of their hosts (Boxshall, 1986; Vidjak et al., 2008; Venmathi Maran et al., 2012; Moon and Hoi, 2014).

Five species of parasitic copepods (*Caligus centrodonti* Baird, 1850; *Colobomatus mulli* Essafi et al., 1983; *Colobomatus steenstrupi* Richiardi, 1876; *Hatschekia mulli* van Beneden, 1851; *Peniculus fistula fistula* Nordmann, 1832) from the surmullet have been listed by Raibaut et al. (1998).

Peniculus fistula fistula Nordmann, 1832 was reported on *Coryphaena hippurus* Linnaeus, 1758 from Aegean Sea, Turkey by Öktener (2008), there was an indefiniteness and doubt about the occurrence of this parasite. This study aims to confirm occurrence of *Peniculus fistula fistula* in Turkey and to present the revised list of host species parasitizing *Peniculus fistula fistula.*

MATERIAL AND METHODS

53 surmullets were sampled by trawling from Marmara Sea, Turkey (40°28’N, 27°15’E – 40°28’N, 27°13’E) in 2017. Parasite recovered from the hosts were fixed in 70% ethanol. Some specimens were cleared in lactic acid and their appendages were dissected out by using Wild M5 stereo microscope. Dissected parts were mounted on slides in glycerin-gelatine mounting medium. The photos were taken with the aid of Canon camera (EOS 1100D) connected to a microscope. All measurements are in millimeters. Terminology of appendage structure follows (Boxshall, 1986; Vidjak et al., 2008; Venmathi Maran et al., 2012; Moon and Hoi, 2014). The scientific names, synonyms of host were checked through the World Register of Marine Species and related online databases (Walter and Boxshall, 2018). The information of feeding habits, habitat characteristics of host were prepared according to Froese and Pauly (2018). The voucher specimen (ESFM- COP/2017-5: *Peniculus fistula fistula*) were deposited in the collections of the Museum of Ege University (ESFM), Faculty of Fisheries, Turkey.

RESULTS AND DISCUSSION

Siphonostomatoida Thorell, 1859; Pennellidae Burmeister, 1835; *Peniculus* Nordmann, 1832; *Peniculus fistula fistula* Nordmann, 1832 (Figs. 1-3).

Infestation values: 82.75% striped surmulet were infested with *Peniculus fistula fistula*, with a mean intensity of 1.4 and abundance of 1.7.

Infestation of site: parasites were attached to host with their antenna embedded in all of the fins ray and body surface (Figs. 3a-f).

Figure 1: *Peniculus fistula fistula* Nordmann, 1832 ♀.

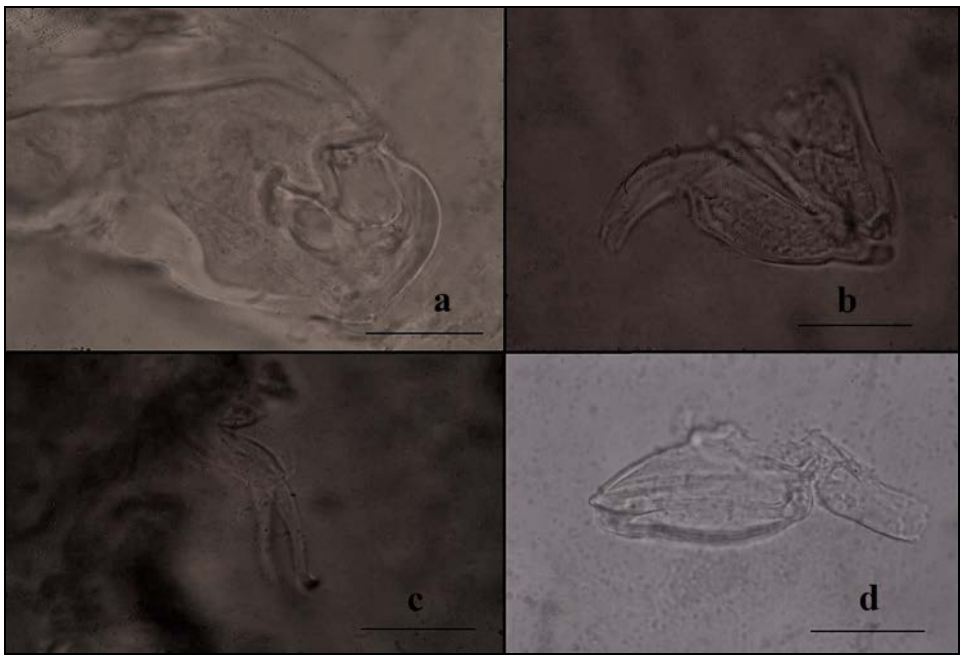


Figure 2: *Peniculus fistula fistula* a) antenna (0.02 mm),
b) maxilla (0.02 mm), c) maxillule (0.03 mm), d) leg one (0.045 mm).

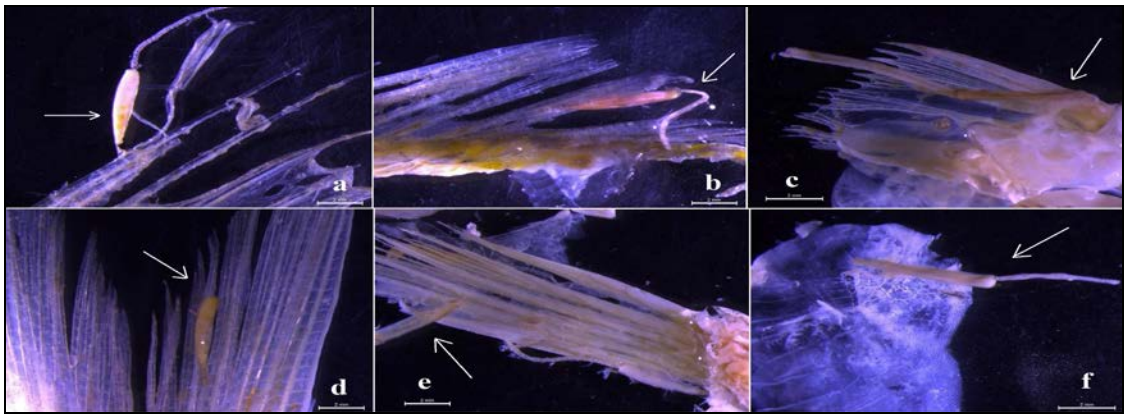


Figure 3: Infestation sites on host of *Peniculus fistula fistula* a) first dorsal fin, b) second dorsal fin, c) anal fin, d) caudal fin, e) pectoral fin, f) scale (two mm).

Morphological characters of postmetamorphosis female. Body (Fig. 1) 5.47 (4.28-6.49; n = 19) mm long, comprising oval head, slender neck, large trunk and reduced abdomen. Cephalothorax 0.354 (0.28-0.69; n = 19) mm longer than wide 0.24 (0.21-0.26; n = 19), ovoidal, flattened dorsally but convex ventrally, with pair of rounded swellings posteriorly to leg one (Fig. 3c). Neck 0.23 (0.17-0.3; n = 19) mm long, slender, shorter than cephalothorax, consisting of three somites bearing legs one, two, and three. Trunk cyclindrical, 6.7 times longer 4.65 (3.46-5.64; n = 19) than wide 0.69 (0.52 x 0.79 mm), bearing leg four proximally. Abdomen elongate, slightly rounded. Fourth pedigerous somite trapezoidal, incorporated into anterior end of trunk. Egg sacs 7.83 (4.56-11) mm long, linear, longer than body. Caudal rami located on abdominal process, with two long, three subequal medium-sized, and one small setae. Antennules, maxilliped, leg five absent. Antenna (Fig. 2a) two-segmented, chelate; terminal segment claw-like, with small seta at base. Maxillule (Fig. 2c) with two lobes having one short and two long setae. Maxilla (Fig. 2b) two-segmented; proximal segment broad; distal claw blunt and curved, with transverse striations and fine spinules. Legs one (Fig. 2d) and two located close together, gap between legs two-three, and legs three-four almost equal. Legs one-two with one setule on anterior margin.

Examination of the parasite specimens showed that they were *Peniculus fistula fistula* Nordmann, 1832 (Pennellidae) according to the general drawings and descriptions given by Boxshall (1986), Vidjak et al. (2008), Venmathi Maran et al. (2012), Moon and Choi (2014).

Peniculus fistula fistula was collected for the first time on the ventral fin of the common dolphinfish, *Coryphaena hippurus* from the Aegean Sea, Turkey (Öktener, 2008). But Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) have made interpretations about Öktener's (2008) article.

Bunkley-Williams and Williams (2009) disapproved that Öktener (2008) examined few fish as quantitative for determination parasite fauna of the common dolphinfish. As is known, it is quite expensive to provide the common dolphinfish in large quantities. It is difficult to provide the project or scholarsip about determination of fish parasite fauna. Öktener's (2008) study was carried out with author's limited possibilities. Thus, author obtained small collection of hosts. Öktener (2008)' short paper did not describe a new species. Although, Bunkley-Williams and Williams (2009) criticized Öktener (2008) for examination of limited fish for determination parasite fauna of the common dolphinfish, Bunkley-Williams et al. (1998). Bunkley-Williams and Williams (2000) reported parasite records about limited fish samples. For example, Bunkley-Williams and Williams (2000) found *Glossobius*

impressus (Cymothoidae) on just one specimen of *Hirundichthys affinis* from Caribbean. Bunkley-Williams et al. (1998) also determined one parasite on five samples examined of *Micropogonias furnieri*; one parasite on five samples examined of *Hemiramphus brasiliensis*; one parasite on six samples examined of *Scomberomorus brasiliensis*. Thus in these cases, should be more appropriate to use the term "accidential infestation" for *Peniculus fistula fistula* as reported in Öktener (2008).

Despite the fact that Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) think that Öktener's (2008) article is a checklist because of including a list, we would like to stress that Öktener (2008)' article is a short communication which consist of four pages, not a checklist. Author's aim was not to present all of hosts of *Peniculus fistula fistula* or he doesn't use words as "checklist" or "all of parasites" in this publication. Öktener's publications are generally reports about ecto parasites including copepod, isopod, monogenean (Öktener, 2000, 2008; Kritsky and Öktener, 2015; Öktener et al., 2015). Öktener also published two checklists of marine and freshwater fish from Turkey in 2003 and 2005, excluding reports.

Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) claimed and critisizms that any other parasite groups was included in the work of Öktener (2008). Generally, checklist studies may include several parasite groups such as protozoa, myxozoa, helminths, etc. Öktener (2008) presented some samples belonging to helminth and crustacean groups of *Corypheana hippurus* in the World.

However, he did not give other parasite groups because of his aim is not to produce a checklist. In addition, it was impossible to prepare a checklist of the common dolphinfish on 2008 due to very limited literature. Although, Öktener (2008) presented *Peniculus fistula fistula* as short report with a short parasite-host list according to referee's recommendation, Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) created a parasite checklist of dolphinfish behalf to Öktener. Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) also compared this created checklist with Palko et al. (1982), Dyer et al. (1997), Öktener (2008), Luna (2009) and Williams and Bunkley-Williams (2010). These checklist studies (database, checklist) were performed by professors and experienced scientists in universities.

Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) claimed that Öktener (2008) gave few synonyms, erraneous and missing information about host of this parasite. Science does not move in a straight line, but in a zig-zag one. All of scientists know that synonyms and valid names of fish and parasites may change during the years. For example, *Meinertia* (*Ceratothoa*) *potassoniensis* and *Ceratothoa poutassouiensis* being typical parasite of *Micromesistius poutassou* which is actually *Elthusa poutassouiensis* (Öktener et al., 2018). Moreover, *Peniculus pissipes* Wilson, 1917 was accepted as a synonym of *Peniculus fistula fistula* according to Kabata and Wilkes (1977), Alexander (1983), and Boxshall (1986).

Bunkley-Williams and Williams (2009), Williams and Bunkley-Williams (2009, 2010) claimed that Öktener (2008) have not given some references. However, it should be considered that the publication date of Vidjak et al. (2008) occurred in the same year of the paper of Öktener (2008) so was no access to that publication. In addition, Öktener (2008) could not give some references (Wilson, 1917, 1935) because of two articles not available for author.

Table 1: Hosts of *Peniculus fistula fistula* in alphabetical order; * Hosts after those listed by Bunkley-Williams and Williams (2009); ** Hosts for those not listed by Bunkley-Williams and Williams (2009).

Hosts	Authors
Atherina boyeri	Brian (1906)
Atherinops affinis	Hobson (1971)
***Anisotremus davidsonii*	Hobson (1971)
**Anisotremus scapularis*	Castro-Romero et al. (2016)
Belone belone	Vidjak et al. (2008)
Boops boops	Zuniga and Suau (1967), Olmo (2008)
***Brachyistius frenatus*	Hobson (1971)
Capros aper	Delamare Deboutteville and Nunes Ruivo (1951)
**Cheilotrema fasciatum*	Castro-Romero et al. (2016)
***Cheilotrema saturnum*	Hobson (1971)
**Chromis crusma*	Castro-Romero et al. (2016)
**Chromis notata*	Moon and Choi (2014)
Coryphaena hippurus	Öktener (2008)
Cymatogaster aggregata	Love and Moser (1983) (personal communication Hanan D. A.)
Diplodus annularis	Brian (1917)
Diplodus vulgaris	Brian (1906)
***Embiotoca jacksoni*	Love and Moser (1983) (communication with Robinson G.), Hobson (1971)
**Girella laevifrons*	Castro-Romero et al. (2016)
Girella nigricans	MacGinitie (1937), Wilson (1935b)
**Hemilutjanus macrophthalmus*	Castro-Romero et al. (2016)
Hypsypops rubicundus	MacGinitie (1937), Wilson (1935)
Hypsurus caryi	Hobson (1971), Love and Moser (1983)
**Isacia conceptionisn*	Castro-Romero et al. (2016)
Lampris guttatus	Brian (1898)
Lithognathus mormyrus	Zuniga and Suau (1967)
Liza richardsonii	Boxshall (1986)
Medialuna californiensis	Hobson (1971)
***Micrometrus minimus*	Hobson (1971)
**Mugil cephalus*	Castro-Romero et al. (2016)
Mullus barbatus barbatus	Delamare Deboutteville and Nunes Ruivo (1951)
Mullus surmuletus	Delamare Deboutteville and Nunes Ruivo (1951), this study
**Odonthestes regia*	Castro-Romero et al. (2016)
**Pagellus bogaraveo*	Gooding (1957), Hermida et al. (2013), Hermida et al. (2015)
Pagellus erythrinus	Delamare Deboutteville and Nunes Ruivo (1951), Larraneta (1964), Boxshall (1986), Gooding (1957)
Pagrus pagrus	Ramdane and Trilles (2007)

Table 1 (continued): Hosts of *Peniculus fistula fistula* in alphabetical order; * Hosts after those listed by Bunkley-Williams and Williams (2009); ** Hosts for those not listed by Bunkley-Williams and Williams (2009).

Hosts	Authors
***Paralabrax clathratus*	(Love and Moser 1983) (personal communication Schultze D.)
***Paralabrax nebulifer*	(Love and Moser 1983) (personal communication Schultze D.)
Phanerodon furcatus	Hobson (1971), Love and Moser (1983)
**Prolatilus jugularis*	Sep'ulveda et al. (2004), Castro-Romero et al. (2016)
Pseudopercis semifasciata	Claus (1868)
***Rhacochilus toxotes*	Hobson (1971)
***Rhacochilus vacca*	Hobson (1971)
Scorpis lineolata	Boxshall (1986)
Synagrops microlepis	Capart (1959)
***Trachurus symmetricus*	Hobson (1971)
Trachurus trachurus	Candeias (1955)
Trachurus picturatus	Candeias (1955)
Zeus faber	Nordmann (1832), Brian (1906)
Xenistius californiensis	Sikkel (1985)

In this study, forty nine host species parasitizing *Peniculus fistula fistula* were listed in table 1. Bunkley-Williams and Williams (2009) presented a host checklist of *Peniculus fistula fistula*. They determined 40 host species of *Peniculus fistula fistula*, but it includes some forgetten host and incorrect host.

Williams and Bunkley-Williams (2009) presented *Symphodus melanocercus* on host list of *Peniculus fistula fistula.* When investigated this host, one reference is only found. Arnal and Moran (2001) found *Peniculus fistula fistula* in the gut of host as diet of *Symphodus melanocercus*. Grutter (2002) listed that several parasitic copepods (caligids, pennellids, bomolochids, pandarids, hastchekia, and lernaeids) were eaten by the cleaner fish. Thus, *Symphodus melanocercus* is removed from the present table.

Hosts of *Peniculus fissipes* were added as hosts of *Peniculus fistula fistula* in this table. Hosts of *Peniculus fistula fistula* reported by Wilson (1917) and Boxshall (1986) were not added to table because of uncertain of valid species level.

The hosts parasitism with *Peniculus fistula fistula* was examined according to order characteristics 84% of 49 host belongs to Perciformes, and 16% to Zeiformes, Atheriniformes, Beloniformes, Mugiliformes, Lampriformes. The hosts parasitism with *Peniculus fistula fistula* was examined according to family characteristics 30% of 49 host belongs to Embiotocidae (eight species) and Sparidae (seven species), and 70% to Acropomatidae, Atherinidae, Atherinopsidae, Belonidae, Caproidae, Carangidae, Haemulidae, Kyphosidae, Lampridae, Mugilidae, Mullidae, Pinguipedidae, Pomacentridae, Sciaenidae, Serranidae, Sparidae, Coryphaenidae and Zeidae. The hosts parasitism with *Peniculus fistula fistula* was examined according to habitat selections; 45% of 49 host fish species are demersal; 21% of them benthopelagic; 12% reef-associated; 14% pelagic-neritic; 4% bathypelagic, 4% pelagic-oceanic. The hosts parasitism with *Peniculus fistula fistula* examined according to feeding habits; 63% of 49 host fish species are carnivorous; 29% omnivorous, 8% herbivorous.

Öktener (2014, 2015) revised two checklists regarding helminth of marine and freshwater fish of Turkey, after 2003 and 2005. For example, after the helminth checklist of marine fish in Turkey was published by Öktener (2005), the number of parasite species increased from 114 to 198, to date (Öktener, 2014). Alaş and Öktener (2015) compared both online database such as WoRMS, Fishbase and checklist studies about fish-parasite. The publications concerning fish-parasite checklist studies are important taxonomic documents. These publications aim to determine: a) the biological diversity, b) the host selectivity, c) the geographic distribution of fish zoonoses, d) the fish-parasite relationships, and e) the complexity of fish parasite fauna among different environments (Alaş and Öktener, 2015).

The online databases of both fish and parasite should include data of both civil society organizations and international scientific centres. Online database (ITIS, 2018; Froese and Pauly (eds), 2018; WoRMS Editorial Board, 2018; Pollerspöck and Straube, 2018, etc.) can contribute to keep update biodiversity and taxonomy records, as well as the current status of the existing flora and fauna in relation to their geographical distribution (Alaş and Öktener, 2015).

CONCLUSIONS

Checklists are important in achieving all of data about parasite and hosts among the countries at a glance. Obviously, the validity of names and synonyms of parasite and host species may change over time. Reports of parasite findings may be published at different/same dates and regions by different researchers (Öktener, 2008; Vidjak et al., 2008). Some information can not be reached (Wilson, 1917, 1935). The revision of checklist studies are important, equally to the possibility of sharing their updates to much more readers. In this sense, checklist studies may include some disadvantages being restrictive and sometimes with some not updated information. Thus, we sustain that online databases are very useful in minimizing doubtful and erroneous reports and notifications of both parasite and host. Therefore, we think online database are more efficient than checklist articles, because they can facilitate in real time the dissemination of information between both the scientific and non-scientific communities.

Öktener (2008) not presented checklist of parasites of *Coryphaena hippurus*. On the contrary, Bunkley-Williams and Williams (2009) evaluated that Öktener's (2008) article as checklist. But their article also includes some prejudiced comments and missing information about parasite-host. In this publication, we also indicated to emphasize about including actual information and being ease for correction of wrong information in the online databases.

ACKNOWLEDGEMENTS

The sampled parasites were obtained during TAGEM/HAYSUD/2014/05/01 project, conducted by the Sheep Research Institute of Ministry of Food, Agriculture and Livestock of Türkiye.

REFERENCES

1. Alaş A., Öktener A. and Türker Çakır D., 2015 – Review of parasitic copepods recorded in fish from Turkey, *Transylvanian Review of Systematical and Ecological Research*, 17, 1, 39-62, https://doi.org/10.1515/trser-2015-0047.
2. Alexander P. D., 1983 – Peniculus haemuloni, a new species of copepod (Siphonostomatoida: Pennellidae) parasitic on Haemulon steindachneri from Ubatuba, Brazil, *Bulletin of the British Museum (Natural History) (Zoology)*, 45, 381-385, https://doi.org/10.5962/bhl.part.28007.
3. Arnal C. and Morand S., 2001 – Importance of ectoparasites and mucus in cleaning interactions in Mediterranean cleaner wrasse Symphodus melanocercus, *Marine Biology*, 138, 4, 777-784.
4. Bănăduc D., Rey S., Trichkova T., Lenhardt M. and Curtean-Bănăduc A., 2016 – The Lower Danube River – Danube Delta – North West Black Sea: A pivotal area of major interest for the past, present and future of its fish fauna – A short review, *Science of the Total Environment*, 545-546, 137-151, DOI: 10.1016/j.scitotenv.2015.12.058, ISSN 0048-9607, eISSN 1879-1026.
5. Bilecenoğlu M., Kaya M., Cihangir B. and Çiçek E., 2014 – An updated checklist of the marine fishes of Turkey, *Turkish Journal of Zoology*, 38, 901-929.
6. Boxshall G. A., 1986 – A new genus and two new species of Pennellidae (Copepoda: Siphonostomatoida) and an analysis of evolution within the family, *Systematic Parasitology*, 8, 215-225, https://doi.org/10.1007/BF00009890.
7. Brian A., 1898 – I. Catalogo di Copepodi parassiti dei pesci della Liguria, *Atti della Société Ligustica di Scienze Naturali e Geografiche*, 9, 5-31. (in Italian)
8. Brian A., 1906 – Copepodi parassiti dei pesci d'ltalia, Genova, 190, https://doi.org/10.5962/bhl.title.58642. (in Italian)
9. Brian A., 1917 – Note sur Copepodes parasites provenant des Musee Oceanographique de Monaco, *Bulletin du Musée océanographique de Monaco*, 324-326, 1-8. (in French)
10. Bunkley-Williams L., Williams E. H. and Bashirullah A. K. M., 1998 – Some isopods assoaciated with Venezuelan fishes, *Caribbean Marine Studies*, 6, 27-30.
11. Bunkley-Williams L. and Williams E. H., 2000 – First Caribbean report of Glossobius impressus (Isopoda: Cymothoidae) and a new host, Fourwing Flyingfish, Hirundichthys affinis, *Caribbean Journal of Science*, 36, 1-2, 155.
12. Bunkley-Williams L. and Williams E. H., 2009 – Hosts and distribution of Peniculus fistula von Nordman, 1832, *Reviews in Fisheries Science*, 17, 4, 538-540, http://dx.doi.org/10.1080/10641260903216012.
13. Candeias A., 1955 – Peniculus fistula Nordman, On two new hosts Trachurus trachurus and Trachurus picturatus, *Notas e Estudos do Instituto de Biologia Marítima, Lisboa*, 8, 1-16.
14. Capart A., 1959 – Copepodes parasites: resultats scientifiques de l'expedition oceanographique Belge dans les eaux cotieres africaines de l'Atlantique Sud (1948-1949), *Bulletin de l'Institut Royal des Sciences Naturelles de Belgique*, 3, 55-126. (in French)
15. Castro-Romero R., Montes M. M., Martorelli S. R., Sepulveda D., Tapia S. and Martinez-Aquıno A., 2016 – Integrative taxonomy of Peniculus, Metapeniculus, and Trifur (Siphonostomatoida: Pennellidae), copepod parasites of marine fishes from Chile: species delimitation analyses using DNA barcoding and morphological evidence, *Systematics and Biodiversity*, 14, 5, 466-483, https://doi.org/10.1080/14772000.2016.1158213.
16. Claus C., 1868 – Beobachtungen über Lernaeocera, Peniculus and Lernaea, bin Beitrag zur Naturgeschichte der Lernaeen, Schriften der Gesellschaft zur Beförderung der gesammten Naturwissenschaften zu Marburg, Marburg und Leipzig, 1868, II, 32. (in German)
17. Delamare Deboutteville C. and Nunes-Ruivo L., 1951 – Existence de "formes biologiques" chez Peniculus fistula (Rudolphi) (Copepoda), *Vie et Milieu*, 2, 448-458. (in French)

18. Dyer W. G., Bunkley-Williams L. and Williams E. H., 1997 – Parasites of the Dolphin fish (Coryphaena hippurus) in Puerto Rico, *Journal of Helminthological Society of Washington*, 64, 188-194.
19. Froese R. and Pauly D. (eds), 2018 – FishBase, World Wide Web electronic publication, www.fishbase.org, version (06/2018).
20. Gooding R. U., 1957 – On some copepoda from Plymouth, mainly associated with invertebrates, including three new species, *Journal of the Marine Biological Association of the United Kingdom*, 36, 195-221, https://doi.org/10.1017/S0025315400016714.
21. Grutter A. S., 2002 – Cleaning symbioses from the parasites' perspective, *Parasitology*, 124, 65-81, https://doi.org/10.1017/S0031182002001488.
22. Hermida M., Cruz C. and Saraiva A., 2013a – Parasites as biological tags for stock identification of blackspot seabream, Pagellus bogaraveo, in Portuguese northeast Atlantic waters, *Scientia Marina*, 77, 4, 607-615, Doi: 10.3989/scimar.03859.17A.
23. Hermida M., Cruz C. and Saraiva A., 2013b – Ectoparasites of the blackspot seabream Pagellus bogaraveo (Teleostei: Sparidae) from Portuguese waters of the north-east Atlantic, *Journal of the Marine Biological Association of the United Kingdom*, 93, 2, 503-510, https://doi.org/10.1017/S0025315412000057.
24. Hobson E. S., 1971 – Cleaning symbiosis among California inshore fishes, *United States National Marine Fish Service Fish Bulletin*, 69, 491-523.
25. ITIS, 2018 – Integrated Taxonomic Information System (ITIS), http://www.itis.gov, accessed 2018-11-11.
26. Kabata Z. and Wilkes S. N., 1977 – Peniculus asinus (Copepoda: Pennellidae), a new species of copepod parasitic on fishes of the genus Sebastes along the west coast of North America, *Canadian Journal of Zoology*, 55, 1988-1991, https://doi.org/10.1139/z77-257.
27. Kılıç H. 1999 – Site selection. The case of Turkey. Aquaculture planning in Mediterranean countries, CIHEAM – Cahiers Options Méditerranéennes, 43, 25-33.
28. Kritsky D. C. and Öktener A., 2015 – Solostamenides paucitesticulatus n. sp. (Monogenoidea: Mazocraeidea: Microcotylidae) from the freshwater mullet Liza abu (Heckel) (Mugiliformes: Mugilidae) from Atatürk Reservoir on the Euphrates River in southern Turkey, *Systematic Parasitology*, 91, 139-144, https://doi.org/10.1007/s11230-015-9562-3.
29. Larraneta M. G., 1964 – Sobre la biologia de Pagellus erythrinus (L.) especialmente del de las costas de Castellon, *Investigacion Pesquera*, 27, 121-146. (in Spanish)
30. Love M. L. and Moser M., 1983 – A checklist of parasites of California, Oregon, and Washington marine and estuarine fishes, NOAA Technical Report NMFS SSRF-777, 572.
31. Luna S. M., 2009 – Diseases, in dolphin and Pompano dolphin, in *FishBase* (Froese R. and Pauly D., eds), World Wide Web electronic publication, www.fishbase.org, version (01/2009) (1990, 1994, 2006), (cited by Williams and Bunkley-Williams 2010).
32. MacGinitie G. E., 1937 – Notes on the natural history of several marine crustacea, *The American Midland Naturalist*, 18, 6, 1031-1037, Doi: 10.2307/2420601.
33. Moon M. S. and Choi S. H., 2014 – Description of two species of Peniculus von Nordmann, 1832 (Copepoda: Siphonostomatoida: Pennellidae) parasitic on commercial fishes from Korea, including a new species, *Systematic Parasitology*, 88, 185-193, http://dx.doi.org/10.1007/s11230-014-9493-4.
34. Nordmann A., 1832 – Mikrographische Beitriige zur Naturgeschichte der wirbellosen Thiere, Berlin: Reumer G., 150. (in German)
35. Öktener A. and Sezgin M., 2000 – Mothocya epimerica Costa, 1851 (Flabellifera: Cymothoidae), an Isopod Parasite in the Branchial Cavities of the Black Sea Silverfish Atherina boyeri Risso, 1810 (Perciformes, Atherinidae), *Turkish Journal of Marine Science*, 6, 1, 23-29.
36. Öktener A., 2003 – A checklist of metazoan parasites recorded in freshwater fish from Turkey, *Zootaxa*, 394, 1-28, http://dx.doi.org/10.11646/zootaxa.394.1.1.

37. Öktener A., 2005 – A checklist of parasitic helminths reported from sixty-five species of marine fish from Turkey including two new records of monogeneans, *Zootaxa*, 1063, 33-52, http://dx.doi.org/10.11646/zootaxa.1063.1.2.
38. Öktener A., 2008 – Peniculus fistula von Nordmann, 1832 (Copepoda: Pennelidae) parasitic on Coryphaena hippurus Linnaeus, 1758 (Teleostei: Coryphaenidae), *Reviews in Fisheries Science*, 16, 445-448, http://dx.doi.org/10.1080/10641260802046668.
39. Öktener A., 2014 – Revision of parasitic helminths reported in freshwater fish from Turkey with new records, *Transylvanian Review of Systematical and Ecological Research*, 16, 1, 1-56, https://doi.org/10.1515/trser-2015-0001.
40. Öktener A., Alaş A. and Türker Çakır D., 2015 – First record of Bomolochus bellones Burmeister, 1833 (Copepoda: Bomolochidae) from Turkish habitats, *Vie et Milieu*, 65, 3, 1-4.
41. Öktener A., 2015 – An updated checklist of parasitic helminths of marine fish from Turkey, *Transylvanian Review of Systematical and Ecological Research*, 16, 2, 55-96, https://doi.org/10.1515/trser-2015-0017.
42. Öktener A., Trilles J. P. and Alaş A., 2018 – Elthusa poutassouiensis (Penso, 1939), comb. nov. (Isopoda, Cymothoidae) for Meinertia (Ceratothoa) poutassouiensis, parasite of the blue whiting, Micromesistius poutassou, *Bulletin – European Association of Fish Pathologists*, 38, 1, 9-20.
43. Olmo A. P., Fernandez M., Raga J. A., Kostadinova A. and Poulin R., 2008 – Halfway up the trophic chain: development of parasite communities in the sparid fish Boops boops, *Parasitology*, 135, 257-268, https://doi.org/10.1017/S0031182007003691.
44. Palko B. J., Beardsley G. L. and Richards W. J., 1982 – Synopsis of the biological data on dolphin-fishes, Coryphaena hippurus Linnaeus and Coryphaena equiselis Linnaeus, NOAA Report, NMFS Circ. 443, FAO Fish, 130 (cited by Williams and Bunkley-Williams 2010).
45. Pollerspöck J. and Straube N., 2018 – Bibliography Database of living/fossil sharks, rays and chimaeras (Chondrichthyes: Elasmobranchii, Holocephali, www.shark-references.com, World Wide Web electronic publication, Version 2018), accessed in 2018-11-11.
46. Raibaut A., Combes C. and Benoit F., 1998 – Analysis of the parasitic copepod species richness among Mediterranean fish, *Journal of Marine Systems*, 15, 185-206, https://doi.org/10.1016/S0924-7963(97)00079-1.
47. Ramdane Z. and Trilles J. P. 2007 – Parasitic copepods (Crustacea: Copepoda) from Algerian marine fishes, *Zootaxa*, 1574, 49-68.
48. Sep'ulveda F., Marin S. L. and Carvajal J., 2004 – Metazoan parasites in wild fish and farmed salmon from aquaculture sites in southern Chile, *Aquaculture*, 235, 89-100, https://doi.org/10.1016/j.aquaculture.2003.09.015.
49. Sikkel P. C., 1985 – Intraspecific cleaning by juvenile salema, Xenestius californiensis (Pisces: Haemulidae), *California Fish Game*, 72, 170-172.
50. Venmathi Maran B. A., Moon S. Y., Oh S.-Y., Soh H. Y. and Myoung J. G., 2012 – Redescription of two Pennellids (Copepoda, Siphonostomatoida) from Korea with a key to species of Peniculus von Nordmann, 1832, *ZooKeys*, 243, 1-14.
51. Vidjak O., Zorica B. and Sinov'cic G., 2008 – First record of parasitic copepod Peniculus fistula von Nordmann, 1832 (Sphinostomatoida: Pennelidae) from garfish Belone belone (Linnaeus, 1761) in the Adriatic Sea, *Cahiers de Biologie Marine*, 49, 209-213.
52. Walter T. C. and Boxshall G., 2018 – World of Copepods database, Peniculus fistula fistula Nordmann, 1832, accessed through: World Register of Marine Species at: http://www.marinespecies.org/aphia.php?p=taxdetails&id=745880 on 2018-11-29.
53. Williams E. H. and Bunkley-Williams L., 2009 – A 226-year-old dolphin isopod mystery solved: identification of barbugede Pampelfisk, Coryphaena apus Brunnich, 1783, *Reviews in Fisheries Science*, 17, 557-561, http://dx.doi.org/10.1080/10641260903243495.

54. Williams E. H. and Bunkley-Williams L., 2010 – Checklists of the parasites of dolphin, Coryphaena hippurus, and Pompano dolphin, equiselis with new records, corrections, and comments on the literature, *Reviews in Fisheries Science*, 18, 1, 73-93, http://dx.doi.org/10.1080/10641260903295909.
55. Wilson C. B., 1917 – North American parasitic copepods belonging to the family Lernaeidae with a revision of the entire family, *Proceedings of the United States National Museum*, 53, 1-150, https://doi.org/10.5479/si.00963801.53-2194.1.
56. Wilson C. B., 1935 – Parasitic copepods from the Pacific coast, *The American Midland Naturalist*, 16, 776-797, https://doi.org/10.5479/si.00963801.35-1652.431.
57. WoRMS Editorial Board, 2018 – World Register of Marine Species, available from http://www.marinespecies.org at VLIZ, accessed 2018-11-29, doi:10.14284/170.
58. Zuniga L. R. and Suau P., 1967 – Nota sombre la presencia de los copepods parasitos Peniculus fistula y Lerneolophus sultanus sobre dos nuevos huespedes, Lithognathus mormyrus y Boops boops, *Investigacion Pesquera*, 3, 3, 485-487. (in Spanish)

WETLANDS AND THEIR FISH DIVERSITY IN ASSAM (INDIA)

Devashish KAR *

* Assam (Central) University, Division of Wetlands, Fisheries and Aquaculture, Department of Life Science, Silchar, Assam, India, IN-788011, devashishkar@yahoo.com.

DOI: 10.2478/trser-2019-0019

KEYWORDS: wetlands, habitat, fish, Epizootic Ulcerative Syndrome.

ABSTRACT

Water is indispensably important for sustenance of life. Wetlands serve as potential reservoirs of water which also harbour coveted bioresources, which sustain animal life. Fish is a potential bioresource for nutrition and offer work places for people. The Asian continent has innumerable wetlands with the Indian sub-continent portraying myriads of wetlands of different kinds, including perennial wetlands (locally called "Beel" or "Taal"), seasonal floodplain wetlands ("Haor") and river-formed oxbow wetlands ("Anua"). In addition to playing a pivotal role in providing nutrition and work places to the people, wetlands also play a significant role in flood management, in regulating biogeochemical cycles, and above all, perhaps, in the rehabilitation of the innumerable fish stocks.

ZUSAMMENFASSUNG: Die Vielfalt der Feuchtgebiete und deren Fischarten in Assam (Indien).

Wasser ist von unentbehrlich für die Erhaltung des Lebens. Die Feuchtgebiete dienen als potentielle Wasserspeicher, die ebenfalls begehrte Bioressourcen beherbergen, die das Leben der Tiere erhalten. Die Fische stellen eine potentielle Bioressource zur Ernährung und beruflichen Betätigung der Bevölkerung dar. Feuchtegebiet finden sich in allen Breiten- und Längen rund um den Erdball. Der asiatische Kontinent umfasst unzählige Feuchtgebiete, wobei sich mit dem indischen Sub-Kontinent Myriaden unterschiedlicher Ausprägungen abzeichnen. Sie reichen von permanenten – lokal als "Beel" oder "Taal" genannten Feuchtgebieten, zeitweilige überfluteten Auen ("Haor") bis hin zu den von Flüssen geschaffenen Altarmen ("Anua"). Zusätzlich zu ihrer grundlegenden Rolle als Nahrungsquelle und berufliche Tätigkeit für die Bevölkerung, spielen die Feuchtgebiete eine signifikante Rolle im Hochwassermanagement, in der Regelung der bio-geochemischen Kreisläufe und vor allem wohl in der Wiederherstellung der unzähligen Fischbestände.

REZUMAT: Diversitatea zonelor umede şi peştii acestora în Assam (India).

Apa este indispensabilă pentru menținerea vieții. Zonele umede servesc drept potențiale rezervoare de stocare a apei, care de asemenea adăpostesc mult solicitatele resurse biologice, asigurând viața animalelor. Peștii constituie o potențială resursă de hrană pentru populație și în același timp le asigură oamenilor și locuri de muncă. Zonele umede sunt răspândite pretutindeni pe glob. Continentul Asiatic adăpostește nenumărate zone umede, în sub-continentul Indiei conturându-se o miriadă de diferite tipuri ale acestora. Sunt incluse zone umede permanente, denumite local „Beel" sau „Taal", zone umede temporare, reprezentate de luncile inundabile („Haor") precum și brațe moarte create de dinamica râurilor. În afară de rolul lor de bază ca sursă de nutriție pentru populație și ofertă de locuri de muncă, zonele umede joacă un rol important în managementul apelor mari, în reglarea circuitelor bio-geochimice și în primul rând se pare în refacerea nenumăratelor stocuri de pești.

INTRODUCTION

Life is water; water is life (Schopf and William, 2002; Steel et al., 2010). Many significant human civilisations and cultures, had made their beginning near the water, including wetlands (Wells, 1922; Bănăduc et al., 2016). These highlight the indispensability of water, which is very broadly classified into two categories based on the type of water bodies. These are, (i) the standing water or the "lentic" water; and, (ii) the running water or the "lotic" water. In this regard, it may be mentioned here that, although the name is "standing water", actually, the water in such bodies is in motion in different ways. Hence, "standing water" does not necessarily mean "static". It simply means that the water does not flow. (Kar, 1990, 2007a, 2013a)

Of late, some scientists believe the lakes to be much the same wherever they occur because similarities are often found among the different lakes with regard to water colour, taste, hardness and aquatic biota (Kar, 1990, 2007a, 2013a). Although a partial survival of this idea is still prevalent among many laymen, with the advent of limnological science, it has been established that lakes as a class manifest most amazing physical, chemical and biological diversity (Kar, 1990, 2007a, 2013a). Further, as a partial indication of lake diversity, it could well be stated that lakes are large, medium or small; deep or shallow; protected or unprotected; with or without tributaries and outlets; fresh, brackish or salty; acidic, neutral or alkaline; hard, medium or soft; turbid or clear; surrounded by bogs, swamps, forest or open shore; high or low in dissolved content; with or without stagnant zones; with marl, muck, sand or clay bottoms; with or without vegetation beds; with high, medium or low biological productivity; young, mature or senescent; etc. Kar, 2013a). However, many intergrades within the various groups of features mentioned above exist. The amazing lake diversity is the effect of multitudinous combinations of many of these characteristics mentioned above. (Kar, 2007a, 2013a).

Some works done and a survey of literature available in the aspects of limnology, wetlands, fish and fish disease (with emphasis on Epizootic Ulcerative Syndrome/EUS), are as follows: APHA, 1995; Banerjea, 1967; Barbhuiya et al., 1999, 2006, 2007a, b; Barhoi et al., 2015; Bimola et al., 2014, 2015a, b, 2016; Battish, 1992; Bennet, 1962; Biswas and Calder, 1955, 1984, Callinan et al., 1996; CAMP, 1998; Chaudhuri, 1960; Choudhury et al., 2017a, b; Chinabut et al., 1995; Chumley, 1910; Cook, 1977; Das and Kar, 2011; Das et al., 2013; Das and Kar, 2013, 2016a, b, c; Das et al., 2018; Das and Kar, 2013, 2014, 2016a, b, c, d; Das et al., 2018; Day, 1873, 1878, 1885, 1889; Devi et al., 2017; Dey, 1973, 1981; Dey and Kar, 1985, 1987, 1989a, b, c, d, 1990, 1994; Dhar, 2004; Dhar et al., 2004; Dutta et al., 2017; Dutta et al., 2014; FAO, 1963, 1974, 1986; Fernando and Furtado, 1975; Forel, 1892-1904, 1895, 1901; Fraser et al., 1992; Frerichs et al., 1986; Fritsch, 1965; Gadgil and Kar, 2000; Ghosh and Lipton, 1982; Gopal et al., 1981; Gunther, 1880; Hamilton, 1822; Hickling, 1971; Henderson and Markland, 1987; Hooker, 1872; Hora, 1953; Hora and Menon, 1952; Hora and Silas, 1952; Hugueny and Paugy, 1995; Hutchinson, 1939, 1967, 1975; Jackson, 1973; Jayaram, 1981, 1999, 2003; Jhingran, 1991; Kar, 1984, 1985, 1990, 1996, 1999a, b, 2000a, b, 2002, 2003a, b, c, 2005, 2006a, b, 2007a, b, 2010a, b, c, 2011a, b, 2012a, b, c, 2013a, b, 2014a, b, c, 2015, 2016a, b); Kar and Barbhuiya, 2000a, b, c, d, 2001, 2002a, b, c, 2004, 2008, 2013; Kar and Dey, 1982a, b, 1986, 1987, 1988a, b, c, d, 1990a, b, c, d, e, 1993, 1995, 1996, 2000a, b, c, 2002; Kar and Sen, 2007; Kar and Upadhyaya, 1998; Kar et al., 1990, 1993, 1994a, b, 1995a, b, c, d, e, 1996a, b, c, d, e, 1997, 1998a, b, c, 1999a, b, c, 2000a, b, c, d, e, 2002, 2003a, b, 2006a, b, 2007a, b, c, 2008a, b, c, 2009, 2010, 2014, 2015; Kar and Kar, 2013, 2014, 2016a, b, c, d, e, f; Kar et al., 2017, 2018; Laskar et al., 2002, 2017; Le Cren, 1951; Lilley et al., 1997; Menon, 1955, 1973, 1974, 1988, 1994, 1999; Misra, 1976; Mookerjee, 1945; Motwani et al., 1962; Moyle, 1976; Narzary et al., 2015; Nath and Dey, 2000; Nautiyal and Lal,

1981; Ogale, 1994; Pearsall, 1938; Pennak, 1953; Pillay and Ghosh, 1958; Riji et al., 2016; Roberts, 1978; Roberts et al., 1992; Sarwar et al., 2016; Sehgal, 1994; Sen, 1982, 1985, 2000; Shaw and Shebbeare, 1937; Silas, 1952; Singh et al., 2013, 2015a, b, c; Southwell and Prashad, 1918; Swingle, 1950; Smith, 1950; Sonowal et al., 2015; Sreenivasan, 1968; Talwar and Jhingran, 1991; Toham and Tuegels, 1998; Umi et al., 2015; Vaas and Schurman, 1949; Welch, 1935, 2003; Wetzel, 1983; Zutshi et al., 1970.

MATERIAL AND METHODS

Fish samples were collected through fishing using caste nets (diameter 3.7-1.0 m), gill nets (vertical height 1.0-1.5 m; length 100-150 m), drag nets (vertical height 2.0 m), triangular scoop nets (vertical height 1.0 m) and a variety of traps. Camouflaging technique was also used to catch the fishes, whenever necessary. Fishes have been preserved at first in undiluted formaldehyde in the field itself and then in 10% formalin solution in the laboratory. Fishes have been identified based on standard literature (Day, 1878, 1889; Shaw and Shebbeare, 1937; Menon, 1974, 1999; Talwar and Jhingran, 1991; Jayaram (1981, 1999, 2010). Yield statistics were extrapolated (Kar, 1990; Dey and Kar, 1990) from daily catch statistics recorded at the fish landing centres (FAO, 1974); while, the trend and cyclic variations were constructed through application of 12 months moving average method (Coxton and Cowden, 1950; Kar, 1990; Dey and Kar, 1990; Kar and Dey, 2000a, b). Physico-chemical characteristics of water were estimated based on standard methods (APHA, 1995).

"Wetlands" are "wet-lands", where the soil is saturated with water for sometime during the year. According to IUCN (1970), wetlands are areas of marsh, fen, etc., temporary or permanent; natural or artificial mass of water, the depth of which generally does not exceed six m. Wetlands are areas which contain substantial amount of standing water with little flow.

Wetlands in North-East India. The North-Eastern (NE) region of India, a typically difficult topography with undulating terrains and enormous amount of water resources represented by intricate network of articulating rivers and associated wetlands containing a bewildering diversity of aquatic biota, perhaps, unparalleled in the history of the world; thus, acquiring its designation as a "hotspot" of biodiversity (WCMC, 1998). However, the region certainly provides enough potential for fish production which could supplement food requirement for the region and respond to the diminishing protein supply (Kar, 2007a).

Wetlands in Assam. Besides lotic territories, the lentic water bodies of 0.72×10^6 ha lake coverage in India have great fishery potential. NE region, in general, and Assam, in particular, is blessed with a number of lentic systems, locally called Beel, Haor, Anua, Hola, Doloni, Jalah, etc., which alone constitute around 81% of the total lentic area (0.12×10^6 ha) in Assam. These lentic systems are generally shallow and open, with a size from 35 to 3458.12 ha and a depth from 0.25 to three metres (in some, however, the maximum depth may exceed six m) at full storage level (FSL). Further, in Assam, there are around 1,392 wetlands having a total of around 22,896 fisheries of different categories, out of which, the number of registered wetlands is only 394 (30.38%) covering an area of around 70,000 ha. Of them, around 19,000 ha are considered in good condition, around 15,000 ha are in semi-derelict condition, and around 35,000 ha are in derelict condition (Government of Assam, 2006). Assam is rich in wetlands, which are located in wildlife sanctuaries, national parks and even in Biosphere reserve areas. Some are Ramsar sites that need to be addressed.

Classification of wetlands in Assam. Wetlands occur throughout the globe in almost all climatic zones and are said to cover around 6% of the earth's surface. One of the simplest classification of wetlands has been provided by IUCN's Ramsar Convention (2004), which is briefly as follows: freshwater lakes/wetlands, oxbow lakes/wetlands, FW (freshwater) ponds, marshes, swamps, bogs, and reservoirs.

In the tropical areas, notably, in the Indian subcontinent, and particularly, in Assam region and adjoining places as Bangladesh, wetlands are usually shallow depressions which could normally be in the form of a basin at the centre of hillocks on all sides; or, could be an abandoned segment of a river (oxbow wetland); or, could be a shallow portion of a river course which may be detached from the main river course during the dry season. Sometimes, wetlands in NE India could be originally formed due to tectonic activities (Kar et al., 1996b; Kar, 2007a, b).

In the Assam region, and also in the adjoining Tripura and Bangladesh regions, three main categories of wetlands can be commonly found. They are regionally known as follows (Kar, 2007a, 2013a): (a) "Beel": perennial wetlands, which contain water throughout the year; (b) "Hoar": seasonal wetlands which contain water for some period of the year only, particularly, during the rainy season; as such, they are also called "floodplain wetlands"; (c) "Anua": these are peculiar river-formed perennial oxbow-type wetlands, which are generally formed due to changes in the river course and which may or may not retain a connection with the original river.

Limnological study of the wetlands in Barak drainage of Assam. Information on the hydrobiological conditions of any water body is considered of prime necessity before endeavouring to utilize it as a productive fishery. It is an established fact that proper planning depends on the availability of reliable data. But, in the limnological and fisheries sector, there is need for more such information for the North-Eastern region of India in order to get a holistic view (Kar, 1990, 2007a, 2013a).

Contrary to such specific background, the naturally-formed lakes and rivers constitute great potential of fishery resource in the Indian sub-continent. Many wetlands are still unregistered and under the control of both government and private sectors. In this context, it is interesting to note that the district of Cachar includes the highest number of unregistered wetlands in Assam (Dey, 1981; Kar and Barbhuiya, 2000a, b, c, d; 2001, 2002a, b, c; 2004).

Notwithstanding the above, some of the significant lentic systems (wetlands) in the Barak Valley area (92°15' to 93°15' E and 24°10' to 25°10' N) located in Assam are briefly listed below:

(i) Beel (perennial wetland): Sone Beel (the biggest**,** 3458.12 ha at FSL), Rata Beel, Sagar Beel, Rani-Meghna Beel, Angang Beel, Medha Beel, Duberi Beel, Auti-Bauti Beel, Narapati Beel, Jabhda Beel, Karkari -Jonamara Beel, Petua Beel, Atoa Beel, Lora Beel, Bishali Beel, Gudi Beel, Chhatradharia Beel, Mahishatal Beel Deochhara Beel, Ashihali Beel, Dhalchhara Beel, Hatichhara Beel, Doloo Beel, Sat Beel, etc.

(ii) Haor (seasonal floodplain wetland): Chatla Haor, Bakri Haor, Puneer Haor, etc.

(iii) Anua (river-formed oxbow wetland): Baskandi Anua, Rupairbala Anua, Dungripar-Kaptanpur Anua, Satkarakandi Anua, Ram Nagar Anua, Baraknadi-Salchapra Anua, Fulbari Anua, Sibnarayanpur Anua, Chiri Anua, Rukni Anua, etc.

Barak Valley is rich in biodiversity, where Brark River, a left bank tributary of Brahmaputra flows.

Fish samples. Fish samples were collected through fishing using cast nets (diameter 3.7-1.0 m), gill nets (vertical height 1.0-1.5 m; length 100-150 m), drag nets (vertical height 2.0 m), triangular scoop nets (vertical height 1.0 m) and a variety of traps. Camouflaging technique was also used to catch the fish, whenever necessary. Fish samples were preserved in undiluted formaldehyde in the field and then in 40% formalin in the laboratory. Fish were identified after consulting standard literature (Day, 1878, 1889; Shaw and Shebbeare, 1937; Menon, 1974, 1999; Talwar and Jhingran, 1991; Jayaram (1981, 1999, 2010). Yield statistics were extrapolated (Kar, 1990; Dey and Kar, 1990) from daily catch statistics recorded at the fish landing centres (FAO, 1974); while, the trend and cyclic variations were constructed through application of 12 months moving average method (Coxton and Cowden, 1950; Kar, 1990; Dey and Kar, 1990; Kar and Dey, 2000a, b).

Environmental parameters. The following water parameters: turbidity, temperature, hydrogen-ion-concentration, dissolved oxygen (DO), free carbon di-oxide (FCO_2), total alkalinity (TA) and specific conductivity (SC), as well as the silt load were studied.

RESULTS AND DISCUSSION

Some of the significant lentic systems (wetlands) in the Barak Valley Region (92°15' to 93°15' E and 24°10' to 25°10' N) of Assam are discussed below.

Geology. This region is geologically unique because the processes of morphogeny, lithogeny and tectonics are said to be active simultaneously. The Barak River basin has been formed by two geotectonic features, (a) the Nagaland-Haflong-Diyung in the north and (b) the ophiolite belt of Nagaland and Manipur in the east (across the Manipur Valley). This strongly-folded mobile belt is separated by the northern thrust boundary from the Assam Platform, which is said to carry sedimentary cover of the same age. In fact, the ophiolite belt separates the zone from the Myanmarese Platform. The ophiolite probably represents the margin of the Indian Plate. It has perhaps continued southward into the Andaman and Nicobar islands through the Arakan Yoma (around Myanmar) and then into the Indonesian chain of islands. In the folded belt, this stage is believed to have passed long ago and the prevalent model of evolution envisages the formation of folded mountain of the subduction margin. As the rising mountain is believed to have pushed back the sea, the next zone to the west has been similarly folded and uplifted. Thus, a progressive migration of orogeny, morphogeny and sedimentation is seen. The area is said to be totally land now and probably remains dynamically active and the direction of evolution is perhaps the same (Kar, 2013a).

Sone Beel

It is situated between 92°24'50" to 92°28'25" E and 24°36'40" to 24°44'30" N within Karimganj District of Assam and falls in a syncline (Fig. 1) (Kar, 1990, 2007, 2013).

The physiography of the district is said to consist of small hillocks intervened by wide low valleys. The hillocks possess NE-SW and NE-SSW trend near the Barail range and N-S trend towards south away from the Barail range. Incidentally, Sone Beel, the biggest "Beel" (wetland) in Assam, is situated in between two hill ranges, namely, the Badarpur-Saraspur range and the Chowkirmukh-Dohalia range. In the east, the neighbouring structure is the Badarpur line of folding; while, there is the Chargola anticline towards the west. A typical geomorphological feature is the tightfoldedness of the anticlines represented by hillocks having very high dips of the sedimentary beds (Kar, 1990, 2007a, 2013a; Kar et al., 1999a).

Information obtained from ONGC and GSI (personal communication Nandi P. K.) reveal that Cachar represents a type area of Surma sediments exhibiting only Tertiary deposits (70 million years). Studies into the rock samples of this wetland have revealed that the hillocks around the wetland are probably formed after Tipam sedimentation. Most of the wetlands in this region, including the mighty Sone Beel, might have been originated after the Dupitila sedimentation during the Mio-Pliocene period (Kar et al., 2003a, b; Kar, 2007a, 2013a).

Around Sone Beel, the soil in the catchment of the plains is generally loamy but occasionally sandy or gravelly admixed with quartz. On the other hand, the hilly portion of the catchment consists generally of fine grain sand stones bearing many angiosperms and, thus, forms the evergreen forest.

The principal feeder of the wetland is the major inflow, the Singla River, which drains a total catchment area of around 46,105 ha. In addition, the wetland receives water from 12 minor inlets and many other canals flowing from both hills and plains, all of which together drain a total of around 18,941.9 ha of the catchment area of the wetland. Out of this, around 11,003.9 ha lies in the plains, while, around 7,938.0 ha falls in the hilly portion of the wetland. These form 58.09% and 41.91%, respectively, of the total catchment area of the wetland (Kar, 2013a; Kar and Dey, 1986, 1987, 1988).

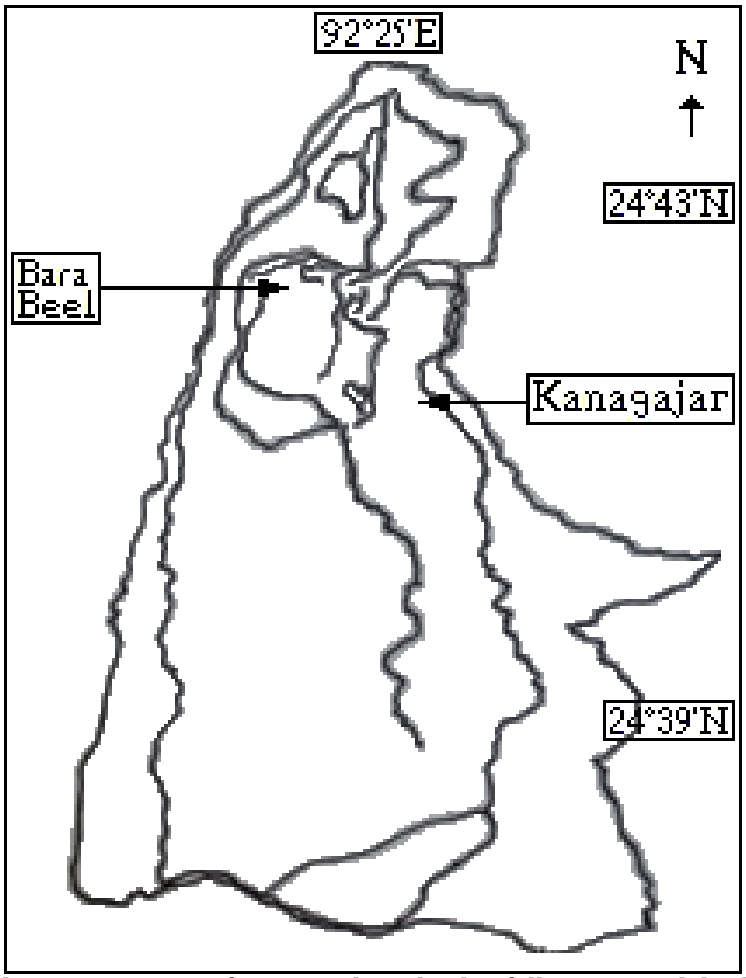


Figure 1: Boundary contour map of Sone Beel Wetland at full storage and dead storage levels.

The catchment of the wetland also includes the reserved forests of the province, notably, the Singla Reserve Forest (RF). During monsoon, the wetland receives some humic, as well as inorganic and organic nutrients from the hillocks and cultivable areas, particularly around the swollen tail end of the wetland.

The maximum length (L) and breadth (B) of the wetland at full storage level (FSL) were measured as 12.5 km and 3.9 km respectively. These values were reduced to 4.07 km and 2.22 km, respectively, at its dead storage level (DSL).

The area of Sone Beel at FSL was measured as 3458.12 ha, while at DSL, the area diminished to only 409.37 ha. The length of the shoreline was measured as 35.4 km while the shore and volume developments were recorded as 1.69 and 0.15, respectively, with a mean depth of 0.29 m. The gross volume of the wetland was found to be 101.54 x 10^6 m^3.

Silt islands (SI) were recorded in the north and south of the wetland. The Gopikanagar SI (area 3.74 ha and 25 m above the sea level/MSL) and Khagdi Tila SI (area 3.31 ha and 21 MSL) were noteworthy. Interestingly, the wetland surface itself is situated 23 m (MSL).

The wetland basin tended to become deeper from south to north. The contours in the west were found to be almost parallel and closer than their counterparts in the east (Fig. 2).

Notwithstanding the above, the wetland exhibited variable water level ranging from 0.07 to 6.0 m at FSL (June-September) and 0.02 to 2.08 m at DSL (November-April). The average depth of the wetland was found to vary from 0.16 m to 3.38 m.

The wetland is mainly fed with the major inlet, the Singla River; although, 12 minor inlets were found to exist in different parts of the wetland. The Singla River originates as "Thing Tlawng Lui" at an altitude of around 365.21 m MSL in Mizo Hills, from where, after traversing a meander course of around 62.75 km, it enters Sone Beel.

The major outflow (there being no minor outflow) of the wetland, the Kachua River originates from the northern most end of the wetland. It drains out the wetland water into the mighty Kushiara River (a tributary of the Barak River) after covering a length of around 19.30 km. Although, the Kachua River was blocked by a blind dam constructed by the Government of Assam in 1950-1951, the dam was replaced by a lock gate in 1964 after experiencing navigational and fishery problems. Consequently, studies revealed pouring-in of 350.0 mg/L of silt into the Sone Beel by the inlet Singla River; and, concomitantly, expulsion 88.1 mg/L of silt by the outlet Kachua River from Sone Beel.

An attempt was made in the present study to reflect the change detection of boundary contour of Sone Beel wetland in Assam on a GIS Platform, using PCI Geomatica version 10.1 by comparing the ground map (prepared through standard survey, Kar, 1990, 2007a, 2013a) with Georeferenced Survey of India Topomap and superimposing the LISS IV Satellite imageries data of 2006 over a period spanning from 1880, 1980 to 2006 (Figs. 1 and 4). Orange coloured region depicts the area for the year 1880, which is around 6,774 ha. Blue colour depicts the area for the year 1980, which is around 3,234.4 ha, while red coloured region depicts the area for the year 2006, which is around 392.4 ha. The latter contour was prepared in winter season, while the other two contours were made during rainy season. So, within a span of around 100 years from 1880 to 1980, there was a shrinkage of around 3,539.6 ha of the water spread area. Extensive deforestation coupled with soil erosion has led to large scale siltation of water bodies, thus, causing shrinkage in the water spread area. One could expect further diminution in the water spread area due to the siltation process, if it continues.

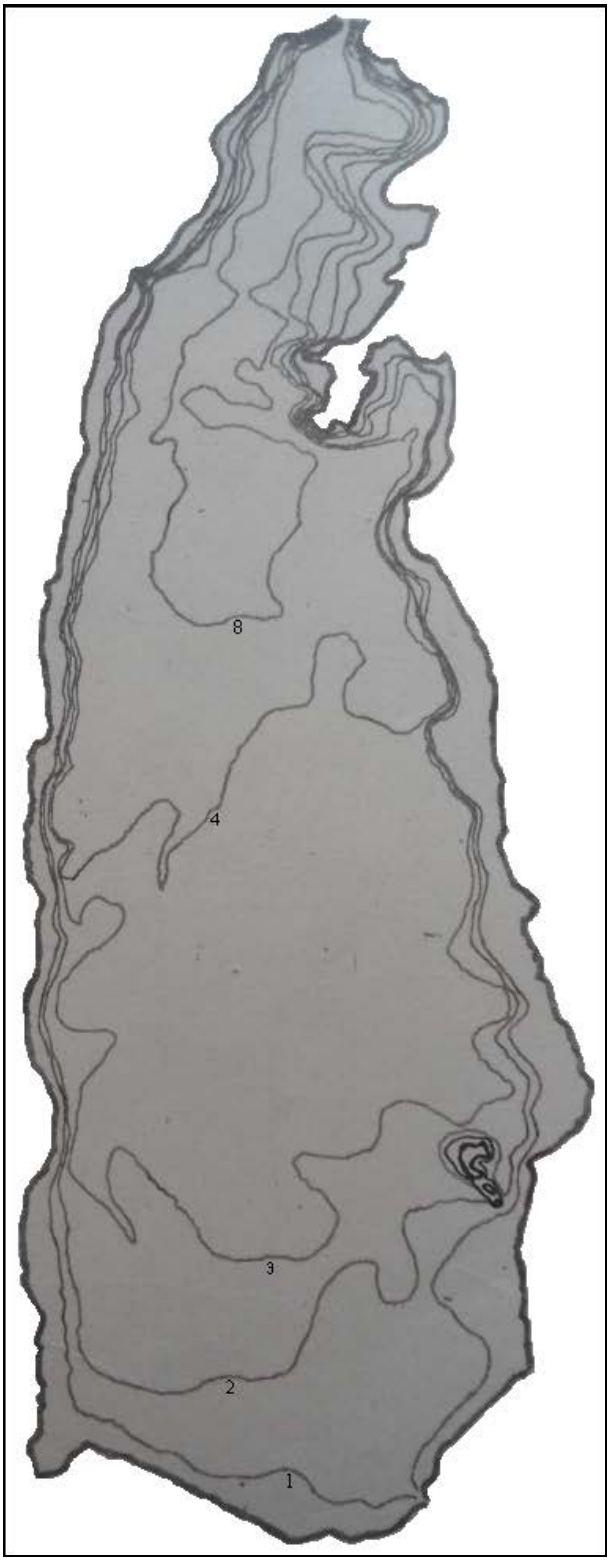


Figure 2: Depth contour map of Sone Beel Lake during live storage level.
(contour at one meter intervals).

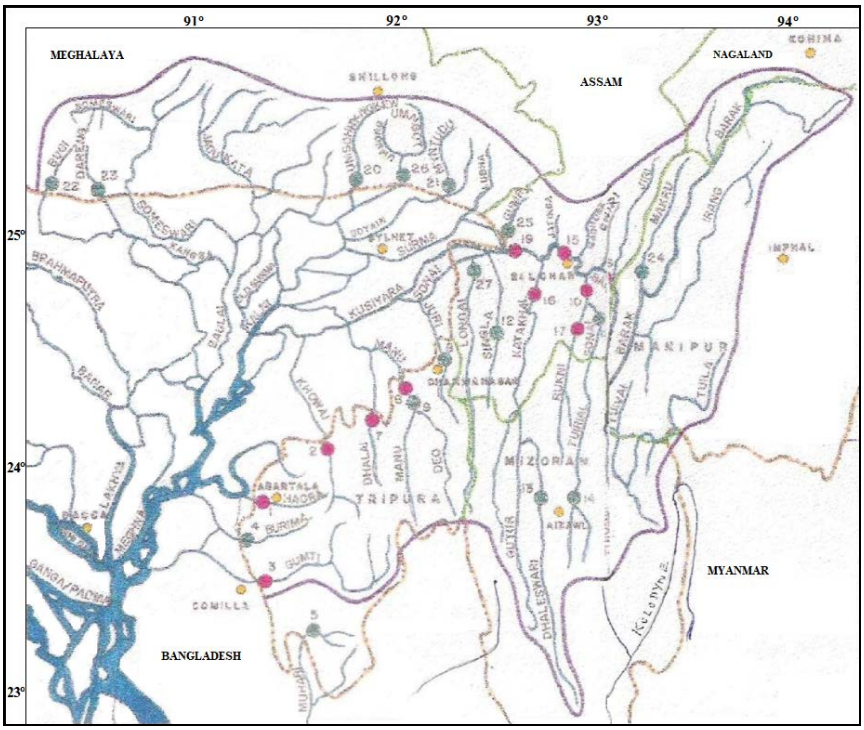


Figure 3: Riverine Network of North-East India; spots colour: blue – water bodies, red – sampling points, yellow – names of places.

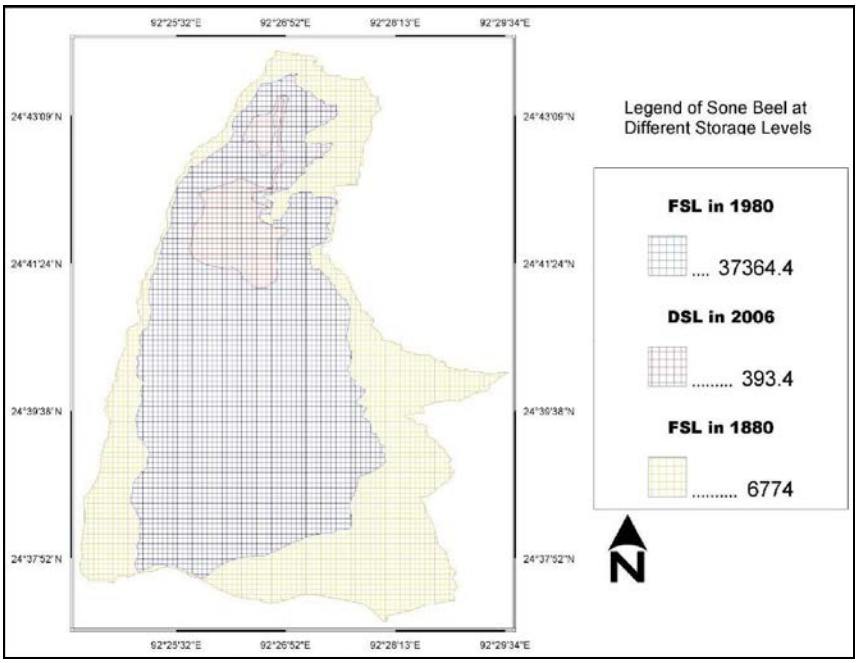


Figure 4: Georeferenced map of Sone Beel,
showing detected changes in the wetland from 1880, 1980 to 2006.

Physico-chemical characteristics of water of Sone Beel

In Sone Beel wetland, the water was found to exhibit interesting trend in its physico-chemical features. The silt load of the inlet water measured at the Beel mouth was found to vary from 27 to 350 mg/L. Concomitantly, the silt load values of the outlet water was found to fluctuate from 9.0 to 88.1 mg/L. The overall result indicated that more amount of silt is retained and deposited in the Beel and lesser amount is expelled through the outlet, thereby, resulting in overall siltation of the Beel (Kar, 1990; Dey and Kar, 1987). The fluctuation trend of water temperature was usually almost constant, with high values during the warm season followed by low values during the cold months. Conversely, low pH values were usually recorded during the monsoon period and higher values during the post-monsoon days.

Concomitantly, low values of DO were observed during rainy days, while higher trend was found in the dry days, exhibiting more or less an identical trend at varying depth levels. The saturation of DO was found to vary from 35.42% to 70.40% at the surface and from 32.34% to 70.31% at the bottom levels. Further, higher values of FCO_2 were generally found during the rains but lower values during the post-monsoon days. In addition, higher values of TA were usually recorded during the dry season while lower values during the rainy season. Higher values of conductivity were sometimes recorded at certain spots around fish landing centres.

Physico-chemical characteristics of soil of Sone Beel

The values of various physico-chemical characteristics of soil of Sone Beel in Assam are as follows (Kar, 1990): temperature (°C): 19.9 – 32.3; pH: 5.09 – 5.99; conductivity (µmhos/cm at 25°C): 47.42 – 322.08; organic carbon (%): 0.25 – 1.74; available phosphorus (mg/100 g): 0.15 – 1.93; and available potassium (mg/100 g): 1.6 – 24.8.

Plankton communities of Sone Beel

A total of 47 different forms of phytoplankton belonging to five groups have been recorded in Sone Beel. Of these, the Chrysophyta include the maximum number and Pyrrophyta, the least. The phytoplankton density in the Beel varies from 48 to 5,308 (average 1,027) units/liter. The minimum population is generally recorded during the rainy season and the maximum during the dry season. The cyanophytes and the euglenophytes generally exhibit prolific growth during the spring and summer with occasional abundance during monsoon. The Chlorophytes usually show higher occurrence intensity during summer and early monsoon with infrequent richness during winter and spring. The Chrysophytes are generally recorded throughout the year. The Pyrrophytes are found mainly during the autumn.

Nineteen different forms of zooplankton, belonging to five groups have been recorded till date in Sone Beel (Michael and Sharma, 1988). The zooplankton density varies from six to 380 (average 49) units/liters. Low density is generally recorded during February-March and high density during November-December. In Sone Beel, a considerable portion of zooplankton population has succumbed to the day-in and day-out fishing operations; thus, leading to their poor population in the Beel. Nevertheless, the copepods have been found to occur throughout the year. On the other hand, the rotifers are quite abundant mainly during the early monsoon and autumn. However, the cladocerans are generally abundant during autumn and winter (Kar, 1990; Dey and Kar, 1994).

An account of aquatic macrophytes (AM) of Sone Beel

Aquatic macrophytes exhibit a heterogeneous assemblage of 23 species. The important AM species are given below (Dey and Kar, 1989a; Kar, 1990, 2007a, 2013a): *Alternanthera sessilis, Azolla pinnata, Cynodon dactylon, Echinochloa stagnina, Eichhornia crassipes, Eleocharis acutangula, Euryale ferox, Hydrilla verticillata, Hygrorhiza aristata, Ipomoea aquatic, Justicia repens, Nechamandra alternifolia, Nymphaea nouchali, Nymphoides cristata, Nymphoides indica, Oryza sativa, Polygonum flaccidum, Sagittaria trifolia, Salvinia cucullata, Scirpus* sp., *Trapa bispinosa, Vallisneria spiralis,* and *Vetiveria zizanoides*.

The biomass of AM varies from 0.58 to 21.90 kg/m^2 (average 2.48 ± 0.82), maximum in December and minimum in May. In addition to water level (WL) and amplitude of flooding (Welcomme, 1979), the growth and distribution of the AM is influenced by the water quality.

Eichhornia crassipes has been the sole perennial species in the wetland, followed by *H. verticillata* and *T. bispinosa,* occurring during most of the months of the year. During dry season, the emergent varieties (e.g. *E. stagnina, E. acutangula, S. eriophorum, O. sativa, S. trifolia* and *P. flaccidum*) and the submerged types (e.g. *H. verticillata, V. spiralis*) generally succeed, flourish and show high abundance at less WL when the wetland exhibits a decreasing trend in its depth. It indicates an indirect relation of AM biomass with WL ($r = -0.130 \pm 0.442$. $P > 0.05$) during this period. Higher ranges of conductivity at this time have been found to sustain a rich biomass of the floating *T. bispinosa* (Pearshall, 1938).

The wetland water during dry season in general portrays high DO produced by photosynthesis at rich insolation, in which FCO_2 is consumed and shows a fall. Concomitantly, a direct relationship of AM biomass with DO ($r = 0.500 \pm 0.340$, $P < 0.05$) and an inverse with FCO_2 ($r = -0.780 \pm 0.178$, $P < 0.05$) is recorded. The pH and TA, which are found to depict rise, portray their direct relationship ($r = 0.850 \pm 0.126$, $P < 0.05$; $r = 0.022 \pm 0.454$, $P < 0.05$) with AM biomass. *H. verticillata* and *V. spiralis,* as indicated earlier, are found to be closely ($P < 0.05$) associated during this period (χ^2, 34.67). Also, a close ($P < 0.05$) association between floating *T. bispinosa* and submerged *V. spiralis* (χ^2, 24.15) and between submerged *H. verticillata* and emergent *S. eriophorum* (χ^2, 31.89) is discernible.

With the onset of monsoon, the floating varieties, *N. nouchali, N. cristatum* and *N. indicum* occur in their flowering stage. Most of the emergent varieties encountered during winter, spring and summer, get submerged and undergo decay during monsoon. The littoral and the sub-littoral zones of the Beel during monsoon are moderately infested with emergent *C. dactylon* and *V. zizanoides. H. verticillata* is sometimes found among submerged varieties. Onset of monsoon, as stated earlier, cause decay of AM, thus, rendering poor AM biomass with corresponding low DO, pH and TA but high FCO_2 during the periods. Concomitantly, a direct relation of AM with DO ($r = 0.940 \pm 0.053$, $P < 0.05$), pH ($r = 0.160 \pm 0.443$, $P > 0.05$) and TA ($r = 0.530 \pm 0.320$, $P < 0.05$) have been recorded. Significant ($P < 0.05$) phyto-social association between *C. dactylon* and *E. crassipes* (χ^2, 12.44), *C. dactylon* and *N. indicum* (χ^2, 10.21), *H. aristata* and *E. crassipes* (χ^2, 13.87), *H. aristata* and *N. cristatum* (χ^2, 18.96) are recorded during this season. However, none of the AM species has formed significant phyto-social relation with *E. ferox*, possibly, due to its thorny body, and, the latter, thus, forms a monospecific unit. High species diversity among the AM species is evident in this wetland. And, the level in Sone Beel is found to be high (biased estimate of $H' = 2.015$; expected value, $E(H') = 2.014$; variance of $H' = 1.431$ E-3) (Dey and Kar, 1989a).

Sat Beel. This wetland is situated in the village of Rongpur of Silchar sub-division in Cachar District of Assam. This Beel is an aggregation of seven wetland units located closely to each other and they become a single sheet of water during monsoon.

The physiography of the locality consists mainly of plain land with a small forest along the right bank of Barak River. The seven wetland units, of which Sat Beel is constituted, are Gajaria, Chepta, Bardoloo, Kachudaram, Mokachakri, Koia, and Kejua. The Barak River, which flows around one km away from the Beel, has diverted its original course by around two km during the last 30 years due to erosion of soil in its right bank. Sat Beel is situated at around 25 m MSL. The geology is mostly Tertiary formation and is generally fertile clayey loam. Dihing series beds are exposed near the Madhura River which flows also near the Sat Beel (Kar, 2007a).

Chatla Haor. It is a seasonal floodplain wetland, situated between 93°15' N and 24°10' E in the Cachar District of Assam. It was considered a "Beel" (perennial wetland) some decades ago having its water spread area reaching Silchar Town. Due to gradual siltation and eutrophication occurring naturally in the succession process, accelerated by human interference, today it has become a "Haor" (seasonal wetland) and retains water for approximately six months in a year having practically no dead storage level (DSL). So, it is almost completely dry during the winter. Having a water spread area of around 1,600 ha at the FSL, Chatla is considered as one of the biggest "Haor" in Assam.

Around Chatla, the soil in the catchment is generally sandy-loam, but shore vegetation is thin. The Haor is drained by a number of small inlets (Jalengachhara, Baluchhara, Salganga) and an outlet (Ghagra River), which drains itself into the Barak River. The catchment of the Haor includes a small portion of the Innerline Reserve Forest. During monsoon, the Chatla, like other similar wetlands, receive some humic as well as inorganic and organic nutrients from the hillocks and surrounding cultivable lands.

The maximum length (L), breadth (B), depth (D) and water spread area (A) of the wetland at FSL have been measured to be 10 km, 2.5 km, 5.5 m and 1,600 ha, respectively. Prominent Silt Islands (SI), namely, Bairagitila and Harintila have been found to occur towards the eastern shore of the Haor. Other small Sis, namely, Haltia, Diblia, and Barshangan, occur towards the SW side of the Haor.

Among the inlets, the Salgonga River originates from the foot hills of the Mizo Hill range, while the Jalengachhara and Baluchhara, which are mostly rheophilic in nature, flow down into the Haor from the Innerline Reserve Forest. The only major outlet, the Ghagra River, drains the water of the Haor directly into the Barak River traversing a tortuous course of around 14 km from the northern boundary of the Haor (Kar, 2007).

Physico-chemical characteristics of water of Chatla Haor. The values of the measured water quality parameters are as follows (Kar, 2007): water temperature: 33°C; turbidity: 83.27 NTU; pH: 6.09; FCO_2: 7.59 mg/L; TA: 83.39 mg/L; conductivity: 142.91 µmhos/cm.

An account of zooplankton of Chatla Haor. Studies done in the around 1,600 ha Chatla Haor in Cachar District have revealed the occurrence of 18 species of zooplankton consisting of two species each of Protozoa and Copepoda, six species of Rotifera and eight species of Cladocera. The occurrence of *Arcella* sp. among the protozoans and this of *Brachionus calyciflorus* among the rotifers probably indicate eutrophic conditions in the wetland. Two protozoans, namely, *Arcella* sp. and *Paramoecium* sp., represent 11.11% of the total zooplankton taxa in the wetland. Verma

and Dalela (1975) report *Arcella* sp. from eutrophic waters. Six rotifers constituting around 33.33% of the total zooplankton taxa have been also identified, of which, *Filinia* sp. and *Lecane* sp. are found to be abundant. The identified copepods include *Cyclops* sp. and *Diaptomus* sp., which represent around 11.11% of the total zooplankton taxa. The total zooplankton count in this case is found to be 68 ± 45 units/litre (Kar and Barbhuiya, 2004).

An account of the aquatic macrophytes (AM) of Chatla Haor. A total number of 23 species of AM have been recorded in the area of 1,600 ha (at FSL) of Chatla Haor. These can be classified as follows: five free-floating, four rooted-floating, two submerged and 12 emergent macrophytes. Six AM can be found throughout the year. These are: *Azolla pinnata, Eichhornia crassipes, Salvinia cucullata, Trapa bispinosa, Justicia repens,* and *Cynodon dactylon.*

Justicia repens flowers during March-May, while, *Nymphaea nouchali* blooms during June-August followed by *Nymphoides cristata* and *Nymphoides indica*, which exhibit a profuse flowering during September-October. *Ipomoea aquatica* shows growth of population during July-August. *Hydrilla verticillata* and *Vallisneria spiralis* among the submerged varieties as well as *Alternanthera sessilis, Cyperus platystylis, Echinochloa stagnina, Eleocharis acutangula, Enhydra fluctuans, Scirpus* sp., and *Sagittaria trifolia* among the emergent varieties succeed at a lesser water level during the dry season. The floating varieties, namely, *A. pinnata, E. crassipes,* and *S. cucullata* are found all the year, being associated with each other. Further, *H. verticillata* and *V. spiralis* among the submerged varieties are found to be associated (Kar, 2007a).

Puneer Haor. It is situated around 38 km away from south of Silchar City, near the village of Dhalai, along the Assam-Mizoram border. This Haor has a water spread area of around 2.5 ha at FSL and around 1.3 ha at DSL. The maximum L, B, and D of Puneer Haor at FSL have been found to be 1.5 km, 0.9 km and 2.5 m, respectively, while its average depth is 0.4 m. The Puneer Khal, flowing along the eastern shoreline of the Haor, originates from Panchhara Hill ranges and its water spills over into the Haor at FSL. A drain from the adjoining Bhubandhar TE flows along the western shoreline of the Haor and water containing TE pollutants is believed to also spill over into the Haor at FSL (Kar, 2007a, b).

Baskandi Anua (river-formed wetland). This oxbow wetland is situated between 24^{o} 10’ N and 93^{o} 15’ E in the Lakhipur sub-division of Cachar District. It has been formed due to changes in course of the Barak River.

The Anua is situated near the Manipur range of hills. The catchment soil is found to be mainly sandy loam. Rain is the main source of water for the Anua. The wetland also receives water from the surrounding catchment having human habitation. The catchment vegetation is represented in this case by herbs, shrubs, and trees, including a lot of bamboos.

The L, B, and A of Baskandi Anua have been found to be 2.230 km, 205 m and 39.2 ha at FSL, and 2.090 km, 190 m and 36.7 ha at DSL, respectively. The wetland basin tends to be deeper towards the southern side as compared to the northern. The Anua exhibits variable water level ranging from 0.25 m to 5.85 m at FSL (June-September) and from 0.14 m to 4.12 m at DSL (November-April) (Dhar, 2004; Kar, 2007a).

An account of the AM of Baskandi Auua. A total of 16 species of AM have been recorded in the Baskandi Anua and they belong to: six free-floating macrophytes (*Azolla pinnata, Eichhornia crassipes, Salvinia cucullata, Lemna pausicostata, Pistia stratiotes,* and *Wolfia* sp.); two rooted submerged macrophytes (*Hydrilla verticillata* and *Vallisneria spiralis)*; six rooted with floating leaves (*Nymphaea nouchali, Nymphoides indica, N. cristata, Trapa bispinosa, Euryale ferox,* and *Nelumbo nucifera)*; and two rooted emergent macrophytes (*Justicia repens* and *Muradania nudiflora*). Of these, six AM species have been found to occur throughout the year. These are *Azolla pinnata, Eichhornia crassipes, Salvinia cucullata, Trapa bispinosa,* and *Justicia repens* (Dhar et al., 2004).

Studies have revealed that wet biomass of AM range from 4.4 to 11.4 kg/m^2. Wet biomass is observed to be higher during monsoon and post-monsoon, reaching trough value during winter and a concomitant increasing trend during summer. Significant positive correlation of AM biomass with water temperature (r = 0.1820) has been recorded during the study period.

Satkarakandi Anua. This oxbow wetland is an abandoned segment of the Barak River situated at a distance of around 32 km from Silchar City. It lies within the jurisdiction of Katigora Revenue Circle in Cachar District of Assam. It has an L, B, and A of around 1.7 km, 0.7 km, and 53 ha, respectively. The catchment soil is mostly loamy. At present, it seems to have a connection with the Banaimulla River (Kar, 2007a).

Sibnarayanpur Anua. This oxbow wetland is an abandoned segment of the Barak River situated at a distance of around 32 km from Silchar City. It lies within the jurisdiction of Katigora Revenue Circle in Cachar District of Assam. It has an L, B, and A of around 1.7 km, 0.7 km, and 53 ha, respectively. The catchment soil is mostly loamy. At present, it seems to have a connection with the Banaimulla River (Kar D., 2007a).

Notwithstanding the above, a comparative picture of the physic-chemical characteristics of the various studied wetlands in the region has been depicted in figure 5 (a, b, c, d).

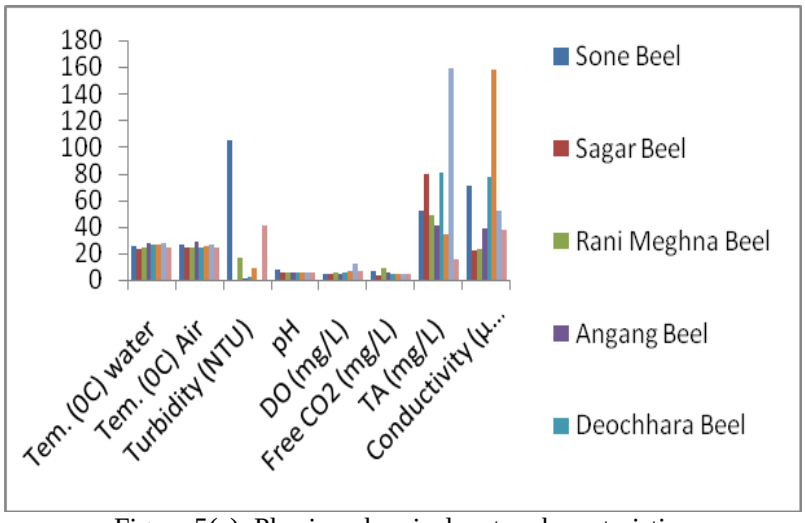


Figure 5(a): Physico-chemical water characteristics
of the different studied wetlands in Assam, India.

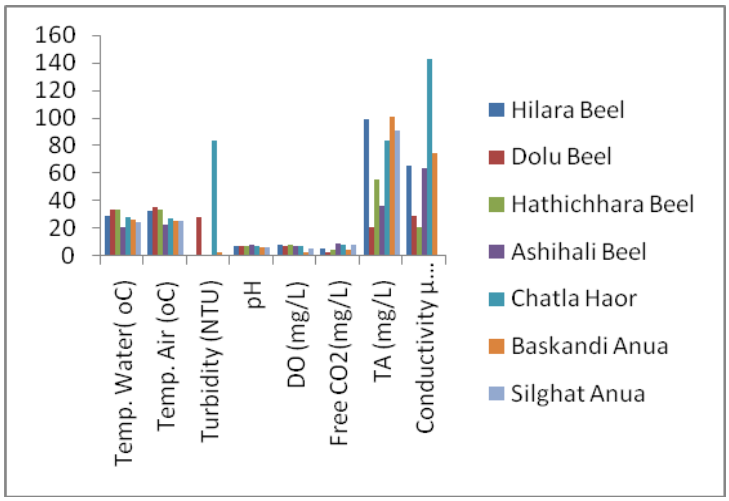


Figure 5(b): Physico-chemical water characteristics of the different studied wetlands in Assam.

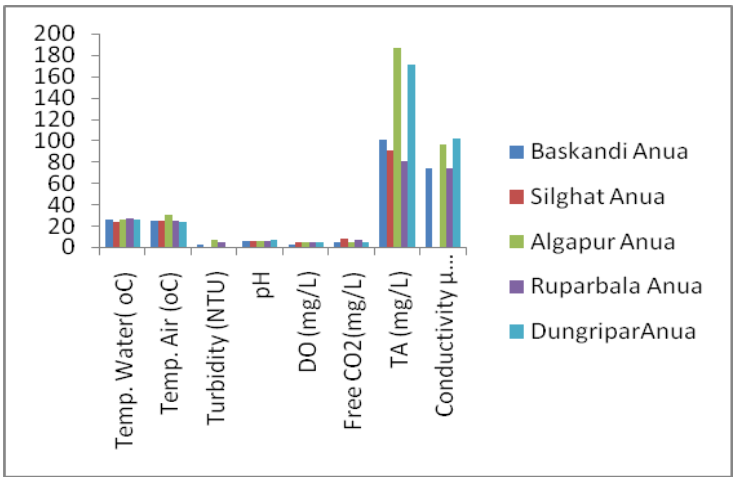


Figure 5(c): Physico-chemical water characteristics of the different studied wetlands in Assam.

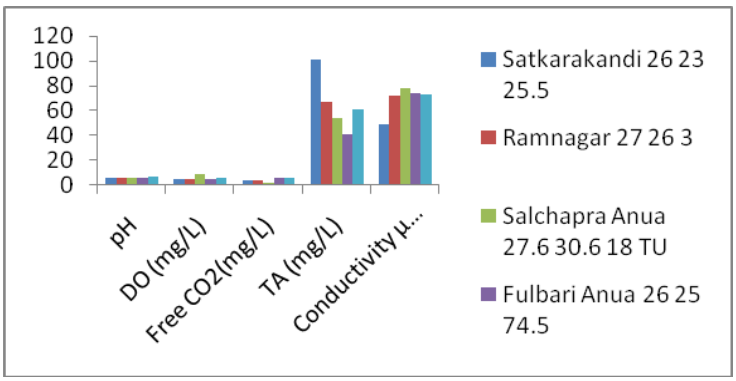


Figure 5(d): Physico-chemical water characteristics of the different studied wetlands in Assam.

Ichthyogeography and ichthyodiversity of the wetlands of Assam

Fish constitute almost half of the total number of vertebrates in the world (Nelson, 1994). They live in almost all conceivable aquatic habitats. Around 21,723 living species of fish have been recorded out of 39,900 species of vertebrates (Nelson, 1994; Jayaram, 1999). Of these, 8,411 are freshwater species and 11,650 are marine. India has one of the mega biodiversity countries in the world and occupies 9th position in terms of freshwater biodiversity (Mittermeier and Mittermeier, 1997). In India, there are around 2,500 species of fish, of which, around 930 live in freshwater (FW) and around 1,570 are marine (Jayaram, 2010; Kar, 2003a). The rich diversity of this region could be assigned to certain reasons, notably, the geomorphology and the tectonics of this zone (Kar, 2005a, b, c). The hills and the undulating valleys of this area gives rise to large number of torrential hill streams, which lead to big rivers; and, finally, become part of the Ganga-Brahmaputra-Barak-Chindwin-Kolodyne-Gomati-Meghna system (Kar, 2000, 2007, 2013).

There is a bewildering diversity of fish in the lentic systems of this region. An account of the ichthyodiversity of the principal lentic bodies of this region is depicted in table 1. The abundance of fish in different wetlands of Assam is portrayed in figure 6.

An account of the ichthyospecies

Zoogeographically, the freshwater fish (FW) have been classified differently by different scientists. Although the classification made by Myers (1949) has been proved to be probably the most useful and widely accepted one, the fish of marine origin have been further classified as peripheral FW forms by Nichols (1928) and Darlington (1957). Incidentally, the ichthyofauna of this region, by and large, have been found to belong to the following categories (Kar, 1990, 2007a, b):

(A) Primary FW Fish

Genera-wise break-up of the species under this group include, among others: *Notopterus, Chitala, Labeo, Cirrhinus, Catla, Cyprinus, Puntius, Rasbora, Cabdio,* (*Aspidoparia) Morar, Amblypharyngodon, Barilius, Devario, Esomus, Salmophasia, Botia, Lepidocephalichthys, Noemacheilus, Somileptus, Rita, Mystus, Wallago, Ompok, Ailia, Eutropichthys, Clupisoma, Silonia, Pangasius, Gagata, Glyptothorax, Clarias, Heteropneustes, Chaca, Badis, Nandus, Anabas, Trichogaster, Mastacembelus, Macrognathus,* and *Tetraodon* (Kar, 1990; 2003a, b, 2007a).

(B) Peripheral FW Fish

Genera-wise break up under this group include, among others: *Gudusia, Hilsa (Tenualosa), Pisodonophis, Chanda, Xenentodon, Aplocheilus, Amphipnous, Sicamugil, Rhinomugil,* and *Glossogobius* (Dey and Kar, 1990).

In addition to the above, on the basis of Indian and extra-Indian fish distribution (Motwani et. al., 1962), the following ichthyospecies of this region could significantly be incorporated under the following two groups:

(a) Widely distributed species

Genera-wise break up under this group include: *Esomus, Puntius, Rasbora, Ompok, Wallago, Clarias, Xenentodon, Channa, Glossogobius, Anabas, Macrognathus,* and *Mastacembelus*. These ichthyospecies, in addition to this region, also occur in India, Pakistan, Bangladesh, Sri Lanka, and Malaya (Kar and Dey, 2000a).

(b) Species of Northern India

Species under this group include, among others: *Bengana elanga, Botia dario, Lepidocephalichthys guntea, Glyptothorax telchitta, Parambassis baculis, Rhinomugil corsula, Sicamugil cascasia,* and *Tetraodon cutcutia* (Kar and Dey, 2000a, b; 1993; Kar, 1990, 2007a, 2013a).

In addition to the foregoing analyses, ecomorphologically (Dey, 1973), the fish of this region could further be categorized into four distinct groups, which are as follows:

(a) True hill-stream or rheophilic forms

Fish with strong body musculature and adapted to torrential habitats, e.g., *Garra, Psilorhynchus, Balitora,* and *Glyptothorax* (Dey, 1973).

(b) Semi-torrential forms

Fish with less body modifications as compared to rheophilic forms, e.g., *Botia, Lepidocephalichthys, Nemacheilus, Schistura, Somileptus,* and *Gagata*.

(c) Migratory forms

Well-built fish having the power of overcoming adverse ecological conditions, such as: *Hilsa (Tenualosa), Barilius, Channa,* and *Badis* (Kar, 2002).

(d) Plainwater forms

Fish having minimum body modifications and insignificant migratory habits: *Pisodonophis, Gudusia, Notopterus, Chitala, Amblypharyngodon, Cabdio,* (*Aspidoparia), Catla, Cirrhinus, Cyprinus, Danio, Esomus, Labeo, Puntius, Rasbora, Salmophasia, Mystus, Sperata, Ompok, Wallago, Rita, Clupisoma, Eutropiichthys, Silonia, Pangasius, Clarias, Heteropneustes, Chaca, Xenentodon, Aplocheilus, Amphipnous, Chanda, Nandus, Sicamugil, Rhinomugil, Anabas, Trichogaster, Glossogobius, Macrognathus, Mastacembelus,* and *Tetraodon.*

Fish diversity in Sone Beel of Assam

A total of 70 species of fish belonging to 49 genera under 24 families and 11 orders have been recorded in Sone Beel, the biggest wetland in Assam.

Of the 70 ichthyospecies of Sone Beel, 59 species under 39 genera belong to the Primary FW group, while 11 species under 10 genera belong to the category of Peripheral FW group (Nichols, 1928; Darlington, 1957). On the other hand, on the basis of Indian and extra-Indian territorial distribution (Motwani et al., 1962; Kar, 1990), 28 ichthyospecies of Sone can significantly be incorporated under two groups, namely, (a) widely distributed species and (b) species of Northern India. Further, among the other species, one species, namely, *Glyptothorax telchitta* has been found to be a true hill stream form; while, five speices, namely, *Botia dario, Lepidocephalichthys guntea, Acanthocobitis botia, Somileptus gongota,* and *Gagata nangra* are recorded as semi-torrential forms (Dey, 1973). Totally, 39 fish species belong to the plainwater group (Kar, 1990, 2007a; Dey and Kar, 1990). Incidentally, the fishermen fishing in Sone Beel belong to four communities (Kar, 1990, 2000a, 2003c, 2007a, 2013a; Dey and Kar, 1989b).

Fish diversity in Sat Beel of Assam

Fourteen species of fish, belonging to 12 genera, six families and three orders, have been recorded in Sat Beel (Kar, 2007a).

Fish diversity in Chatla Haor of Assam

A total number of 57 species of fish, belonging to 28 genera, 17 families and nine orders, have been recorded in Chatla Haor (Kar and Barbhuiya, 2000b; Kar, 2007a, 2013a; Kar and Dey, 2002).

Zoogeographically, the ichthyospecies of Chatla Haor consist of 79.62% of primary FW fish, while the rest (20.38%) belong to the peripheral class (Nichols, 1928; Darlington, 1957; Kar, 1990, 2007a). Further, on the basis of Indian and extra-Indian territorial fish distributional pattern (Motwani et al., 1962), ichthyospecies of Chatla Haor contain fish, which belong to the groups called widely distributed species (notably, *Puntius, Ompok, Channa, Anabas*) and species of Northern India (notably, *Botia dario*, *Lepidocephalichthys guntea*, etc.). Ecomorphologically (Dey, 1973), fish species of Chatla Haor contain only the "semi-torrential" forms and the "plainwater" forms (notably *A. mola*, *C. catla, C. carpio*, *Puntius* spp., and *Mystus* spp.) (Kar, 2007a).

Fish Diversity in Puneer Haor of Assam

The Puneer Haor contains altogether 24 species of fish belonging to 22 genera, 15 families and eight orders (Laskar et al., 2002).

Fish diversity in the Anuas of Assam

Rupairbala Anua

In this Anua, 24 species of fish belonging to 21 genera, 15 families and nine orders have been recorded (Kar, 2000b, 2007a; Kar et al., 2000a, b, c).

Baskandi Anua

In Baskandi Anua, 13 species of fish belonging to 10 genera, six families and four orders have been recorded (Kar, 2007a; Kar et al., 2000a, b, c; Dhar, 2004).

Fulbari Anua

In course of a pilot survey, seven species of fish, belonging to six genera, six families and six orders, have been recorded from Fulbari Anua (Kar et al., 2000a, b, c).

Sibnarayanpur Anua

A total of 22 species of fish belonging to 21 genera, 10 families and five orders have been recorded from Sibnarayanpur Anua (Kar et al., 2000a, b, c).

Table 1: Fish diversity in southern Assam Wetlands ("+" Present, "–" Absent).

Fish species	Sone Beel	Sat Beel	Chatla Haor	Puneer Haor	Rupairbala Anua	Baskandi Anua	Fulbari Anua	Sibnarayan pur Anua
Pisodonophis boro (Hamilton)	+	–	–	–	–	–	–	–
Gudusia chapra Hamilton)	+	–	+	–	+	–	+	+
Tenualosa ilisha (Hamilton)	+	–	+	–	–	–	–	–
Chitala chitala (Hamilton	+	–	+	–	–	–	–	–
Notopterus notopterus (Pallas)	+	–	+	+	+	–	–	–
Amblypharyngodon mola (Hamilton)	+	+	+	+	+	+	–	–
Aspidoparia morar (Hamilton)	+	–	–	–	–	–	–	–
Barilius bendelisis (Hamilton)	+	–	–	–	–	–	–	–
Osteobrama cotio (Hamilton)	–	–	–	–	–	–	–	+
Catla catla (Hamilton)	+	–	+	–	–	–	–	+
Cirrhinus mrigala (Hamilton)	+	–	+	–	–	–	–	+
Cirrhinus reba (Hamilton)	+	–	+	+	–	–	–	–
Chela laubuca (Hamilton)	+	–	–	–	–	–	–	+
Cyprinus carpio (Linnaeus)	+	+	+	–	–	–	–	–
Ctenopharyngodon idellus (Valenciennes)	–	–	+	–	–	–	–	–
Hypophthalmichthys molitrix (Valenciennes)	–	–	+	–	–	–	–	–
Devario devario (Hamilton)	+	–	+	–	–	–	–	–
Esomus danricus (Hamilton)	+	–	+	–	–	–	–	+
Labeo bata (Hamilton)	+	–	–	–	–	–	–	–
Labeo calbasu (Hamilton)	+	+	+	+	–	–	–	–
Labeo gonius (Hamilton)	+	–	+	–	+	–	–	+
Labeo nandina (Hamilton)	+	–	–	–	–	–	–	–
Labeo rohita (Hamilton)	+	–	+	–	–	–	–	–

Table 1 (continued): Fish diversity in southern Assam Wetlands ("+" Present, "–" Absent).

Fish species	Sone Beel	Sat Beel	Chatla Haor	Puneer Haor	Rupairbala Anua	Baskandi Anua	Fulbari Anua	Sibnarayan pur Anua
Pisodonophis boro (Hamilton)	+	–	–	–	–	–	–	–
Gudusia chapra Hamilton)	+	–	+	–	+	–	+	+
Puntius chola (Hamilton)	+	+	+	–	+	–	+	+
Puntius conchonius (Hamilton)	+	–	+	+	+	+	–	+
Puntius saranasarana (Hamilton)	+	–	+	–	–	–	–	–
Puntius ticto (Hamilton)	+	+	+	+	+	+	+	+
Rasbora daniconius (Hamilton)	+	–	+	–	–	+	–	–
Bengana elanga (Hamilton)	+	–	–	–	–	–	–	–
Salmophasia bacaila (Hamilton)	+	–	+	+	–	+	–	+
Securicula gora (Hamilton)	–	–	–	+	+	–	–	+
Botia dario (Hamilton)	+	–	+	–	+	–	–	–
Lepidocephalichthys guntea (Hamilton)	+	+	+	–	+	–	–	–
Acanthocobitis botia (Hamilton)	+	–	+	–	–	–	–	–
Somileptus gongota (Hamilton)	+	–	–	–	–	–	–	–
Mystus bleekeri (Day)	–	+	–	+	–	–	+	–
Mystus cavacious (Hamilton)	+	–	+	–	+	–	+	–
Mystus corsula (Hamilton)	+	–	+	–	–	–	–	–
Pisodonophis boro (Hamilton)	+	–	–	–	–	–	–	–
Gudusia chapra (Hamilton)	+	–	+	–	+	–	+	+
Tenualosa ilisha (Hamilton)	+	–	+	–	–	–	–	–
Chitala chitala (Hamilton)	+	–	+	–	–	–	–	–
Notopterus notopterus (Pallas)	+	–	+	+	+	–	–	–
Amblypharyngodon mola (Hamilton)	+	+	+	+	+	+	–	–
Aspidoparia morar (Hamilton)	+	–	–	–	–	–	–	–
Barilius bendelisis (Hamilton)	+	–	–	–	–	–	–	–
Osteobrama cotio (Hamilton)	–	–	–	–	–	–	–	+
Catla catla (Hamilton)	+	–	+	–	–	–	–	+
Cirrhinus mrigala (Hamilton)	+	–	+	–	–	–	–	+
Cirrhinus reba (Hamilton)	+	–	+	–	–	–	–	–
Chela laubuca (Ham)	+	–	+	–	–	–	–	–
Cyprinus carpio (Linnaeus)	+	+	+	–	–	–	–	–
Ctenopharyngodon idellus (Valenciennes)	–	–	+	–	–	–	–	–
Hypophthalmichthys molitrix (Valenciennes)	–	–	+	–	–	–	–	–
Devario devario (Hamilton)	+	–	+	–	–	–	–	–
Esomus danricus (Hamilton)	+	–	+	–	–	–	–	+
Labeo bata (Hamilton)	+	–	+	–	–	–	–	+
Labeo calbasu (Hamilton)	+	+	+	+	–	–	–	+
Labeo gonius (Hamilton)	+	–	+	–	+	–	–	+

Table 1 (continued): Fish diversity in southern Assam Wetlands ("+" Present, "–" Absent).

Fish species	Sone Beel	Sat Beel	Chatla Haor	Puneer Haor	Rupairbala Anua	Baskandi Anua	Fulbari Anua	Sibnaraya pur Anua
Pisodonophis boro (Hamilton)	+	–	–	–	–	–	–	–
Gudusia chapra Hamilton)	+	–	+	–	+	–	+	+
Puntius chola (Hamilton)	+	+	+	–	–	–	–	–
Labeo nandina (Hamilton)	+	–	–	–	–	–	–	–
Labeo rohita (Hamilton)	+	–	+	–	–	–	–	+
Puntius chola (Hamilton)	+	+	+	–	–	–	–	–
Puntius conchonius (Hamilton)	+	–	+	+	+	+	–	+
Puntius saranasarana (Hamilton)	+	–	+	–	–	–	–	–
Puntius ticto (Hamilton)	+	+	+	+	+	+	+	+
Securicula gora (Hamilton)	–	–	–	+	+	–	–	+
Botia dario (Hamilton)	+	–	+	–	+	–	–	–
Lepidocephalichthys guntea (Hamilton)	+	+	+	–	+	–	–	–
Acanthocobitis botia (Hamilton)	+	–	+	–	–	–	–	–
Somileptus gongota (Hamilton)	+	–	–	–	–	–	–	–
Mystus bleekeri (Day)	–	+	–	+	–	–	+	–
Mystus cavacious (Hamilton)	+	–	+	–	+	–	+	–
Mystus corsula (Hamilton)	+	–	+	–	–	–	–	–
Mystus tengara (Hamilton)	+	–	+	–	–	–	–	–
Mystus vittatus (Bloch)	+	+	+	+	–	–	–	–
Sperata seenghala (Sykes)	+	+	+	–	–	–	–	–
Rita rita (Hamilton)	+	–	–	+	–	–	–	+
Ompok bimaculatus (Bloch)	+	+	+	+	+	–	–	–
Rasbora daniconius (Hamilton)	+	–	+	–	–	+	–	–
Bengana elanga (Hamilton)	+	–	–	–	–	–	–	–
Salmophasia bacaila (Hamilton)	+	–	+	+	–	+	–	+
Wallago attu (Bloch and Schneider)	+	+	+	–	–	–	–	–
Ailia coila (Hamilton)	+	–	+	–	–	–	–	–
Clupisoma atherinoides (Hamilton)	+	–	+	–	–	–	–	–
Clupisoma garua (Hamilton)	+	+	+	–	–	–	–	+
Eutropiichthys vacha (Hamilton)	+	–	+	–	–	–	–	+
Eutropiichthys murius (Hamilton)	–	–	+	–	–	–	–	–
Silonia silondia (Hamilton)	+	–	–	–	–	–	–	–
Pangasius pangasius (Hamilton)	+	–	–	–	–	–	–	–
Nangra nangra (Hamilton)	+	–	–	–	–	–	–	–
Glyptothorax telchitta (Hamilton)	+	–	–	–	–	–	–	–
Clarias batrachus (Linnaeus)	+	–	+	+	–	–	–	+

Table 1 (continued): Fish diversity in southern Assam Wetlands ("+" Present, "–" Absent).

Fish species	Sone Beel	Sat Beel	Chatla Haor	Puneer Haor	Rupairbala Anua	Baskandi Anua	Fulbari Anua	Sibnarayan pur Anua
Heteropneustes fossilis (Bloch)	+	–	+	+	–	–	–	–
Chaca chaca (Hamilton)	+	–	–	–	–	–	–	–
Xenentodon cancila (Hamilton)	+	–	+	+	+	–	–	+
Aplocheilus panchax (Hamilton)	+	–	+	+	+	–	–	–
Channa orientalis (Schneider)	+	–	+	–	–	–	–	–
Channa marulius (Hamilton)	+	–	–	–	–	+	–	–
Channa punctata (Bloch)	+	+	+	+	–	+	+	–
Channa striata (Bloch)	+	–	+	–	–	+	–	–
Amphipnous cuchia (Hamilton)	+	–	+	–	–	–	–	+
Parambassis baculis (Hamilton).	+	–	+	–	+	–	–	–
Parambassis ranga (Hamilton)	–	–	+	+	+	+	+	–
Chanda nama (Hamilton)	+	–	+	–	+	–	–	+
Badis badis (Hamilton)	+	–	+	–	+	+	–	+
Nandus nandus (Hamilton)	+	–	+	+	–	–	–	–
Oreochromis mossambica (Peters)	–	–	–	+	+	–	–	–
Rhinomugil corsula (Hamilton)	+	–	–	–	–	–	–	–
Sicamugil cascasia (Hamilton)	+	–	–	–	–	–	–	–
Glossogobius giuris (Hamilton)	+	–	+	–	+	+	–	–
Anabas testudineus (Bloch)	+	–	+	+	+	–	–	–
Trichogester fasciata (Schneider)	+	–	+	+	+	–	–	–
Trichogester lalia (Hamilton)	–	–	+	–	+	–	–	–
Trichogester sota (Hamilton)	–	–	–	+	–	–	–	–
Macrognathus aral (Bloch and Schneider)	+	–	+	–	–	+	–	–
Macrognathus pancalus (Hamilton)	+	+	+	–	+	+	+	+
Mastacembelus armatus (Lacepede)	+	–	+	+	–	–	–	+
Tetraodon cutcutia (Hamilton)	+	–	–	–	+	–	–	–

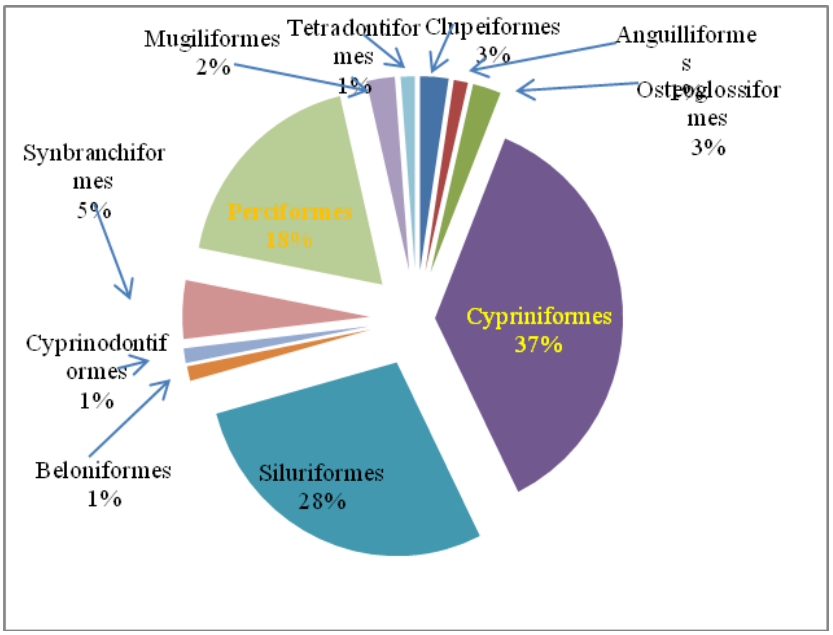


Figure 6: Orderwise abundance of fish in different wetlands of Assam.

Management and conservation of wetlands: A case study in Sone Beel in Assam

Profitable harnessing of fish resources from these natural "Beels" depend today on systematic management of these water bodies (Kar et al., 1996b; Kar, 2007a, 2013a). Sone Beel could be considered as an example.

At dead storage level (DSL), Sone Beel has eight deeper fishing centres locally called "Bundhs" (November – April: 5 ha – around 200 ha; depth: 1 m – 1.75 m). Now the "Bundhs" witness only "Capture Fishing".

Conversely, scientific pisciculture in these "Bundhs" could increase the fish yield (FY) and could generate employment and income.

Concomitantly, certain other measures, forming part of the management strategies, (which could also be applicable to other similar "Beels") are as follows:

1. Regulation of siltation at the upstream region of the inlet(s) coupled with construction of "check dams", wherever necessary, along with concomitant allotment of "Patta" (land ownership right) to the local inhabitants to prevent further encroachment into the Beel mainly for paddy cultivation.

2. Leasing-out of the Sone Beel to Peoples' Organisations as Sone Beel Fishermens' Co-operative Society (SBFCS) instead of individuals with complete responsibility of its management to SFFCS; as well as, imposition and realization of its proper monetary share. Government may do developmental works through the earnings.

3. SEFCS may further earn through collection of token tolls from the fishermen as well as the fish traders on the basis of fish caught and purchased, respectively.

4. The generation of employment and income through proper management would prevent avaricious exploitation of the Beel, check exodus of fishermen from the Beel to the cities; and, thus, would help conserving fishermen as fishermen.

5. Proper steps to be taken by the Board of Management to control fish disease such as the Epizootic Ulcerative Syndrome (EUS) in order to prevent large scale mortality of fish.

6. Similar management strategies could be thought in other lentic and lotic systems.

Habitat mapping by remote sensing

Remote Sensing (RS) tools have an important role in applications relating to wetland monitoring and mapping. In optical RS, the visible and infra-red part of the electromagnetic spectrum is used to characterize objects. However, during monsoon season, the suitable atmospheric windows for acquisition of optical data are limited to cloud-free periods. This is a major lacuna for wetland applications because wetlands are highly seasonal and dynamic systems compared to terrestrial ecosystems. The radar imaging systems are said to overcome many of these limitations by providing increased canopy penetrations and day and night acquisitions nearly independent of weather conditions (Ramsey, 1995; Ramsey and Laine, 1997**)**. Therefore, it is imperative to use radar data for a better understanding of the dynamics of wetland ecosystems as well as their assessment, monitoring and management. There are also several advantages of using microwave data. Microwave sensors have a unique sensitivity to the moisture content of the earth material. They are also highly sensitive to textural properties of vegetative cover. Therefore, they can be used to discriminate between grasses, aquatic vegetation, forest, and crop cover. In this way, the surrounding people can use them to identify the encroachment inside a national park for agricultural activities.

Identification of different habitats is also a main activity for wetland monitoring and management. Studies have indicated that Synthetic Apeliure Radar data are far superior to optical satellite data in the delineation of open water habitat and aquatic vegetation. Although radar remote sensing could play an important role in wetlands, so far, very little amount of work has been done and there is huge potential to explore and exploit the different capabilities of radar data for wetland research. High Incidence Angle Radar data have been used to delineate the open water habitat with aquatic vegetation critical to waterfowl in wetlands. The study of Keoladeo Ghana National Park in Bharatpur has shown that radar data are three to four times better in delineating the extent of open water, aquatic vegetation categories and also localities of high soil moisture content (Srivastava et al., 2001). Such information could be of great significance in formulating Habitat Suitability Index (BS) models for a variety of species.

Wetland habitat mapping exemplified

An attempt has been made to map few wetlands in Assam in GIS platform (Figs. 7-34).

Using IRS-IC, LISS-III and IV data, mapping of some of the wetlands in Assam have been done preliminarily using GIS software. The study reveals that almost all the wetlands of Assam are affected by siltation. They are shallow and some of them are not rich in aquatic macrophytes. Turbidity is generally high during rainy season. Land use pattern mainly involves fishing and sometimes cultivation of paddy mainly during the spring season.

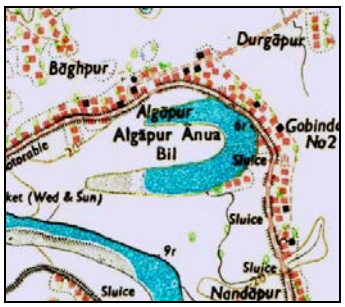


Figure 7: Algapur Anua.

Figure 8: Andhurua Beel.

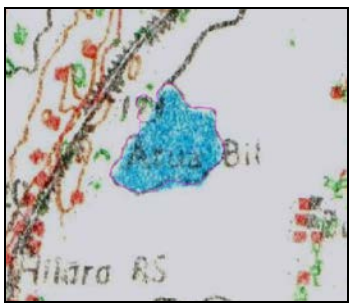


Figure 9: Atoa Beel.

Figure 10: Bakri Haor.

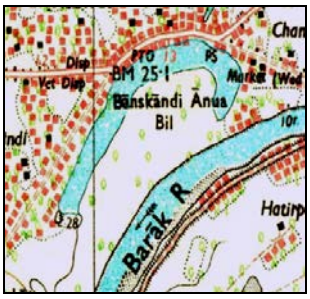


Figure 11: Baskandi Anua.

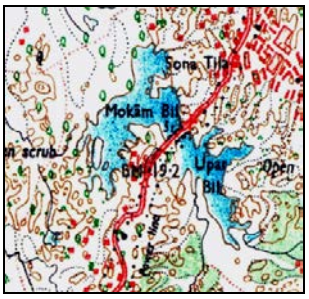


Figure 12: Chatla Haor.

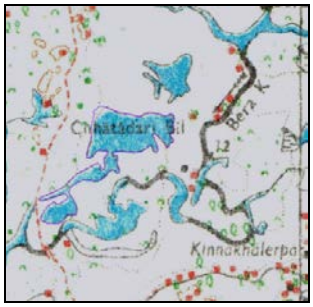


Figure 13: Chatradharia Beel.

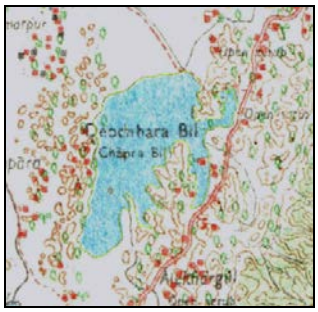


Figure 14. Deocherra Beel.

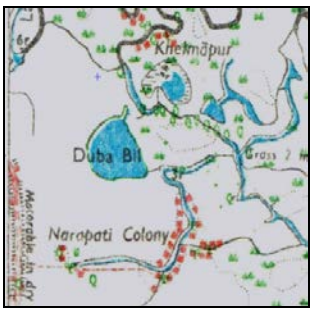


Figure 15: Dholi Beel.

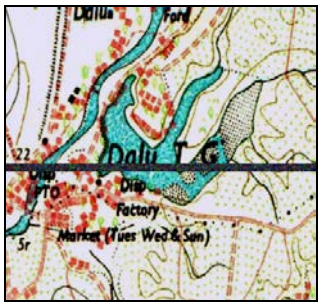


Figure 16: Dolu Lake.

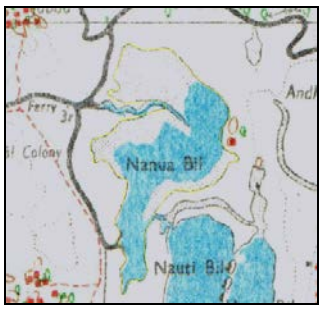


Figure 17: Jabda Beel.

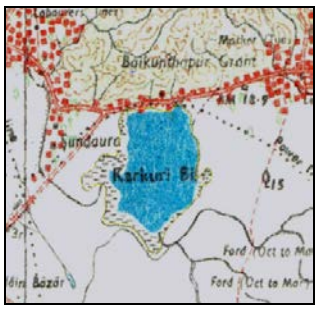


Figure 18: Korkori Beel.

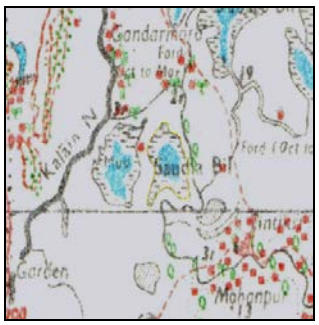


Figure 19: Suskacharua Beel.

Figure 20: Malini Beel.

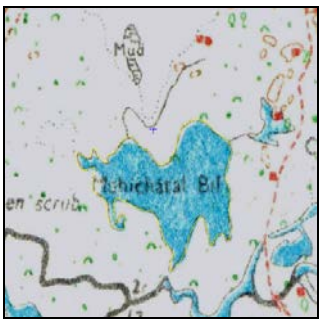


Figure 21: Mahisatal Beel.

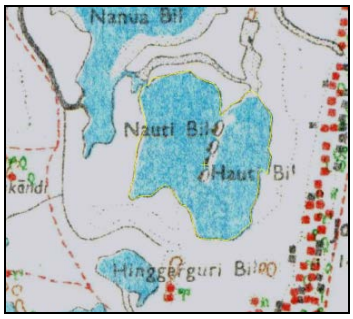


Figure 22: Outi-bouti Beel.

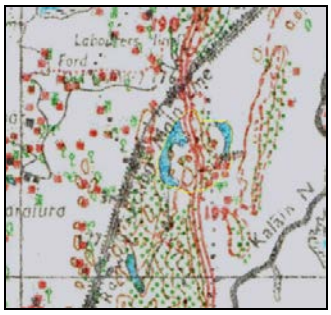


Figure 23: Petoa Beel.

Figure 24: Punir Haor.

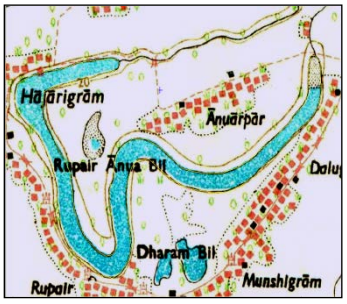


Figure 25: Rupairbala Anua.

Figure 26: Ramnagar Anua.

Figure 27: Salchapra Anua.

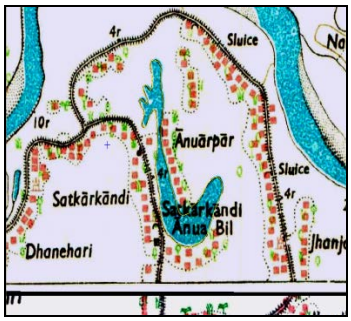


Figure 28: Satkarakandi Anua.

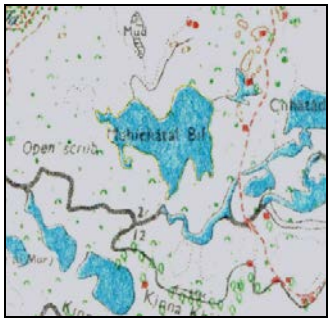


Figure 29: Mohisatal Beel.

Figure 30: Chatradharia Beel.

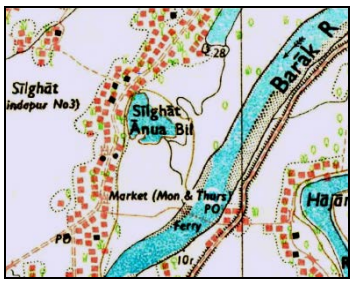


Figure 31: Silghat anua.

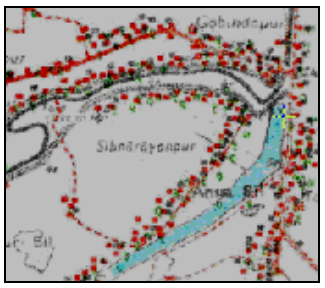


Figure 32: Shivnarayanpur Anua.

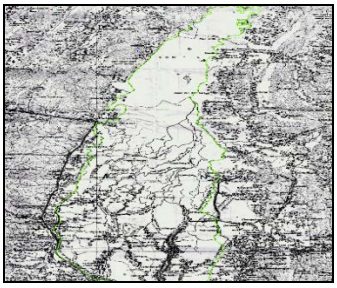


Figure 33: Sone Beel.

Figure 34: Kuria Beel.

Epizootic Ulcerative Syndrome (EUS fish disease)

The dreadful and virulent Epizootic Ulcerative Syndrome (EUS) has been sweeping the freshwater fish (FW) in an epidemic dimension, unhindered, unimpeded and unabated, almost semi-globally today. This disease has caused large-scale mortality among fish since 1988, rendering many of them endangered. It also leads to fear psychosis among the fish-eating people, causing untold misery to the fishermen and fish farmers, as well as devastation to the economy of the nation. The epizootic ulcerative syndrome has revealed fluctuations in its intensity in relation to species affected. Our studies, involving aspects, such as: limnology, chemistry, physics, bacteriology, mycology, and virology, including tissue culture and electron microscopy, have revealed interesting findings including isolation of a virus. There is urgent need for managing this unimpeded fish disease (Plates 1, 2, 3) (Kar, 2015).

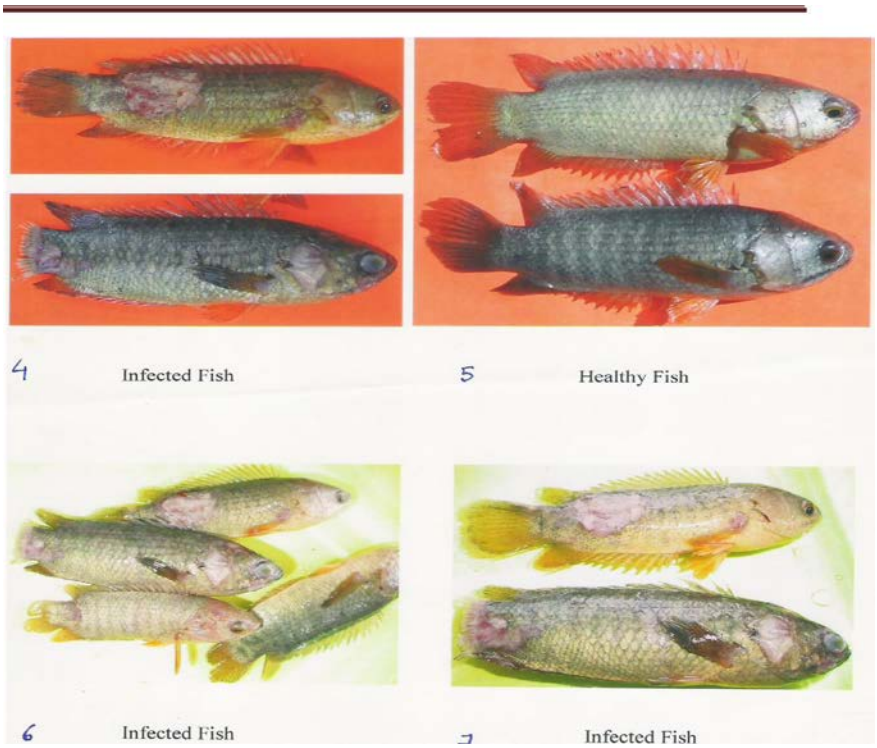


Plate 1: Some of the fish species affected by the epizootic ulcerative syndrome (EUS) fish disease.

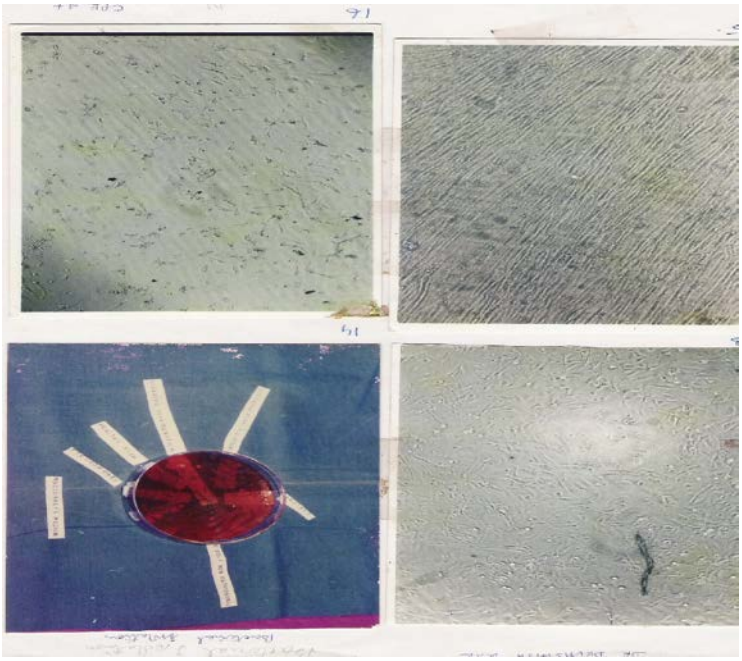


Plate 2: Microbiological and tissue cultural isolation of EUS fish bacteria and virus.

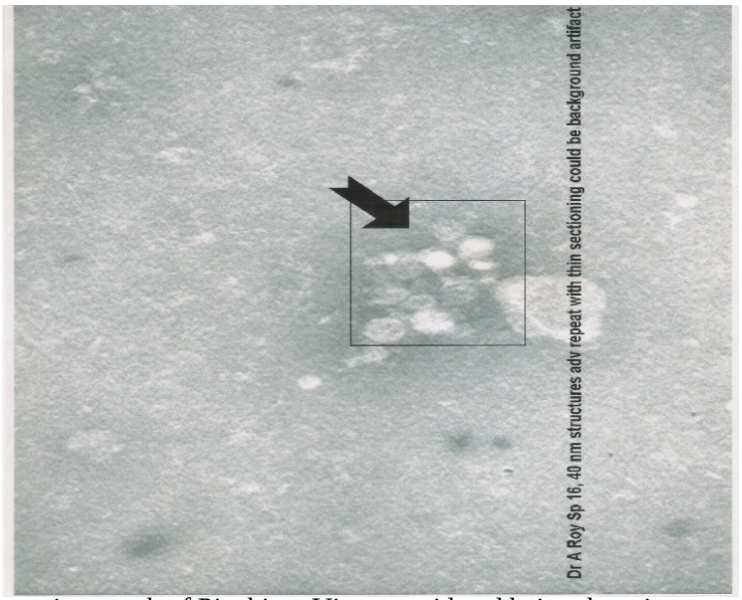


Plate 3: An electron micrograph of Picobirna Virus considered being the primary aetiology of EUS fish disease.

In addition to the above, present status of the wetlands in this region with regard to their potentialities and problems have been summarized in table 2. The wetlands in this region could function very well with regard to pisciculture and flood management in this severely flood-prone area. They could also serve significantly in the rehabilitation of the innumerable immigrated fishermen.

The potentialities of Beels, Haors and Anuas are reflected in the many aspects presented here: vast waterspread area, presence of continuous inlets and outlets, maximum depth sometimes up to six metres, occurrence of high fish diversity to the extent of 70 species in a single Beel (Sone Beel), presence of migratory *Hilsa* in some of the Beels, etc. Likewise, some of the Haors have rich diversity of phyto- and zooplankton and occurrence of juveniles of IMCs and *Hilsa*; thus, indicating such wetlands serving as possible natural breeding grounds of IMCs and *Hilsa*. The Anuas, being detached from original course of the rivers, could serve as ideal sites for culture fishery.

Notwithstanding the above, significant problems faced by these wetlands are mostly man-induced, e.g., diversification of the course of the inlets and blocking of the outlets, which results in siltation of the Beels and the channels due to less expulsion of silt from the Beel and leads to diminution of depth and water-spread area rendering loss of breeding ground for the large growing fish (LGF); exposure of the land, their subsequent encroachments and paddy cultivation often using chemical fertilizers and pesticides. Day-in and day-out fishing operations by thousands of unrehabilitated fishermen using 26 different types of fishing gears (some of which are fine-meshed) and methods (Kar, 2007a, 2013a) is a problem of concern. Acute weed problems in some of the "Anuas" are another problem of serious concern.

Some of the important suggestions include removal/modification of man-made blockades in order to revive the migration of fish, to help boost fish trade through navigation and to enable some amount of natural desiltation. Furthermore, proposed measures include: some amount of man-made desiltation could revive the breeding ground of the LGF, discourage paddy cultivation due to re-submergence of the exposed wetland beds; rehabilitation of the innumerable immigrated fishermen, minimum education and monitoring of the wetland users by the NGOs for less input towards eutrophication; culture of IMCs in the deep fishing centres at the DSL to boost local earnings; and, initiation/re-vamping of the Fishermen Co-operative Societies. These measures could contribute to maintainig the health of the Wetlands and Wetland-users and in the emancipation of the poor fishermen.

Table 2: Potentialities and problems of the wetlands in Assam.

Wetlands	Potentialities	Problems
Sone Beel	Biggest wetland in Assam, continuous inlet, outlet, big size IMCs, naturally growing *Hilsa*, ideal site for rehabilitation of displaced fishermen (Plate 4)	Inlet diversifications, outlet diversifications, outlet blockade, siltation, mahajal operation, paddy cultivation, big size carnivorous fish, and exotic carps, day-in, day-out fishing operations, fish disease (EUS)
Sat Beel	Near the rivers Barak and Madhura, ideal site for culture fishery	Siltation, weeds
Malini Beel	Near the Barak River, ideal site for culture fishery and tourism	Siltation, urbanization
Tapang Beel	Big natural Beel, good site for capture fishing	Siltation, encroachment of the Beel
Srikona Beel	Near the Barak River , ideal site for culture fishery	Weeds
Dubria Beel	Ideal site for culture fishery	Siltation
Hatichhara Beel	Big size, ideal site for fish stocking	Turbidity, tea garden effluents
Doloo Beel	Big size, ideal site for fish stocking	Tea garden effluents
Hotoir Beel	Potential site for culture fishery	Siltation, weeds
Karkari Beel	Potential site for culture fishery	Siltation
Sagar Beel	Potential site for culture fishery	Bad transport
Rani Meghna Beel	Potential site for culture fishery	Bad transport
Angang Beel	Potential site for culture fishery	Weeds
Deochhara Beel	Potential site for fish stocking	Weeds
Baua Beel	Potential site for culture fishery	Siltation, paddy cultivation

Table 2 (continued): Potentialities and problems of the wetlands in Assam.

Wetlands	Potentialities	Problems
Chatla Haor	A very big Haor in Assam, potential site for fish culture, if water be retained; IMC and *Hilsa* juveniles occur (Plate 5). Ideal site for rehabilitation of displaced fishermen	Siltation, mahajal operation, tea garden effluents
Puneer Haor	Potential site for culture fishery	Tea garden effluents
Bakri Haor	Near the Dhaleswari River, ideal site for capture fishery	Siltation, encroachments, paddy cultivation
Baskandi Anua	Potential site for IMC culture	Weeds
Algapur Anua	Potential site for IMC culture	Weeds
Silghat Anua	Potential site for IMC culture	Weeds
Rupairbala Anua	Potential site for IMC culture	Weeds
Dungripar Anua	Potential site for IMC culture	Weeds
Satkarakandi Anua	Potential site for IMC culture	Weeds
Ram Nagar Anua	Potential site for IMC culture	Weeds
Fulbari Anua	Potential site for IMC culture	Not much weeds, less problematic
Sibnarayanpur Anua	Good site for capture fishery	Siltation, paddy cultivation
Ashiali Beel	Good site for capture fishery	Siltation, paddy cultivation

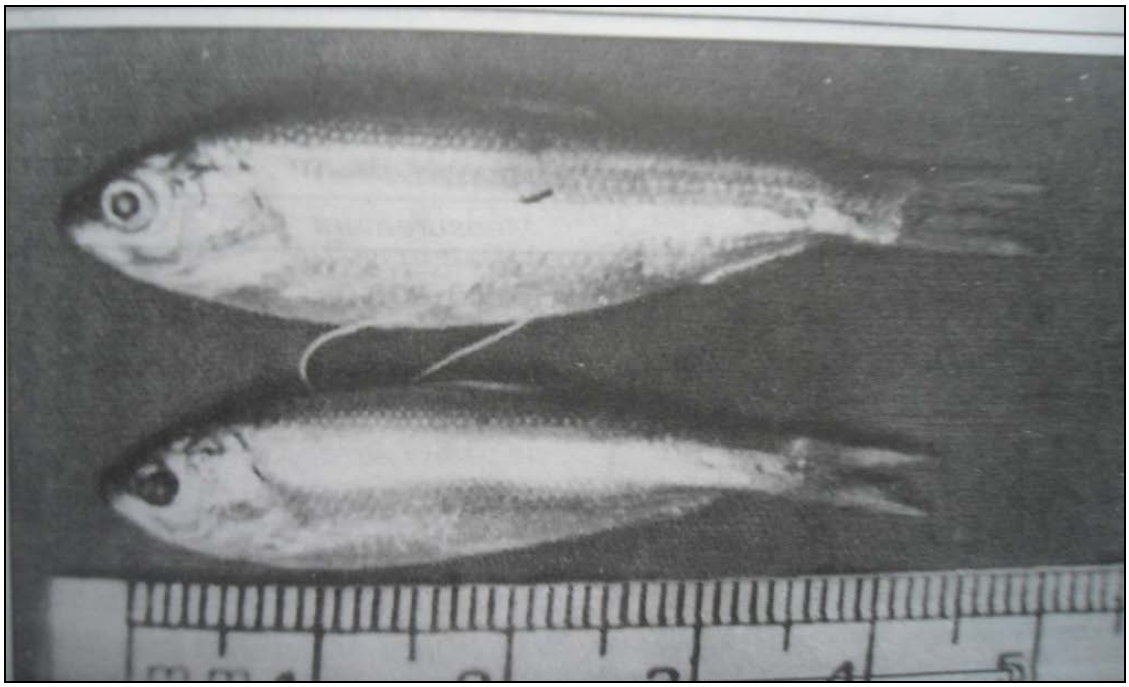


Plate 4: Naturally occurring *Hilsa* in Sone Beel Wetland of Assam.

Plate 5: Natural occurrence of *Hilsa* juveniles in the Chatla Haor wetland in Assam.

CONCLUSIONS

Hilsa is a transboundary fish in the international waters, particularly in the Asian continent. Its distribution ranges from Persian Gulf through Pakistan to India, Bangladesh, China, Myanmar (Jayaram, 2010). As such, its natural occurrence in the Sone Beel is highly significant. Further, occurrence of *Hilsa* juveniles in the Chatla Haor wetland in Assam is of tremendous importance in view of the said biotope, probably, acting as the breeding ground of *Hilsa* (Kar and Dey, 2002). Such aspects are to be taken due care of at the international level.

Hilsa fish migrate from sea to river for breeding and spawning purpose during monsoon season. However, wetlands support about 77 other fish species assemblages in Barake Valley. Among them, many species also have migratory tendency within freshwater bodies in the river drainage network, and are playing important role for species specific interaction due to different trophic interactions. Many species of cat fishes migrate to these wetlands during flooding season of the river basin for spawning and breeding. Therefore, conclusion has to be revised accordingly, highlighting the overall importance of wetlands.

Shrinkage of water spread area of the wetlands, of late, seems to be a common ailment with them, thus, providing less water availability for the aquatic biota as well as the human population. This matter seems to be a common phenomenon almost throughout the entire Asian continent. Thus, it has to be internationally taken care of.

Likewise, eutrophication of the wetlands seems to be a common disease at the international level, and, hence, has to be taken care of.

Epizootic Ulcerative Syndrome (EUS), the hitherto unknown dreadful, virulent and enigmatic fish disease, which has been sweeping the freshwater fish semi-globally, unabated and unhindered in an epidemic dimension, has been affecting the fish even today. Hence, EUS, causing large-scale mortality of the wetland and the farmed fish, devastating economy and the health of the people, has to be tackled.

The fisher folk are the instruments of fish handling. But, these economically backward and perennially poverty-stricken useful human resources are yet to be rehabilitated properly. As such, this aspect is to be taken care of on a priority basis.

ACKNOWLEDGEMENTS

The author utilises the privilege of this opportunity to express his gratitude to the innumerable fisher folk who gave pleasant company and care to the author in many a stormy nights in the strenuous field works by the author spanned over few decades. Their help can, perhaps, neither be returned nor be acknowledged fully. Nevertheless, the author expresses his heartfelt gratitude to all the people involved in this unsanctioned self-financed work (sacrificing his remuneration and leave for long). The author also gratefully acknowledges the tremendous amount of assistance rendered by his student, Mr. Satyajit Das, in the secretarial works.

REFERENCES

1. APHA, 1995 – Standard Methods for the Examination of Water and Wastewater, American Public Health Association, USA, xxxix + 1193.
2. Bănăduc D., Rey S., Trichkova T., Lenhardt M. and Curtean-Bănăduc A., 2016 – The Lower Danube River–Danube Delta–North West Black Sea: A pivotal area of major interest for the past, present and future of its fish fauna — A short review, *Science of the Total Environment* 545-546, 137-151.
3. Banerjea S. M., 1967 – Water quality and soil condition of the fish ponds in some states of India in relation to fish production, *Indian Journal of Fish*, 14, 1-2, 115-144.
4. Barbhuiya M. H., Kar D. and Goswami U. C., 1999 – Studies on Aquatic Biodiversity of Barak-Nadi Salchapra Oxbow lake in Cachar district of Assam with a note on its Management and Conservation, National Symposium on Trends in Environ-mental biology (23-25 June, 1999), NEHU, Shillong, Abstract, 19.
5. Barbhuiya M. H., Goswami M. M. and Kar D., 2006 – Fishes of Barak Nadi Salchapra Anua with a note on their conservation, *Proceedings of the National Conference on Zoology*, Pune.
6. Barbhuiya M. H., Goswami M. M. and Kar D., 2007 a – Water quality parameters of Barak Nadi Salchapra Anua wetland in Barak Valley region of Assam, *Proceedings of the Indian Science Congress*, Annamalai University, Tamil Nadu.
7. Barbhuiya M. H., Goswami M. M. and Kar D., 2007 b – Zooplankton diversity of Salchapra wetland in Cachar district of Assam, Abstracts, All-India Congress of Zoology, 18, 109.
8. Barhoi A., Das S., Das B. K. and Kar D., 2015 – A preliminary survey on the Icthyospecies diversity of Hasila Beel, Urpad Beel, Kumri Beel, Sidli Beel and Seksekia Beel in the Goalpara District of Assam, India, *International Journal of Advanced Research*, 3, 6, 678-684.
9. Bimola M., Singh Shashikumar O., Kar D. and Jajo E., 2014 – A preliminary study on Zooplankton record from Yenapat, a freshwater lake at Bishnupur district, Manipur, North-East India, *Proceedings of the National Seminar*, Recent Advances in fishery science, D. M. College of Science, Manipur, 58-72.
10. Bimola M., Singh Shashikumar O. and Kar D., 2015a – Diversity and abundance of Rotifer in Yenapat Lake of Bishnupur District, Manipur, N. E. India, *International Journal of Current Research*, 7, 1, 11849-11851.
11. Bimola M., Singh Shashikumar O. and Kar D. 2015 b – Studies on zooplankton community in relation with physico-chemical properties of water of the Yenapat, a freshwater lake at Bishnupur District, Manipur, N. E. India, *Life Sciences Bulletin*, 11, 2, 153-156.
12. Bimola M., Das U., Das P., Kar S., Singh O. S., Kar D. and Aditya G., 2016b – Rotifer Species Assemblages in Three Freshwater Habitats of Manipur, India, *Proceedings of the Zoological Society*, Springer, 1-9.
13. Battish S. K. ,1992 – Freshwater Zooplankton of India, Oxford and IBH Publishing Co., Ltd., New Delhi, vi + 233.
14. Bennet G. W., 1962 – Management of artificial lakes and ponds, Reinhold (New York), 1-283.
15. Biswas K. and Calder C. C., 1955 – Handbook of Common Water and Marsh Plants of India and Burma, 1936), *Health Bulletin*, 24, Malaria Bureau of Government of India Press (Calcutta), 216.
16. Biswas K. and Calder C. C., 1984 – Handbook of Common Water and Marsh Plants of India and Burma, Bishen Singh Mahendra Pal Singh, Dehra Dun, India, 216.

17. Callinan R. B., Sammut J. and Fraser G., 1996 – Epizootic Ulcerative Syndrome (Red Spot Disease) in estuarine fish: Confirmation that exposure to acid sulphate soil runoff and an invasive fungus, Aphanomyces sp., are causative factors, *Proceedings of the National Conference on Acid Sulphate Soils*, Robert J. Smith and Associates and ASSMAC, Australia.
18. CAMP, 1998 – Report of the Workshop on `Conservation, Assessment and Management Plan (CAMP) for Freshwater Fishes of India', Zoo Outreach Organization and NBFGR, 22-26 Sep., 1997, Lucknow, 156.
19. Chaudhuri H., 1960 – Experiments on induced spawning of Indian carps with pituitary injections, *Indian Journal of Fish*, 7, 20-48.
20. Choudhury M. H., Das U., Kar S., Das P. and Kar D., 2017a – Analysis of Zooplankton Diversity and Physico-Chemical Parameters of Truncated part of Dhaleswari River Hailakandi, Assam, India, *Life Science Leaflets*, 88, 30-35.
21. Choudhury A. N., Das P., Das U., Kar S. and Kar D., 2017b – Studies on zooplankton abundance and physico-chemical parameters of Rukni Anua at Bekirpar in Cachar district, Assam, *International Journal of Fisheries and Aquatic Studies*, 5, 3, 372-374.
22. Chinabut S., Roberts R. J., Willoughby L. G. and Pearson M. D., 1995 – Histopathology of snakehead, Channa striatus (Bloch), experimentally infected with the specific Aphanomyces associated with Epizootic Ulcerative Syndrome (EUS) at different temperatures, J*ournal of Fish Diseases*, 18, 41-47.
23. Chumley J., 1910 – Bibliography of limnological literature, 659-673, in Murray and Pullar's Bathymatrical Survey of the Scottish Lochs, 1, List of Publications by Forel, 635-689.
24. Cook, R.E., 1977 – Raymond Lindeman and the trophic dynamic concept in ecology, *Science*, 198, 22-26.
25. Coxton F. E. and Cowden D. J., 1950 – Applied General Statistics, Sir Isaac Pitman and Sons, London, 944.
26. Darlington P. J. (Jr.), 1957 – Zoogeography: The Geographical Distribution of Animals, John Wiley and Sons, New York, 675.
27. Das B and Kar D., 2011 – Essentials of Limnology and Fishery Science, Mangalam Publishers, New Delhi, 190.
28. Das B. K., Chakraborty A. and Kar D., 2013 – Calculation of Length of a Fish using Two-Dimensional Geometry, *International Journal of Scientific Research*, 2, 10, 48-51.
29. Das P. and Kar D., 2013 – Studies on zooplankton diversity and physico-chemical parameters of Ramnagar anua, Cachar, Assam, *International Journal of Current Research*, 5, 3058-3062.
30. Das P. and Kar D., 2016a – Composition abundance and diversity of zooplankton population from three different wetlands from Barak Valley, Assam, *International Journal of Applied and Nature Sciences*, 5, 5, 41-46.
31. Das P. and Kar D., 2016b – Biodiversity of Zooplankton in a floodplain lake of the Barak Valley, Assam, North-East, India, *International Journal of Advance Research*, 4, 4, 906-910.
32. Das P. and Kar D., 2016c – Diversity and abundance of zooplankton in a Temple pond, Barak Valley, Assam, *International Journal of Environmental Sciences*, 6, 6, 1117-1122.
33. Das P., Mukherjee S., Kar S., Das U., Kar D. and Aditya G., 2018 – Zooplankton as dietary component of selected freshwater fish: network analysis based on gut content, *AACL Bioflux*, 11, 1, 232-244.
34. Das U. and Kar D., 2013 – A comparative study on qualitative and quantitative analysis of zooplankton in relationship with physico-chemical properties of water between Karbala Lake and Baram Baba Pond of Cachar District, Assam, *International Journal of Current Research*, 5, 3038-3041.
35. Das U. and Kar D., 2014 – Qualitative and quantitative study of planktons including physico-chemical properties of water of Assam University Pond, Silchar, Assam, India, *Research Frontiers in Wetlands, Fishery and Aquaculture*, 247-254, in Research Frontiers in Wetlands, Fishery and Aquaculture, Kar D., (ed.), Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.

36. Das U. and Kar D., 2016a – Studies on biodiversity and spatial distribution of Rotifers, Cladocerans and Copepods from Chatla Haor, a seasonal floodplain wetland of Assam, Lake 2016, International Conference on Conservation and Sustainable Management of Ecologically Sensitive Regions in Western Ghats, The 10th biennial Lake Conference; Alva's College, Moodavidri, Mangalore.
37. Das U. and Kar D., 2016b – Diel and seasonal variation of zooplankton from the freshwater pond of North Tripura District, India, Lake 2016 International Conference on Conservation and Sustainable Management of Ecologically Sensitive Regions in Western Ghats, The 10th biennial Lake Conference; Alva's College, Moodavidri, Mangalore.
38. Das U. and Kar D., 2016c – Diversity status of zooplankton in a typical pond ecosystem of Cachar District, Assam, India, *International Journal of Applied and Natural Sciences*, 5, 4, 139-144.
39. Das U. and Kar D., 2016 d – Diversity status of zooplankton in a typical pond ecosystem of Cachar District, Assam, India, *International J of Applied and Natural Sciences*, 5, 4, 139-144.
40. Das U., Das P., Kar S., Jayapalan C. and Kar D., 2018 – An assessment on zooplankton diversity between three freshwater habitats of Barak Valley, Assam, *Uttar Pradesh journal of zoology*, 38, 1, 26-34.
41. Day F., 1873 – Report on the freshwater fish and fisheries of India and Burma, Calcutta, 22, 23, 35, 36.
42. Day F., 1878 – The fishes of India, being a natural history of the fishes known to inhabit the seas and freshwaters of India, Burma and Ceylon, Text and Atlas in 4 parts, W_M Dawson and Sons Ltd., London, xx + 778.
43. Day F., 1885 – Relationship of the Indian and African freshwater fish fauna, *Journal of the Linnean Society (Zoology)*, 18, 308-317.
44. Day F., 1889 – The fauna of British India, including Ceylon and Burma: Fishes, I and II, 548 and 509.
45. Devi W. S., Das U., Das P., Kar S. and Kar D., 2017 – Limnological study with emphasis on fish diversity of Loktak Lake, Manipur, India, *Bulletin of the Environmental Pharmacology, Life Science*, 6, 8, 75-77.
46. Dey S. C.,1973 – Studies on the distribution and taxonomy of the ichthyofauna of the hill streams of Kamrup-Khasi-Garo Regions of Assam with special reference to the functional morphology of some rheophillic fishes, D.Sc. Thesis, University of Calcutta, India, xi + 299.
47. Dey S. C., 1981 – Studies on the hydrobiological conditions of some commercially important lakes (Beels) of Kamrup district of Assam and their bearing on fish production, Final Technical Report, North-Eastern Council, Govt. of India, Shillong, 177.
48. Dey S. C and Kar D., 1985 – Studies on the aquatic macrophytes in Sone, a tectonic lake of Assam, *Proceedings of the Indian Science Congress*, 72, 67.
49. Dey S. C and Kar D., 1987 – Physico-chemical complexes of water and soil in Sone, an ichthyologically potential tectonic lake of Assam, *Journal of the Assam Science Society*, 30, 1, 1-11.
50. Dey S. C and Kar D., 1989 a – Aquatic macrophytes of Lake Sone in Assam, *Environment and Ecology*, 7, 1, 253-254.
51. Dey S. C and Kar D., 1989 b – Fishermen of Lake Sone in Assam: their socio-economic status, *Science and Culture*, 55, 395-398.
52. Dey S. C and Kar D., 1989 c – An account of Hilsa ilisha (Hamilton) of Lake Sone in the Karimganj District of Assam, *Bangladesh Journal of Zoology*, 17, 1, 69-73.
53. Dey S. C. and Kar D., 1989 d – Phytosociology of the aquatic macrophytes of Lake Sone in the Karimganj District of Assam, *Proceedings of the Indian Science Congress*, 76, 38.

54. Dey S. C and Kar D., 1990 – Fish Yield Trend in Sone, a tectonic lake of Assam, Matsya, 15-16, 39-43.
55. Dey S. and Kar D., 1994 – Phytoplankton dynamics of Lake Sone in Assam, *Bulletin of Life Sciences*, IV, 49-54.
56. Dhar N., 2004 – Certain aspects of limnology and fishery of Baskandi Lake in the Cachar District of Assam, PhD Thesis, University of Gauhati, Assam,165.
57. Dhar N., Goswami M. M. and Kar D., 2004 – Aquatic macrophytes in Baskandi Lake, an oxbow lake of Barak Basin, Assam, *Environment and Ecology*, 22, Suplement 4, 606-608.
58. Dutta A., Kar S., Das P., Das U., Das S. and Kar D., 2017 – Studies on physico-chemical aspects and zooplankton diversity of a freshwater wetland in Cachar, Assam, *International Journal of Science, Environment and Technology*, 6, 3, xx – xx 2277-663X (P).
59. Dutta B., Bailung B., Das B. K., Kar D. and Biswas S. P., 2014 – Ichthyofaunal diversity in the wetlands (Beels) of Charaideo Subdivision, Sivasagar District, Assam and their Health and Management, *Environment and Ecology*, 32, 1A, 363-367.
60. FAO, 1963 – Modern fishing gears of the world, Proc. 2nd, World Fishing Gear Congress, London.
61. FAO, 1974 – Design of fisheries statistical surveys: Inland Waters, Food and Agricultural Organisation, *Fisheries Technical Paper*, 133, 1-122.
62. FAO, 1986 – Report of the expert consultation on ulcerative fish diseases in the Asia-Pacific Region, TCP/RAS/4508, Bangkok, 5-9 Aug 1986, FAO Regional office for Asia and the Pacific, Bangkok.
63. Fernando C. H. and Furtado J. J., 1975 – Reservoir fishery resources of South-East Asia, *Bulletin of Fisheries Research Station*, Sri Lanka, 26, 1-2, 83-95
64. Forel F. A., 1892-1904 – Le Le'man, Monographie limnologique, Lausanne, I-III.
65. Forel F. A., 1895 – Le Le'man, Monographie limnologique, II, Lausanne, 651.
66. Forel F. A., 1901 – Handbuch der Seenkunde. Allgemeine. Limnologie, Stuttgart, 249.
67. Fraser G. C., Callinan R. B. and Calder L. M., 1992 – Aphanomyces species associated with Red Spot Disease: an ulcerative disease of estuarine fish of Eastern Australia, *Journal of Fish Diseases*, 15, 173-181.
68. Frerichs G. N., Millar S. D. and Roberts R. J., 1986 – Ulcerative Disease Rhabdovirus in Fish in South-East Asia, *Nature*, 322, 216.
69. Fritsch F. E., 1965 – The structure and reproduction of Algae, II, Phaeophyceae and Myxophyceae, Cambridge University Press, UK.
70. Gadgil M. and Kar D., 2000 – Conserving India's biodiversity: let people speak, 583-589, in Setting Biodiversity Conservation, 707, World Wide Fund (WWF) for Nature-India, New Delhi.
71. Ghosh S. K. and Lipton A. P., 1982 – Ichthyofauna of the NEH Region with special reference to their economic importance, ICAR Research Complex, NEH Region, Shillong, *Special Bulletin*, 1, 119-126.
72. Gopal B., Goel P. K., Sharma K. P. and Trivedy R. K., 1981 – Limnological study of a freshwater reservoir, Jamwa Ramgarh (Jaipur), *Hydrobiologia*, 83, 2, 283-294.
73. Government of Assam, 2006 – Statistical Handbook of Assam, Directorate of Economics and Statistics, Govt. of Assam, Guwahati.
74. Gunther A., 1880 – An introduction to the study of fishes, Adams and Charles Black, Edinburgh, 720.
75. Hamilton B., 1822 – Account of the fishes found in the River Ganges and its tributaries, Edinburgh, UK, 405.
76. Hickling C. F., 1971 – Fish culture, 2nd edition, Faber and Faber, London 317.
77. Henderson S. and Markland H. R., 1987 – Decaying lakes: the origins and control of cultural eutrophication: detailed analysis, John Wiley and Sons, New York, 254.
78. Hooker J. D., 1872 – Flora of British India, I-VI, London.

79. Hora S. L., 1953 – Fish distribution and Central Asian orography, *Current Science*, 22, 4, 93-94.
80. Hora S. L. and Menon A. G. K., 1952 – Distribution of Indian fishes of the past and their bearing on the geography of India. 1 The extinct freshwater Dipnoan and Ganoid fishes of India, *Everyday Science*, 1, 26-37.
81. Hora S. L. and Silas E. G., 1952 – Evolution and distribution of glyptosternoid fishes of the Family Sisoridae (Order: Siluroidea), *Proceedings of the National Institute of Science, India*, 18, 4, 309-322.
82. Hugueny B. and Paugy D., 1995 – Unsaturated fish communities in African rivers, *American Naturalist*, 146, 162-169.
83. Hutchinson G. E., 1939 – Ecological observations on the fishes of Kashmir and Indian Tibet, *Ecological Monograph*, 9, 2, 147-181.
84. Hutchinson G. E., 1967 – A treatise on limnology, II, Introduction to lake biology and the limnoplankton, John Wiley and Sons, Inc., New York, ix + 1115.
85. Hutchinson G. E., 1975 – A treatise on limnology, III, Limnological botany, John Wiley and Sons, New York, ix + 660.
86. Jackson M. L., 1973 – Soil chemical analysis, Prentice Hall of India Pvt. Ltd., New Delhi, xiv + 498.
87. Jayaram K. C., 1981 – The freshwater fishes of India, Pakistan, Bangladesh, Burma, Sri Lanka: a Handbook, Zoological Survey of India, Calcutta, xxii +475.
88. Jayaram K. C., 1999 – The Freshwater fishes of the Indian Region, Narendra Publishing House, Delhi, xvii +551.
89. Jayaram K. C., 2003 – Ecostatus and conservation strategies for Mahseer fishes of India with special reference to Deccan species, 3-12, in Welfare biology in the New Millennium, Kar D., Dey S. C. and Datta N. C., (eds), Allied Publishers Pvt. Ltd., Bangalore, xx + 97.
90. Jhingran V. G., 1991– Fish and fisheries of India, Hindustan Publishing Corporation, New Delhi, xxiii + 727.
91. Kar D., 1984 – Limnology and fisheries of Lake Sone in the Cachar District of Assam, India, PhD Thesis, University of Gauhati, Assam, viii + 201.
92. Kar D., 1985 – An overview of the Freshwater fishery in Assam, India, *Proceedings of the London Freshwater Group*, Queen Marry College, University of London, UK.
93. Kar D., 1990 – Limnology and fisheries of Lake Sone in the Cachar District of Assam (India), PhD Thesis (Published), University of Gauhati, Assam (1984), Matsya 15-16, 209-213.
94. Kar D., 1996 – Biodiversity conservation prioritisation project, WWF (India) - WWF (USA).
95. Kar D., 1999a – Preliminary study of limnology and aquatic biota of Rudra Sagar wetland in South Tripura, *Proceedings of the Regional Seminar on Biodiversity*, Guwahati, Assam, 1.
96. Kar D. 1999b – Microbiological and environmental studies in relation to fish disease in India, Gordon Research Conference, Connecticut, USA.
97. Kar D., 2000a – Socio-economic development of the fisherwomen through aquaculture with emphasis on integrated farming in the villages around Chatla Haor Wetland in Silchar, Assam. Seminar presented on DBT (Govt. of India)-sponsored Awareness Workshop on biotechnology-based programmes for women and rural development, NEHU, Shillong, 1, 13-14.
98. Kar D., 2000b – An account of physico-chemical characteristics of twenty lentic systems in relation to eutrophication status in Barak Valley region of Assam, *Proceedings of the National Symposium on Current Trends in Wetlands and Fisheries Research in the New Millennium*, 1, 19.
99. Kar D., 2002 – Waterbodies and fishes: resources and development, *Conservation Forum Journal*, 1, 15.

100. Kar D., 2003a – Fishes of Barak Drainage, Mizoram and Tripura, 203-211, in Environment, Pollution and Management (eds) Kumar A., Bohra C. and Singh L. K., APH Publishing Corporation, New Delhi, xii + 604.
101. Kar D., 2003b – An account of the fish biodiversity in South Assam, Mizoram and Tripura along with a brief account of Epizootic Ulcerative Fish Disease Syndrome in freshwater fishes. UGC-sponsored Invited Lecture in Dept. of Environmental Engg., Guru Jambeswar University, Hissar, Haryana.
102. Kar D., 2003c – Peoples' perspective on fish conservation in the water bodies of South Assam, Mizoram and Tripura, 325-328, in Participatory approach for fish biodiversity conservation in North-East India (eds) Mahanta P. C. and Tyagi L. K., National Bureau of Fish Genetic Resources (ICAR), Lucknow, v + 412.
103. Kar D., 2005 – Fish diversity in the major rivers in Southern Assam, Mizoram and Tripura, 679-691, Proceedings of 2nd International Symposium on GIS and Spatial Analyses in Fisheries and Aquatic Sciences, 2-6 Sep 2002, University of Sussex, Brighton (UK), (eds), 2, Nishida T., Kailola P. J. and Hollingworth C. E., Fisheries and Aquatic GIS Research Group, Kawagoe, Saitama, Japan.
104. Kar D., 2006a – Panorama of wetlands in North-East India with special emphasis on their eutrophication status, *Science and Society*, 4, 2, 167-180.
105. Kar D., 2006b – Study of fish diversity in a wetland, Activity Guide "Biodiversity", 37-38, National Childrens' Science Congress, NCSTC Network and Department of Science and Technology, Government of India.
106. Kar D., 2007a – Fundamentals of limnology and aquaculture biotechnology, Daya Publishing House, New Delhi, xiv + 609.
107. Kar D., 2007b – Lentic fishery: fishery of a tropical wetland (Beel) in Assam, S*cience and Society*, 5, 1, 53-72.
108. Kar D., 2010a – Water bodies, fish diversity and sustainable aquaculture, Annual Journal of Womens' College, Silchar, Assam, 168-194.
109. Kar D., 2010b – Biodiversity Conservation Prioritisation, xi + 167, Swastik Publications (New Delhi), ISBN: 978-93-80138-26-8.
110. Kar D., 2010c – Present status of fish diversity and water bodies in North-East India with a note on their conservation, keynote address of the session chair, Lake 2010 International Conference, Indian Institute of Science, Bangalore, December 2010.
111. Kar D., 2011a – Panorama of wetlands, rivers and fishes of North-East India with a note on the health of fishes. Proceedings of International Symposium on Ecological Sciences, Kerala University, 9-10 November 2011.
112. Kar D., 2011b – Fish diversity, fish habitats, fish disease and aquaculture in North-East India hotspot: A synopsis, *Conservation Forum Journal*, 3, 5.
113. Kar D., 2012a – Wetlands, rivers, fish diversity, Fish disease and aquaculture in North-East India, *Fishing Chimes*, 31, 12, 35-37.
114. Kar D., 2012b – Essentials of fish biology, Dominant Publishers, (New Delhi), vii + 244.
115. Kar D., 2012c – Taxonomy, BSc, MSc, NET, SLET, APH Publications (New Delhi), 102.
116. Kar D., 2013a – Wetlands and lakes of the world, Springer, London, Print ISBN 978-81-322-1022-1, e-Book ISBN: 978-81-322-1923-8, xxx + 687.
117. Kar D., 2013b – Wetlands, rivers and fishes of North-East India with a note on the health of fishes, Proceedings of International Symposium, Kerala University, 3-5 October 2013.
118. Kar D., 2014a – Wetlands of Assam with special reference to Sone Beel, the biggest wetland in Assam and MoEF-Listed Wetland of National Importance, Research Frontiers in Wetlands, Fishery and Aquaculture, 19-42, in Research Frontiers in Wetlands, Fishery and Aquaculture, (ed.) Kar D., Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.

119. Kar D., 2014b – Epizootic Ulcerative Syndrome Disease in wetland fishes, Research Frontiers in Wetlands, Fishery and Aquaculture, 43-58, in Research Frontiers in Wetlands, Fishery and Aquaculture (ed.) Kar D., Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.
120. Kar D., 2014c – Research Frontiers in Wetlands, Fishery and Aquaculture, Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.
121. Kar D., 2015 – Epizootic Ulcerative Fish Disease Syndrome, Elsevier, Academic Press, USA, xix + 293, 314.
122. Kar D., 2016a – Wetlands, Rivers, Fish Resources and Fish Disease in North-East India: An Overview, Proceedings of International Symposium on Aquaculture and Fisheries (as part of the International Conference on Environmental Sustainability for Food Security (ENFOSE, 2016), 23 September 2016, held at Fisheries College and Research Institute (FCRI), Tamil Nadu Fisheries University (TNFU), 6.
123. Kar D., 2016b – Wetlands, rivers, fish, plankton resources and fish disease and aquaculture in North-East India: an overview, Proceedings of International Symposium, Lake 2016, 37, Indian Institute of Science, Bengaluru, and Alva's Education Foundation, India.
124. Kar D and Barbhuiya A. H., 2008 – Panorama of wetlands, rivers and fish diversity in North-East India with a glimpse on fish health, in Fish and Fisheries (eds) Pandey B. N., Trivedy S. P., Kamal J., Kaur Sethi N., Sarup Book Publishers, New Delhi, 263.
125. Kar D. and Barbhuiya A. H., 2013 – Frontiers of wetlands, fishers and aquaculture research, Mangalam Publications, New Delhi, 263.
126. Kar D. and Barbhuiya M. H., 2000a – Length-weight relationship and condition factor in Gudusia chapra (Hamilton-Buchanan) and Botia dario (Hamilton-Buchanan) in Chatla Haor (Floodplain Wetland) in Cachar District of Assam, *Environment and Ecology*, 18, 1, 227-229.
127. Kar D. and Barbhuiya M. H., 2000b – Ichthyodiversity of Chatla Haor: a floodplain wetland in Barak Valley region of Assam, 3-6, in *Advances in Zoology and Environmental Degradation and Biodiversity*, (eds) Pandey B. N. and Singh B. K., Daya Publishing House, New Delhi, 279.
128. Kar D and Barbhuiya M. H., 2000c – Studies on the abundance and Diversity of Zooplankton in Chatla Haor: a floodplain wetland in Cachar District of Assam, Proceedings of National Symposium Current Trends in Wetlands and Fisheries Research in the New Millennium, 1, 11.
129. Kar D. and Barbhuiya M. H., 2000d – Water bodies and fishes: resources and development, National Symphosium, Current Trends in Wetlands and Fisheries Research in the New Millennium, 1, 25.
130. Kar D and Barbhuiya M. H, 2001 – Ecology of Aquatic Macrophytes of Chatla Haor, a floodplain wetland in Cachar District of Assam, *Environment and Ecology*, 19, 1, 231-233.
131. Kar D. and Barbhuiya M. H., 2002a – Macrophytic diversity in certain wetlands of Barak Valley region of Assam, 86-89, in Restoration of lakes and wetlands (eds) Ramachandra T. V., Rajasekara Murthy N. and Ahalya N., Allied Publishers (P) Ltd., Bangalore, xxii + 400.
132. Kar D. and Barbhuiya M. H., 2002b – Waterfowls in Chatla Haor, a seasonal floodplain in Cachar District of Assam with a note on waterfowl and wetland conservation, *Environment and Ecology*, 20, 3, 689-691.
133. Kar D. and Barbhuiya M. H., 2002c– Aquatic macro-invertebrates of Baraknadi Salchapra Anua in Barak Valley Region of Assam, *Environment and Ecology*, 20, 2, 696-699.
134. Kar D. and Barbhuiya M. H., 2004 – Abundance and diversity of zooplankton in Chatla Haor, a floodplain wetland in Cachar District of Assam, *Environment and Ecology*, 22, 1, 247-248.
135. Kar D. and Dey S. C., 1982a – Hilsa ilisha (Hamilton) from Lake Sone in Cachar, Assam, Proceedings of Indian Science Congress, 69, 77.

136. Kar D. and Dey S. C., 1982b – An account of Hilsa ilisha (Hamilton) of Sone Beel (Cachar district, Assam, India), Proceedings of All-India Seminar of Ichthyology, 2, 3.
137. Kar D. and Dey S. C., 1986 – An account of ichthyospecies of Lake Sone in Barak Valley of Assam, Proceedings of All-India Seminar, Ichthyology, 2, 3.
138. Kar D. and Dey S. C.,1987 – An account of the fish and fisheries of Lake Sone in the Barak Valley of Assam (India), Proceedings of Workshop Development of Beel Fisheries in Assam, 1, 13.
139. Kar D. and Dey S. C., 1988a – A critical account of the recent fish disease in the Barak Valley of Assam, Proceedings of Regional Symposium on Recent outbreak of Fish Diseases in North-East India, 1, 8.
140. Kar D. and Dey S. C., 1988b – Impact of recent fish epidemics on the fishing communities of Cachar District of Assam, Proceedings of Regional Symposium on Recent outbreak of Fish Diseases in North-East India, 1, 8.
141. Kar D. and Dey S., 1988c – Preliminary electron microscopic studies on diseased fish tissues from Barak Valley of Assam, Proceedings of Annual Conference of Electron Microscopic Society of India, 18, 88.
142. Kar D. and Dey S. C., 1988d – An account of fish yield from Lake Sone in the Barak Valley of Assam, Proceedings of Indian Science Congress, 75, 49.
143. Kar D. and Dey S. C., 1990a – Fish disease syndrome: a preliminary study from Assam, Bangladesh, Journal of Zoology, 18, 115-118.
144. Kar D. and Dey S. C., 1990b – A preliminary study of diseased fishes from Cachar District of Assam, Matsya, 15-16: 155-161.
145. Kar D. and Dey S. C., 1990c – Epizootic Ulcerative Syndrome in Fishes of Assam, Journal of Assam Scientific Society, 32, 2, 29-31.
146. Kar D. and Dey S. C., 1990d – An account of the Indian major carps of Lake Sone in Assam, Proceedings of Indian Science Congress, 77, 70.
147. Kar D. and Dey S. C., 1990e – Interrelationship and dynamics of fish population of Lake Sone in Assam, Proceedings of Indian Science Congress, 77, 69.
148. Kar D. and Dey S. C., 1993 – Interrelationship and dynamics of fish population of Lake Sone in Assam, *Environment and Ecology*, 11, 3, 718-719.
149. Kar D. and Dey S. C., 1995 – Scooping gears of Lake Sone in Assam, Proceedings of Indian Science Congress, 82.
150. Kar D. and Dey S. C., 1996 – Zooplankton dynamics of Lake Sone in Assam, Proceedings of Indian Science Congress, 83, III, 14.
151. Kar D. and Dey S. C., 2000a – A brief account of the limnology and fishery of Sone Beel, the biggest wetland in Assam, *Proceedings of Natural Symposium, Wetlands and Fisheries Research in the New Millennium*, 1, 17.
152. Kar D. and Dey S. C., 2000b – Yield and conservation of Indian major carps of Lake Sone in Assam, *Environment and Ecology*, 18, 4, 1036-1038.
153. Kar D. and Dey S. C., 2000c – An overview of the fish diseases in India with special emphasis on Epizootic Ulcerative Syndrome, Proceedings of International Symposium, Lake 2000, Indian Institute of Science, Bangalore, 1, 21.
154. Kar D. and Dey S. C., 2002 – On the occurrence of advanced fry of Hilsa (Tenualosa) ilisha (Hamilton-Buchanan) in Chatla Haor Seasonal Wetland of Assam, Proceedings of Zoology Society, Calcutta, Springer, 55, 2, 15-19.
155. Kar D. and Sen N., 2007 – Systematic list and distribution of fish biodiversity in Mizoram, Tripura and Barak drainages in North-East India, *ZOOs' Print Journal*, 22, 3, 2599-2607.
156. Kar D. and Upadhyaya T., 1998 – Histopathological studies of fish tissues affected by Epizootic Ulcerative Syndrome in Assam, *Technical Bulletin*, XIII Convention and National Symposium of Indian Association of Veterinary Anatomists (IAAM), 11-13 Dec 1998, College of Veterinary Sciences, Assam Agricultural University, Guwahati.

157. Kar D., Dey S. C., Michael R. G., Kar S. and Changkija S. 1990 – Studies on fish epidemics from Assam, India, *Journal of Indian Fisheries Association*, 20, 73-75.
158. Kar D., Dey S. C., Kar S., Bhattacharjee N. and Roy A., 1993 – Virus-like particles in Epizootic Ulcerative Syndrome of fish, *Proceedings of International Symposium on Virus-Cell Interaction: Cellular and Molecular Responses*, 1, 34.
159. Kar D., Dey S. C., Kar S., Roy A., Michael R. G., Bhattacharjee S. and, Changkija S., 1994 – A candidate virus in Epizootic Ulcerative Syndrome of Fish, Proceedings of National Symposium of the Indian Virological Society, 1, 27.
160. Kar D., Dey S. C. and Kar S., 1994b – Variegated Encircling gears in Lake Sone of Assam, Proceedings of Indian Science Congres, 81, 64.
161. Kar D., Roy A., Dey S. C., Menon A. G. K. and Kar S., 1995a – Epizootic Ulcerative Syndrome in fishes of India, World Congress of in Vitro Biology, *In Vitro*, 31, 3, 7.
162. Kar D., Kar S., Roy A. and Dey S. C., 1995b – Viral Disease Syndrome in fishes of North-East India, *Proceedings of International Symposium of International Centre for Genetic Engineering and Biotechnology (ICGEB) and the University of California at Irvine*, 1, 14.
163. Kar D., Dey S. C. and Kar S., 1995c – Lake Sone in Assam and its Biodiversity, Xth Annual Congress on Man and Environment, National Environment Science Academy and National Institute of Oceanography, 10, 52.
164. Kar D., Dey S. C. and Kar S., 1995d – Fish and fisheries of Lake Sone in Assam, *Journal of North-Eastern Council*, 15, 2-3, 49-57.
165. Kar D., Dey S. C., Kar S. and Roy A., 1995e – Epizootic Ulcerative Disease Syndrome among the fishes of North-East India, *Journal of North-Eastern Council*, 14, 4, 21-24.
166. Kar D., Dey S. C., Purkayastha M. and Kar S., 1996a – An overview of the impediments in conservation of biodiversity of Lake Sone in Assam, *Proceedings of Seminar on Conservation of Biodiversity in Indian Aquatic Ecosystems*, 1, Jawahar Lal Nehru University, New Delhi.
167. Kar D., Dey S. C., Kar S. and Michael R. G. and Gadgil M., 1996b – Ichthyoecology, management and conservation of fish resources of Lake Sone in Assam (India), Tiger Paper (Food and Agricultural Organisation of the United Nations), XXIII, 3, 27-32.
168. Kar D., Purkayastha M. and Kar S., 1996c – Biodiversity Conservation Prioritisation Project: A case study from Sone Beel in Assam, Proceedings of National Workshop on Biodiversity Conservation Prioritisation Project (BCPP), World Wide Fund (WWF) for Nature-India and Centre for Ecological Sciences, Indian Institute of Science, Bangalore.
169. Kar D., Dey S. C. and Kar S., 1996d – An account of the trawls of Lake Sone in Assam, Proceedings of Indian Science Congress, 83, III, 14-15.
170. Kar D., Purkayastha M. and Kar S., 1996e – Biodiversity Conservation Prioritisation Project: A case study from Sone Beel in Assam, Proceedings of National Workshop on Biodiversity Conservation Prioritisation Project (BCPP), 1, World Wide Fund (WWF) for Nature-India and Centre for Ecological Sciences, Indian Institute of Science, Bangalore.
171. Kar D., Saha D., Laskar R. and Barbhuiya M. H., 1997 – Biodiversity Conservation Prioritisation Project (BCPP) in Barak Valley Region of Assam, Proceedings of National Project Evaluation Workshop on BCPP, 1, Betla Tiger Reserve and National Park, Palamu.
172. Kar D., Purkayastha M. and Dey S. C., 1998a – An account of the avifauna of Lake Sone in Assam, Proceedings of Indian Science Congress, 85, III, 2.
173. Kar D., Dey S. C. and Kar S., 1998b – An account of the littoral macro-fauna of Lake Sone in Assam, Proceedings of Indian Science Congress, 85, III, 2-3.
174. Kar D., Barbhuiya M., Barbhuiya M. H. and Saha D., 1998c – Wetland birds of Sat Beel in Cachar District of Assam, Proceedings of Indian Science Congress, 85, III, 4.

175. Kar D., Saha D., Barbhuiya R. L., Barbhuiya M. H., Kar S. and Dey S. C., 1999a – Limnological studies of some of the wetlands of Assam, Mizoram, Tripura and Arunachal Pradesh related to their status of Eutrophication, Proceedings of Indian Science Congress, 86, III, 55.
176. Kar D., Rahaman H., Barnman N. N., Kar S., Dey S. C. and Ramachandra T. V., 1999b – Bacterial pathogens associated with Epizootic Ulcerative Syndrome in freshwater fishes of India, *Environment and Ecology*, 17, 4, 1025-1027.
177. Kar D., Mandal M. and Bhattacharjee S., 1999c – Fungal pathogens associated with Epizootic Ulcerative Syndrome in fishes of Barak Valley region of Assam, Proceedings of 1st National Conference on Fisheries Biotechnology, Central Institute of Fisheries Education (CIFE), 1, 34.
178. Kar D., Mandal M., Laskar B. A., Dhar N. and Barbhuiya M. H., 2000a – Ichthyofauna of some of the oxbow lakes in Barak Valley region of Assam, *Proceedings of the National Symposium on Wetlands and Fisheries Research in the New Millennium*, 1, 16.
179. Kar D., Mandal M., Laskar B A. and Das P., 2000b – On a collection of fishes from some of the lentic systems in Barak Valley of Assam, *Proceedings of the National Symposium on Wetlands and Fisheries Research in the New Millennium*, 1, 17.
180. Kar D., Das S., Das S., Das Talukdar A., Das S., Datta J. and Upadhyay H., 2000c – A collection of fishes from Hatkhal Beel in Rongpur Village of Silchar City in Assam, *Proceedings of the National Symposium on Wetlands and Fisheries Research in the New Millennium*, 1, 33.
181. Kar D., Barbhuiya M. H. and Goswami U. C., 2000d – Phytoplankton diversity of Chatla Haor, a floodplain wetland in Cachar District (Assam), Regional Seminar on Recent Trends in Zoology, 14 Sep 2000, NEHU, Shillong Abstracts, 18.
182. Kar D., Dey S. C., Roy A. and Mandal M., 2000e – Epizootic Ulcerative Syndrome Fish Disease in Barak Valley region of Assam, India, *Proceedings of the National Symposium on Wetlands and Fisheries Research in the New Millennium*, 1, 2.
183. Kar D., Dey S. C., Roy A. and Mandal M., 2002 – Epizootic Ulcerative Syndrome in Fishes of Barak Valley of Assam, India, 303-307, in Restoration of Lakes and Wetlands (eds) Ramachandra T. V., Murthy Rajasekhara S. and Ahalya N., Allied Publishers (P) Ltd. Bangalore, xii + 400.
184. Kar D., Dey S. C. and Datta N. C., 2003a – Welfare Biology in the New Millennium, Allied Publishers Pvt. Ltd., Bangalore, xx + 97.
185. Kar D., Dey S. C., Roy A. and Mandal M., 2003b – Epizootic Ulcerative Syndrome Fish Disease in Barak Valley Region of Assam, 73-78, in Welfare biology in the new millennium (eds) Kar D., Dey S. C. and Datta N. C., Allied Publishers Pvt. Ltd., Bangalore, xx + 97.
186. Kar D., Nagarathna A. V., Ramachandra T. V. and Dey S. C., 2006a – Fish diversity and conservation aspects in an aquatic ecosystem in North-East India, *ZOOS' Print Journal*, 21, 7, 2308-2315.
187. Kar D., Mazumdar J., Devi P., Devi B. R. and Devi V., 2006b – Isolation of Aeromonas hydrophila from fishes affected by Epizootic Ulcerative Syndrome as well as from corresponding healthy fish species and from their habitat, *Journal of Current Sciences*, 9, 1, 323-327.
188. Kar D., Barbhuiya A. H. and Saha B., 2007a – Panorama of wetland diversity in South Assam, Abstracts in National Conference on Wetlands, Science and Society: An assessment of their integration: Ministry of Environment, Forests and Climate change, Government of India and University of Delhi, 48-50.
189. Kar D., Mazumdar J., Halder I. and Dey M., 2007b. – Dynamics of initiation of disease in fishes through interaction of microbes and the environment, *Current Science*, Bangalore, 92, 2, 177-179.
190. Kar D., Mazumdar J. and Barbhuiya M. A., 2007c – Isolation of Mycotic flora from fishes affected by Epizootic Ulcerative Syndrome in Assam, India., *Asian Journal of Microbiology and Biotechnology*, 9, 1, 37-39.

191. Kar D., Barbhuiya A. H., and Das B., 2008a – Fish diversity and Epizootic Ulcerative Syndrome Fish Disease in India, Key Speaker, International Meet of Asian Fisheries Forum, Central Inland Fisheries Research Institute (CIFRI), Calcutta.
192. Kar D., Barbhuiya A. H. and Das B., 2008b – Wetlands, rivers and fish diversity in North-East India, Key Speaker at International Symposium of Indian National Cartographic Association, Indian Space Research Organisation (ISRO), Ahmedabad, November 2008.
193. Kar D., Barbhuiya A. H., Thangjam G., Devi S. M., Deb S., Das B., Chanu H. and Nishima H., 2008c – Panorama of fish biodiversity in certain rivers and wetlands in Manipur, Proceedings of Zoological Society, India, 7, 2, 123-134.
194. Kar D., Barbhuiya A. H., Baruah A. R., Choudhury C., Banerjee P., Pal R., Bhattacharjee A., Saikia R., Das B., Barman R. and Saha B., 2009 – Panorama of fish diversity in certain rivers, wetlands and protected areas in Assam, *Geobios*, 36, 57-64.
195. Kar D., Sharma R., Das B. and Barbhuiya A. H., 2010 – An overview of the Wetlands, rivers and fishes in North-East India with a brief note on their present status using GIS tools, 151-164, in Biodiversity and Human Welfare, (eds), Goswami U. C., Sharma D. K., Kalita J. and Saikia P. K., Narendra Publishing House, New Delhi.
196. Kar D., Bharbhuiya A. H. and Saha B., 2014 – Panorama of wetland diversity in South Assam, Frontiers of Wetlands, Fishers and Aquaculture Research, 187-210, in Research Frontiers in Wetlands, Fishery and Aquaculture, (eds) Kar D., Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.
197. Kar D., Singha R., Das B. K., John R., George R., Mansoor M. and Selva M., 2015 – Preliminary epidemiological studies on Epizootic Ulcerative Syndrome (EUS) in freshwater fishes of Assam, *International Journal of Scientific Research in Science, Engineering and Technology*, 1, 5, 256-263.
198. Kar S. and Kar D., 2013 – Studies on zooplankton diversity of an Oxbow lake of South Assam, India, *International Journal of Current Research*, 5, 9, 3412-3417.
199. Kar S. and Kar D., 2014 – Ecology of four wetlands in South Assam: a comparison, 239-246, in: Research Frontiers in Wetlands, Fishery and Aquaculture, (ed.) Kar D., Dominant Publishers and Distributors Pvt. Ltd., New Delhi, xi + 320.
200. Kar S. and Kar D., 2016a – Zooplankton diversity of a freshwater pond in Cachar District of Assam, India, *International Journal of Life Sciences*, 4, 1, 125-128.
201. Kar S. and Kar D., 2016b – Zooplankton diversity of a freshwater perennial pond in Silchar city of Assam, India, *American International Journal of Research in Formal, Applied and Natural Sciences*, 14, 1, 10-14.
202. Kar S. and Kar D., 2016c – Zooplankton diversity of a freshwater pond in Cachar District of Assam, India, *International Journal of Life Sciences*, 4, 1, 125-128.
203. Kar S. and Kar D., 2016d – Zooplankton diversity in a freshwater lake of Cachar, Assam, *International Journal of Applied Biology and Pharmaceutical Technology*, 7, 1, 301-305.
204. Kar S. and Kar D., 2016e – Zooplankton diversity of a freshwater wetland of Assam, *International Journal of Advanced Biotechnology and Research*, 7, 2, 614-620.
205. Kar S. and Kar D., 2016f – Seasonal variations of zooplankton in a perennial water body of Silchar City, Assam, Lake 2016, Conference on conservation and sustainable management of ecologically sensitive regions in Western Ghats, The 10th biennial Lake Conference, Indian Institute of Science and Alva's College, Moodavidri, Mangalore.
206. Kar S., Das P., Das U., Bimola M., Kar D. and Aditya G., 2017 – Culture of the zooplankton as fish food: observations on three freshwater species from Assam, India, *AACL Bioflux*, 10, 5, 1210-1220.

207. Kar S., Das P., Das U., Bimola M., Kar D. and Aditya G., 2018 – Correspondence of zooplankton assemblage and water quality in wetlands of Cachar, Assam, India: Implications for environmental management, *Limnological Review*, 18, 1, 9-19.
208. Laskar B. A., Das S., Nath D. and Kar D., 2002 – Ecological studies in Puneer Haor Wetland in Cachar District of Assam with special emphasis on Aquatic macrophytes, ichthyofauna and wetland birds, *Conservation Forum Journal*, 1, 25.
209. Laskar M. F., Kar S., Das P., Das U., Das S. and Kar D., 2017 – Analysis of zooplankton diversity and limnological parameters of Salchapra Anua, an oxbow lake in Silchar, Assam, J*ournal of Environmental Science, Toxicology and Food Technology*, 6, III, 12-15.
210. Le Cren E. D., 1951 – The Length-Weight relationship and seasonal cycle in gonad weight and condition of perch (Perca fluviatilis), Journal of Animal Ecology, 21, 210-219.
211. Lilley J. H., Hart D., Richards R. H., Roberts R. J., Cerenius L. and Söderhäll K., 1997 – Pan-Asian spread of single fungal clone results in large-scale fish-kills, *Veterinary Record*, 140, 653-654.
212. Menon A. G. K., 1955 – The external relations of Indian freshwater fishes with special reference to the countries bordering the Indian ocean, Journal of Asiatic Sciences, 21, 2, 31-38.
213. Menon A. G. K., 1973 – Origin of the freshwater fish fauna of India, Current Science, 42, 16, 553-556.
214. Menon A. G. K., 1974 – A checklist of the fishes of the Himalayan and the Indo-gangetic Plains, Inland Fisheries Society, India, Barrackpore, viii + 136.
215. Menon A. G. K., 1988 – Conservation of the Ichthyofauna of India, 55-33, in Conservation and Management of the Inland Capture Fisheries Research Bulletin, 57, Central Inland Capture Fisheries Research Institute, Barrackpore.
216. Menon A. G. K., 1994 – Criteria for determining the status of threatened categories of Indian freshwater fishes, 1-5, in Threatened Fishes of India, Natcon Publication, 4, 384, UP.
217. Menon A. G. K., 1999 – Checklist: freshwater fishes of India, Occasional Paper, 175, Zoological Survey of India, Calcutta, xviii + 366.
218. Misra K. S., 1976 – The Fauna of India and the adjacent countries: Pisces, 2nd edit.: 3. Teleostomi: Cypriniformes, Siluri, 387.
219. Mookerjee H. K., 1945 – Life history of some major carps of Bengal, *Scientific and Culture*, 10, 9, 400-402.
220. Motwani M. P., Jayaram K. C., and Sehgal K. L., 1962 – Fish and fisheries of Brahmaputra River system, Assam, I, Fish fauna with observation on their zoogeographical significance, Tropical Ecology, 3, 17-43.
221. Moyle P. B., 1976 – Fish introduction in California, history and impact on native fishes, *Biological Conservation*, 9, 101-118.
222. Myers G. S., 1949 – Salt tolerance of freshwater fish groups in relation to geographical problems, *Bijdr tot de Dierk*, 28, 315-322.
223. Narzary A., Das S., Das B. K., Singh Ng. R., Kar S., Das P., Dutta B. and Kar D., 2015 – A preliminary study on zooplankton diversity of Ramnagar Anua, Srikona Beel and Tapang Haor of Cachar District, Assam, India: a project report, J*ournal of Chemical, Biological and Physical Sciences* (An international peer review E-3 Journal of Sciences), 5, 3, 2809-2817.
224. Nath P. and Dey S. C., 2000 – Conservation of fish germplasm resources of Arunachal Pradesh, 49-67, in Fish biodiversity of North-East India (eds.) Ponniah A. G. and Sarkar U. K., NATP Publication 2, National Bureu of Fish Genetic Resources (NBFGR), Lucknow, xiii + 228.
225. Nautiyal P. and Lal M. S., 1981 – Recent records of Garhwal Mahseer (Tor putitora) with a note on its present status, Journal of the Bombay Natural History Society, 79, 593-595.
226. Nelson J. S., 1994 – Fishes of the World, 600, 3rd Ed. John Wiley and Sons, USA.
227. Nichols J. T., 1928 – Fishes of the White Nile (with table of World's freshwater fish faunae), *American Museum Novitates*, 319.

228. Ogale S. N., 1994 – Endangered Deccan Mahseer, Tor khudree (Sykes): A case Study, 213-218, in Threatened Fishes of India, Natcon. Publication, 4, 384, UP.
229. Pearsall W. H., 1938 – The Soil complex in relation to Plant communities, I. Oxidation-reduction potentials in soils, Journal of Ecology, 26, 180-193.
230. Pennak R. W., 1953 – Freshwater invertebrates of the United States, The Roland Press Co., New York, ix + 769.
231. Pillay T. V. R. and Ghosh A. N., 1958 – A note on hilsa fisheries of Assam, Journal of the Bombay Natural History Society, 55, 174-177.
232. Ramsar Convention Secretariat, 2004 – Ramsar handbooks for wide use of wetlands. 2nd Edition, Ramsar Convention Secretariat, Gland, Switzerland.
233. Riji J. K., Rosalind M., Kar D., Md, Mansoor, Kumar, Mahesh., Singha, Ratnabir, Waikhom, Gushein Z., 2016 – Detection of Ranavirus infection in cultivated carps of North-East India, *Fish Pathology*, 51, special issue, 66-74.
234. Roberts R. J. (ed.), 1978 – Fish pathology, Bailliere Tindall, London, x + 318.
235. Roberts R. J., Frerichs G. N. and Millar S. D., 1992 – Epizootic Ulcerative Syndrome: the current position, 431-436, in Diseases in Asian Aquaculture: I. (eds) Shariff I. M., Subasinghe R. P. an, Arthur J. R., Fish Health Section, Asian Fisheries Society, Manila, The Philippines. x + 318,
236. Sarwar, Ahmed and Kar D., 2016 – Study of physico-chemical and biological features of Junamara, Karkari, Shundarkoi, Moichatal and Chatrodoria Beels in Katigorah, Cachar, Assam, Indian Journal of Applied Research, 6, 8.
237. Schopf J. W. (ed.) 2002 – Life's origin: the beginnings of biological evolution. University of California Press, ISBN 0-520-23391-3, A recent survey of the field, 208.
238. Sehgal K. L., 1994 – State-of-Art of Endangered, Vulnerable and Rare Coldwater Fishes of India, 127-135, in Threatened Fishes of India, Natcon Publication, 4, 384, UP.
239. Sen N., 1982 – Studies on the systematics, distribution and ecology of the ichthyofauna of Meghalaya and their bearing on the fish and fisheries of the state, PhD Thesis, University of Gauhati, Assam, vi + 576.
240. Sen T. K., 1985 – The fish fauna of Assam and the neighbouring North-Eastern states of India, *Records of Zoological Survey of India*, Occasional Paper, 64, 1-216.
241. Sen N., 2000 – Occurrence, distribution and status of diversified fish fauna of North-East India, 31-48, in Fish Diversity of North-East India (eds) Ponniah A. G. and Sarkar U. K., National Bureau of Fish Genetic Resources (NBFGR), ICAR, Lucknow, 228.
242. Shaw G. E. and Shebbeare E. O., 1937 – The fishes of Northern Bengal, *Journal of the Royal Asiatic Society of Bengal, Science*, 137.
243. Silas E. G., 1952 – Further studies regarding Hora's Satpura Hypothesis, (2) Taxonomic assessment and levels of evolutionary divergence of fishes with the so-called Malayan affinities in Peninsular India, *Proceedings of the National Institute of Sciences of India*, 18, 5, 423-448.
244. Singh N. R., Das B. K., Shomorendra M. and Kar D., 2013 – Fish diversity of Pumlen Lake in Manipur with a note on traditional fish catching devices, *Indian Journal of applied Research*, 3, 10, 46-48.
245. Singh N. R., Singh M. S. and Kar D., 2015a – A check list of fish species diversity of Sone Beel, the biggest wetland in Assam, *NeBIO*, 6, 1, 21-26.
246. Singh N. R., Das B. K. and Kar D., 2015b – Length-weight relationship (LWR) of Glossogobius giuris (Hamilton-Buchanan, 1822) of Pumlen Lake Thoubal, Manipur, India, *International Journal of Environment and Natural Sciences*, 5, 1-5.
247. Singh M. S., Singh N. R., Devi I. N., Devi B. D., Ranibala T. and Kar D., 2015c – Check List of fish species of Loktak Lake, Bishnupur District, *Biological Forum*, 7, 1, 171-179.

248. Smith G. M., 1950 – The freshwater algae of the United States, McGraw Hill Book Co. Inc. New York, vii + 719.
249. Sonowal M., Kar S., Das B. K., Das S., Singh N. R., Das P., Dutta B. and Kar D., 2015 – Preliminary studies on zooplankton diversity of certain wetlands of Southern Assam, *Life Science Leaflets*, 67, 68-78.
250. Southwell T. and Prashad B., 1918 – On Hilsa investigations in Bengal, Bihar and Orissa, Bulletin of Fishing Department, Bengal, Bihar and Orissa, 15.
251. Sreenivasan A., 1968 – Limnology of tropical impoundments, V, Studies on two upland impoundments in the Nilgiris, Madras State, India, *Phykos*, 7, 144-160.
252. Steel M. and Penny D., 2010 – Origins of life: common ancestry put to the test, *Nature*, 465, 7295, 168-169, doi:10.1038/465168a, PMID 20463725.
253. Swingle H. S., 1950 – Relationship and dynamics of balanced and unbalanced fish populations, Bulletin of Alabama Agricultural Experiment Station, 274, 73.
254. Talwar P. K. and Jhingran A. G., 1991 – Inland fishes of India and adjacent countries, I and II, Oxford and IBH Co., Pvt. Ltd., New Delhi, 1158.
255. Toham A. K. and Tuegels G. G., 1998 – Diversity patterns of fish assemblages in the Lower Ntem River basin (Cameroon) with notes on potential effects of deforestation, *Archiv für Hydrobiologie*, 141, 4, 421-446.
256. Umi N. D., Singh N. R. and Kar D., 2015 – Studies on fish affected with Epizootic Ulcerative Syndrome with special emphasis on parasitic infestation: a project report, *Biological Forum*, 7, 1, 155-164.
257. Vaas K. F. and Schurman J. J., 1949 – On the ecology and fisheries of some Javanese freshwaters, Common Agriculture Research Station, Buitenzorg Java, 97, 1-60.
258. Welch P. S., 1935 – Limnology, McGraw Hill Book Company, Inc., New York, xiv + 471.
259. Wells H. G., 1922 – A short history of the World (1st edit.), New York: Macmillan. Retrieved 1 July 2016 – via Internet Archive, 455.
260. Welch P. S., 2003 – Limnological methods, Narendra Publising House (Indian Edition, New Delhi), xviii + 381.
261. Wetzel R. G., 1983 – Limnology, Saunders College Publishing, Philadelphia, ix + 858.
262. WCMC, 1996 – Freshwater biodiversity: a preliminary gobal assessment, a document prepared for the 4th meeting of the Conference of the Practices to the Convention of Biological Diversity, World Conservation Monitoring Centre.
263. Zutshi D. P., Wanganeo A. and Raina R., 1970 – Limnology of a man-made lake, Geobios: 30-32.

A RETURN TO THE GHANAIAN CULTURAL VALUES OF CLOSED FISHING SEASON IN GHANA'S ARTISANAL MARINE FISHING: AN ESSENTIAL MEANS OF RESTORING SMALL PELAGIC FISH STOCKS

*Dickson ADOM *, Paul Appiah SEKYERE *** and *Lily YARNEY ****

* Kwame Nkrumah University of Science and Technology, Department of Educational Innovations in Science and Technology, P. O. Box NT 1, Kumasi, Ghana, adomdick2@gmail.com

** Kwame Nkrumah University of Science and Technology, Department of Chemistry, P. O. Box NT 1, Kumasi, Ghana, ksekyerepaul@gmail.com

*** University of Ghana Business School, Department of Public Administration and Health Services Management, Ghana, P. O. Box LG 78, Legon-Accra, Ghana, babyaraba95@yahoo.com

DOI: 10.2478/trser-2019-0020

KEYWORDS: closed fishing season, Ghanaian cultural values, artisanal marine fishing, small pelagic fish, fish sustainability.

ABSTRACT

Closed fishing season for artisanal and inshore fishing is an effective management measure for restoring the fish stock. The study aimed at assessing the impacts of the closed fishing season observed in the Sekondi harbour in Ghana. The findings revealed that the one month closure period was too short and/or lack of strict supervision to realize any significant change in fish population and sizes. A more transparent discussion on the period for the closure, longer closure period up to three months as well as provision of alternative sources of livelihood were suggested to ensure more cooperation from the fisher folks.

RÉSUMÉ: Un retour sur les valeurs culturelles Ghanéennes de la saison de pèche fermée dans la pèche marine artisanal du Ghana: Un but essentiel pour la restauration des petits bancs de poisson pélagique.

Les saisons de pèche fermée pour la pèche côtière artisanal est une mesure efficace pour la restauration des bancs de poissons. L'étude avait pour but d'évaluer l'impact de la saison de pèche fermée dans le port de Sekondi au Ghana. Les résultats ont démontrés qu'un mois de fermeture de la pèche était trop court et/ou manquait d'une supervision stricte pour réaliser un changement important dans la taille et la population des poissons. Une discussion plus transparente sur la période de fermeture de la pèche, une période de fermeture plus longue de trois mois comme la disposition d'alternatives pour des moyens de subsistances ont été suggérés pour assurer une meilleure coopération avec les pécheurs locaux.

REZUMAT: O reîntoarcere la valorile culturale ghaneze ale sezonului închis de pescuit în sezonul de pescuit ghanez artizanal: un mijloc esenţial pentru restaurarea stocurilor de peşti pelagici.

Sezonul de pescuit închis pentru pescuit artizanal costier este o măsură de management efectiv pentru refacerea stocurilor de peşti. Studiul a urmărit evaluarea impactului sezonului de pescuit închis observat în portul Sekondi din Ghana. Rezultatele au relevat că perioada de închidere de o lună a fost prea scurtă şi/sau lipsa unei supravegheri stricte pentru a realiza orice schimbare semnificativă a populaţiei şi dimensiunilor peştilor. O discuţie transparentă privind o perioadă de închidere mai lungă de până la trei luni, precum şi la furnizarea de surse de trai alternative au fost sugerate pentru a se asigura mai multă cooperare din partea pescarilor.

INTRODUCTION

The fisheries resources of Ghana have long been a pillar of the national economy, contributing significantly to socio-economic development (Adom, 2018a). The fisheries sector generates over US$1 billion in revenue each year and accounts for at least 4.5% of Ghana's Gross Domestic Product (Dogbevi, 2015). With a marine coastline of five hundred and fifty (550) kilometres stretching from Aflao in the East to Half Assini in the West, the fishing industry plays a major role in sustainable livelihoods and poverty reduction in several households and communities (Mensah, 2009).

The sector also provides livelihood for an estimated 10% of the population representing about 2.5 million people who are employed directly or indirectly including their dependents. Significantly, fish constitutes 60% of the animal protein consumed in Ghana (Fisheries Management Plan of Ghana Marine Fisheries Sector 2015-2019). In the area of food security, fish is recognised as the most important source of animal protein in Ghana and is consumed by most people in all regions of the country from the rural poor to the urban rich. The role of the sector in terms of poverty reduction is very important. Many people rely on the fisheries sector either directly or indirectly for their livelihoods. Post-harvest fisheries activities clearly provide a wide range of full-time and seasonal livelihood opportunities to many vulnerable people. Employment in fishing and aquaculture has grown rapidly over the past few decades, increasing more than threefold from 13 million people in 1970 to over 41 million in 2004. Employment in the fisheries sector has grown more rapidly than both world population and employment in agriculture (Fig. 1). Most of this growth is in Asia, where over 85 percent of the world's fisher folk live, and is largely due to the expansion of aquaculture in this period (FAO, 2006; FAO, 1999).

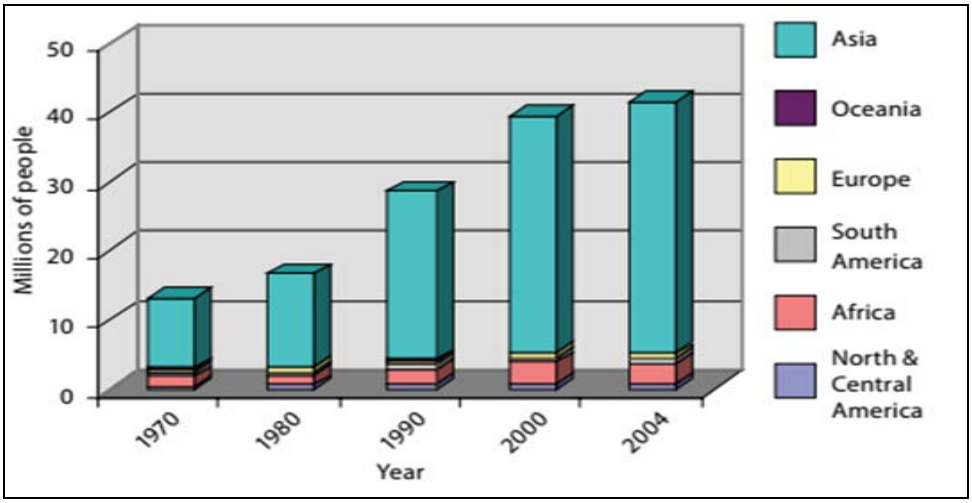


Figure 1: Employment in fisheries and aquaculture
Source: FAO (2006).

Millions of women in developing countries are employed in fisheries and aquaculture, participating at all stages in both commercial and artisanal fisheries, though most heavily in fish processing and marketing. In capture fisheries, women are commonly involved in making and repairing nets, baskets and pots, baiting hooks, setting traps and nets, fishing from small boats and canoes (Cambria, 2016). Greater percentage

of fish production is for export, around 40% of the global production being traded internationally, and exports from developing countries accounting for some 60% of this (Delgado et al., 2003). Human exploitation of fish and other aquatic animals such as crustaceans and mammals is virtually ubiquitous on Earth and since ancient times has provided humanity with food, income and other social goods such as recreation (Arlinghaus and Cooke, 2009). The fisheries sector provides a wide range of employment opportunities for many in the community. These are the fish harvesters, processors, traders, post-stick cutters, pot makers, boat builders, net makers, and ice suppliers. People also earn money by scaling and gutting fish.

Unfortunately, trawl surveys in Ghanaian fishing communities closer to the shores of the Gulf of Guinea show great decline in fish stock close to at least 50% (Afrolnews, 2004). USAID (2016) reports indicate that over a decade, the total marine fish landings declined while fishing effort continues to increase, and thus catch per unit of effort is getting lower, and sizes of landed fish are diminishing – a clear case of growth overfishing (Abreu et al., 2016). Scientific evidence has consistently shown that Ghana's marine fisheries are in crisis, with a decline in fish landings over the last decade. The European Union in 2013 warned Ghana by given her a yellow card for lack of legislative effort to fight unregulated fishing (Thiago and Mensah, 2014). There has also been weak enforcement and noncompliance with the fishery management measures. Reversing the trend of stock depletion to ensure food security for the present and future generations require bold and immediate policy and management actions (Fisheries Management Plan of Ghana Marine Fisheries Sector, 2015-2019). It is therefore, imperative to develop a strategic framework to terminate a further decline and rebuild the fish stocks through closed season fishing. There is little theoretical justification for seasonal closures in most instances. Temporal or seasonal closures may have both direct and indirect effect (Jim and Mark, 2007).

Overly depleted species have avoided apparent extinction due to seasonal closures is among the direct effects. Indirect effects resulting from proper application of closed seasonal fishing is that it protects resources that are vulnerable, causing improvement in economic returns when the market or resource conditions are poor, and restrict harvest during seasonal toxicity or unpalatability of some species (Casey and Myers, 1998). Seasonal fishery closures are commonly used in fisheries management for various purposes, including limitation of effort, protection of spawners, and maximization of the yield or value that can be obtained from a cohort (Watson et al., 1993). More specifically, closed seasons are often imposed during the breeding period of the targeted species in the belief that this will increase reproductive success (Arendse et al., 2007). Its purpose is to reduce catching power and fishing mortality by limiting the amount of fishing to a desired level, which would then supposedly increase stock size (Anderson, 2004).

The principle is based on biological returns, potential, allowing fish to reproduce during the breeding season before they are harvested (USAID, 2016).

Biologists have supported spawning area closures only to the extent that they have contributed to reduction of exploitation rate (Halliday, 1988).

There are many instances around the world where the implementation of a closed season has resulted in an increase of yield and higher economic returns to the fishing sector. In the U.S.A., almost all current fisheries management plans include a form of closed fishing season for commercial or recreational fisheries or both. For example, a closed season for *Tautogaonitis*, a slow growing demersal species, in 2001 in Narragansett Bay in Rhode Island, USA for two months during spawning season. The stock recovered in 2012, with the full rebuilding of the stock projected to be realized by 2016 (Rhode Island Division of Fish and Wildlife, 2015). In Senegal, a two-month seasonal closure in 2010 for octopus, has provided an approximately 35% increase in yield, and allowed the rebuilding of the stock to sustainable levels. Arendse et al., 2007 has reported that the frequent application of closed seasons to species that are not disturbed by harvesting and do not aggregate to breed is therefore generally invalid, despite wide belief that it improves reproductive successes. Seasonal closures have numerous documented failures, particularly when used as the only management strategy in a fishery (Jim and Mark, 2007). The most notable failures have been in large temperate fisheries, such as in the Pacific Halibut fishery and in the ground fish fishery off the New England coast (Sinclair and Valdimarsson, 2003). Seasonal closures are not deemed very effective and therefore alternative strategies are being implemented in which alternatives were more beneficial in the protection of threatened and endangered species (Federal Register, 2004). Culturally, Ghana has a culture for closed seasons for fishing shrouded in traditional beliefs (Adom, 2018b). These closure seasons are termed as nnabone, believed by societal members to be days when the ancestors are purported to perform some events in and around the shores of seas and rivers over some timelines (Adom, 2016) from 1st August to 1st December every year (Adom, 2018b). Interestingly, the fishing closure period coincided with the times when the fishes laid their eggs and/or nursed their young ones (Boateng, 1998). The period allowed considerable time for the fishes to regain their population through breeding and feeding. Watson et al. (1993) concurs that the duration for the fishing closure also affects the yield. He argued that a six-month closure starting from December or January could increase the value of the fishery by 5-10%, compared with a fishery with the same fishing pattern and no closure. However, there seems to be a cessation of the traditional cultural seasonal closure for fishing which was stipulated for longer periods of time in Ghana. Recently, the Ghana Ministry of Fisheries and Aquaculture announced a seasonal ban on fishing activities for a period of one month between the 15th of May to the 15th of June 2019. The ban has raised mixed feelings among the stakeholders in the fishing industry in Ghana. The preliminary research conducted by the researchers at in some fishing communities revealed that some fisher folks think the cessation of fishing for some period was not necessary as it stifled their economic gains during the fallow period. Others felt it was important as it would raise their yield eventually during the open season. Still, others felt that the period was too short to realize any significant increase in fish yield. Some of the workers at the Ministry of Fisheries and Aquaculture strongly felt that a revitalisation of the traditional culture of fishing closures for two to three months would increase field yield and restore the constant dwindling in the population of fishes in Ghana. The traditional authorities felt same but insisted that alternative sources of livelihood to support their poor fisherfolks. Therefore, this study was undertaken to assess the impacts of the closed fishing season of small pelagic fish stock observed within the period of 15th May 2019 to 15th June 2019 in the Albert Bosumtwi fishing harbour in Sekondi, Western Region of Ghana. The study was worth undertaking to help increase the fish stock for the small pelagic fish which is now in low population due to overfishing activities in Ghana. It would also help regulate the fishing closure seasons in Ghana so that the Ministry of Fisheries and Aquaculture Development could formulate resilient policies on fishing closures in the country.

MATERIAL AND METHODS

The study was a phenomenological study rooted in the field of cultural anthropology at Sekondi-Takoradi in the Western Region, Southern Ghana. The study was carried out over a five month period before and after the seasonal fishing closure from April 2019 to August 2019. The study was hinged in the qualitative research approach owing to the socio-cultural context (Denzin and Lincoln, 1994; Fraenkel et al., 2012) within which it was situated as well as its interactive nature. Private interviews, focus group discussions and participant-observant method of observation were used for the ganering of the data for the study. These data collection instruments have been proven to be efficient in Cultural Anthropology studies in soliciting for rich data on varying topics of investigation (Leedy and Ormrod, 2010). To prevent social desirability response set, the informants were told of the purpose of the study (Leedy and Ormrod 2010). Names of the participants were not inquired. However, pseudo-identification that allows anonymity of particpants was used. The responses of the participants were coded and used in describing their views expressed in this paper.

The main objective of the researchers was to seek for more enlightenment on how the seemingly short closed season affected fishing stock and the fishing activity as a whole to suggest proactive ways of using this cultural closed season arrangement to boost the fishing population of small pelagic fish, the phenomenology research method was used (Pietkiewicz and Smith, 2014). Long participant engagement through lengthy interviews conducted by the researchers aided in capturing the thoughts of the participants comprehensively (Creswell, 2009). Purposive sampling was used in deliberately selecting the various categories of participants who were seen as key stakeholders in the fishing industry in Sekondi (Fraenkel et al., 2012) as well as those who knew the cultural values associated with the practice of closed fishing season amongst the people. They included fisher folks, fish mongers and traders, traditional authorities, workers at the Ministry of Fisheries and Aquaculture Development (MOFAD), as well as elderly residents from the age of 50 in Sekondi totalling a sample size of 51 out of the estimated 130 participants. Apart from the fishing leader of Sekondi, leading members of the fishing groups as well as the priests and chiefs of the sea, the other members interviewed were selected randomly. The Interpretative Phenomenological Analysis (IPA) was used for analyzing the final rich data on the phenomena studied from the respondents. Thick quotations from the responses of informants were used in constructing the meanings of the data generated (Fade, 2004; Smith and Osborn, 2008; Pietkiewicz and Smith, 2014).

Figure 2: Map of Sekondi-Takoradi (study area).

Table 1: Breakdown of interviewees; researchers' construct from field survey, 2019.

No.	Category of interviewees	Total number selected	Details
1.	Leaders of fishing groups	5	They were selected purposively and interviewed privately.
2.	Fish mongers and traders	18	They were selected randomly and interviewed in three focus group discussions.
3.	Traditional chiefs	2	They were selected purposively and interviewed privately.
4.	Traditional priest	1	He was selected purposively and interviewed privately.
5.	Elderly residents (50 years and above)	9	They were selected randomly and interviewed in six different focus group discussions.
	Young residents (below 25 years)	8	They were selected randomly and interviewed in two focus group discussions.
6.	Workers at the MOFAD	8	They were selected randomly and interviewed in two focus group discussions.
TOTAL SAMPLE		51	

DESCRIPTION OF THE PROJECT AREA

Sekondi-Takoradi is the fourth most populated metropolitan area in Ghana, the largest city and capital of the Western Region of Ghana and the hub for industrial and commercial activities with a population of close to six hundred thousand (Sekondi-Takoradi Metropolitan Assembly, 2017). The Dutch and the British built ports in Sekondi in the 17th Century that were destroyed by the Ahanta people in the Western Region (Ghana Web, 2019). Sekondi covers a land area of 219 km^2 and its the adminstrative headquarters of the Sekondi-Takoradi Metropolitan Assembly (STMA, 2017). It is located just 280 kilometres away from La Cote d'voire border to the West. The coastlines of Sekondi-Takoradi are fringed with coconut trees along the sandy beaches. The vegetation is both evergreen and moist semi-deciduous forest types rich in timber species.

The Albert Bosomtwi Sam Fishing Harbour was commissioned on the 2nd of June 1999 by the former president of Ghana Rawlings J. J. The harbour has a 200 m long breakwater and a 76 m long jetty with two wharfs for inshore vessels, an ice-making plant, ice storage unit, a shed for fish handling, water supply system and a fire fighting system (GhanaWeb, 1999).

As a fishing community, the main occupation in Sekondi is fishing with a larger section of the women engaged in staple crop production mainly for subsistance consumption. Though majority of the women do not engage directly in the fishing activity, they rather trade in the smoking and selling of the fish at the shores as fish mongers to market women to be sold in the markets.

RESULTS AND DISCUSION

The findings presented and discussed under this section focuses on the main objectives of the study that aimed at assessing the benefits, challanges and suggestions for improving the seasonal closure for fishing among artisanal fisher-folks observed from May 15 to June 15 2019 at the fishing communities in the Sekondi Fishing Harbour in the Western Region of Ghana.

Wider publicity and proper consultation versus short notice and poor consultation on seasonal closure for fishing

Interviews with the older fisher-folks (all twelve of them, including the traditional chiefs and traditional priest) revealed that in the olden days when seasonal closures for fishing were cultural prohibitions, every member of the society knew of it due to their wider publicity and consultation. One of the traditional chief interviewed mentioned that it was a communal consultation. He told the researchers: A general community meeting was convened after prior information had been given. The traditional priest and his cabinet of elders discuss the closure period with the members of the society as well as the sanctions for breacking it. This included spiritual and physical punishments. These sanctions assisted the fisherfolks in making prior arrangements for alternative sources of livelihood before the closure period. (TC1, Personal Communication, 20th May, 2019).

The elderly fisherfolks, twenty out of the total twenty three, told the researchers in a focus group discussion that many of them engaged in farming activities during the closure period to cater for their families. They added that others also followed building contractors to work on their building projects to earn money to cater for themselves and their families. However, many of the fisherfolks interviewed admitted that they were not well informed of the May 15 to June 15 closure on fishing activities. In separate focus group discussions with the researchers, some of them admitted: We were given a short notice of the closure. Many of us did not make any plans on how to engage in other businesses to cater for our families. We had gone for loan facilities to engage in business during the closure period only to be told just two weeks to the closure period that there will be a ban on fishing. This specific situation has left many of us impoverished and in great debt (FF-1-FGD, Personal Communication, 18th May, 2019).

A section of the elderly fisherfolks (nine out of the 23) told the researchers that they had to ask their wards to stop schooling for the closure period because they couldn't fend for their schooling expenses due to the short notice of the fishing closure period. Eight young people interviewed expressed that they were at the receiving end of the economic hardship that came as a result of the unpreparedness of their fathers who are fisher-folks toward the seasonal closure for fishing. Three out of the eight said that they had to stop schooling for the half of the remaining semester because of failure on the

part of their fathers to pay for their school fees. Six out of the eight said that they had to engage in short term trading (selling items) and engaging in constructional activities and/or farming activities to support their families financially. These comments show that when wider publicity of seasonal closures are not given before their implementation, fisher-folks fail to make prior arrangements toward seasonal closures resulting in dire consequences.

Focus group discussions with eight workers at the Ministry of Fisheries and Aquaculture Development revealed that a year-long notice of the seasonal closure was given the fisher-folks before the implementation. They told the researchers of the then intention of the Ministry to observe the seasonal closure in 2018 but was resisted by the fishing communities and unions, claiming they were not reliably informed. The Ministry then called off the August 7th 2018 seasonal closure on fishing. The ministry then asked the fisher folks in several consulations to come out with new dates for the closure in 2019, of which they proposed the May 15 to June 15. They added that: The fisher-folks don't want to observe any seasonal closure for their fishing activities and thus came out with this date with the expectation that the ministry would ignore it. But, to their dismay, the ministry accepted it. Now, they are coming out with a false allegation that they were given a short notice and were not consulted' (MOFAD-FGD-1, Personal Communication, 20th May, 2019).

The views of the workers of MOFAD are justified in a news report by Joy FM in Ghana on the 10th of April, 2019 titled "Was the Fisheries Ministry coerced into accepting May 15 closed season?" Abubakar Ibrahim, one of their news reporters interviewed the sector minister, Hon. Elizabeth Afoley Quaye who shared similar views that the dates were given by the fisher-folks after extensive consultations with them. Thus, it would not be fair for the fisher-folks in the Sekondi Fishing Harbour to blame the ministry for not giving them more time to plan for the seasonal closure. The two traditional chiefs interviewed confirmed the position of the workers at MOFAD, concurring that the fisher-folks were well informed ahead of the time for the seasonal closure they proposed. Their lack of preparedness, according to the workers at MOFAD and the traditional chiefs was as a result of their expectation that the ministry would call off the seasonal closure since the timing was not within the dates the ministry endorsed. Judging from the larger section of the fisher-folks at the grassroot sharing the view of the short notice of the closure may suggest that the leaders of their fishing groups probably did not inform them earlier at the local level. There is still the need for greater education on the seasonal closure for fishing among the fisher-folks as many of them expressed negative views about it, having no knowledge about the benefits of the seasonal closures to fishing. The discretion of those who are relied upon to implement policy in the field is a key factor in its successful implementation (Burke et al., 2012).

The bottom-up theorists believe that centralized decision-making adapted to local conditions and flexibility is important to reach goals. This approach enhances democratic accountability and the ability of policy leaders to structure local behaviors (Landry, 2017). Therefore, the fisheries ministry must put up measures in ensuring that policy information reaches the grassroot, probably adapting the bottom-up approach in policy dissemination.

A step towards mutual understanding between the Fisheries Ministry and the other stakeholders in the fishing industry on appropriate periods for the seasonal closures

The workers at MOFAD disclosed to the researchers that they initially came out with dates for the seasonal closure on fishing which was from August 7th to September end in 2018. The August month was appropriate because it is scientifically proven that the popular fish stock *Sardinella maderensis* in Ghana's marine waters referred to as the "people's fish" breeds most during the month of August (Apetorgbor, 2018). The eggs produced by the older female fishes are bigger in size and hold greater potential of getting fertilized. Thus, it would be best to observe the seasonal closure within this period to allow the fishes to rest and spawn. Unfortunately, the fisher-folks revolted against the decision, blaming the Fisheries Ministry as being autocratic. To be a listening ministry, the sector minister asked the leaders of the fisher-folks nationwide to propose their dates for the seasonal closure. After deliberations with their members, they came out with the May 15th to June 15th. The post effects of the seasonal closure did not register very significant benefits in terms of fish stock and yield as the fisher-folks admitted to the researchers. Even before the observance of the seasonal closure date given by the fisher-folks, their leaders came back to suggest the initial date expertly given by the Fisheries Ministry. However, their plea was nullified because the closed season had to be observed this year (2019). Thus, the date given by the fisher-folks which was May 15th to June 15th was observed. After the seasonal closure in June end 2019 when the fisher-folks were interviewed, they suggested that the 2020 seasonal closure should be observed in the months of August and September. Some of the views they expressed in one focus group discussion were: "The May 15th to June 15th seasonal closure did not help us (artisanal fishers). We want it to be observed between August and September as we have heard that the fishes spawn and increase in their sizes and numbers. We want to get bumper harvest after the long fallow period during the seasonal closure" (FF-2-FGD, Personal Communication, 22nd June, 2019).

The Fisheries Ministry must immediately hold a consultative forum with all the stakeholders in the fishing industry to deliberate on the appropriate timespan for the observance of the seasonal closure. The Fisheries Ministry, being the sector ministry with the right expertise and mandated by law to manage the sector must well educate the fisher-folks on the need to stick to the months that they will get greater yield of fishes. Though they must not impose their views on the fisher-folks, they must reason with them on the need to accept the August-September closure period. This consultative forum must be done prior to the seasonal closure period in the following year. The proceedings of the meeting must be well disseminated especially at the grassroots level to the ordinary fisher-folk. This can be achieved if the Fisheries Ministry task the leaders of the local agencies and fishing groups in the various fishing communities as well as the traditional authorities and the local media houses to broadcast and discuss the seasonal closure periods and its benefits to the people. This would ensure that every stakeholder is well informed and educated so as to avert any last minute surprises and unpreparedness.

Benefits or no benefits of the one month seasonal closure for fishing

Admittedly, a considerable number of them (46 out of the total 51 participants) told the researchers that the one month closure was a vacation for fisher-folks to rest and for them to mend their nets and repair their canoes. In a focus group discussion, they told the researchers: "Many of us do not get adequate time to rest, drastically affecting our health. As such, the one month closer gave us ample time to go on vacation from our work to have considerable rest and relaxation" (FF-2-FGD, personal communication, 22nd June, 2019).

"Some of our colleagues are greedy and hardly spend time mending their nets and repairing their damaged canoes because of their constant use for fishing activities. The one month closure gave them the time to mend their torn nets that even reduced their catch at sea as well as in repairing their canoes" (FF-3-FGD, personal communication, 23rd June, 2019).

The main benefits of closed fishing season which are to control fishing, to increase the spawning potentials of fishes by protecting adults during the closure period and/or protect juveniles from extinction (Beets and Manuel, 2007) were not fully realized because of poor timing and lack of proper enforcement as noted in the responses of participants.

Figure 3: A fisher-folk at the Sekondi Harbour mending his fishing net during the closed season source: fhotographed by the researchers.

Duration of seasonal fishing closure versus strict compliance of the ban on fishing

All the fisher-folks interviewed said after the post seasonal closure that the sizes of fishes and their population remained the same. 18 out of 23, attributed it to the short closure period. The leaders of the fishing groups and the traditional authorities indicated that if the period will be longer, they will benefit by a greater fish yield and an increase in the sizes of the pelagic fishes. The traditional authorities mentioned that, their ancestors assigned two to three months for the seasonal closures, and suggested that collaboration between the Fisheries Ministry and other stakeholders in the fishing industry would lead to better decisions regarding the increase of the seasonal closure period from one month to two-three months. Examples can be gleaned from Phillipines that observe two months seasonal closure as well as Senegal that observes four months closure on the fishing of octopus and small pelagics with increase in fish yield (Zaney, 2019). Guinea, Mauritania, Morrocco, U.S.A. observe closures for over a month.

Other participants held contrary view. They said that the problem was not with the duration for the seasonal closure but ensuring strict compliance of all the stakeholders in the fishing industry. The leaders of the fishing groups registered their displeasure for the weak supervision of the closed fishing season. One of them told the researchers: "Some foreign nationals (Chinese) engage in fishing despite the ban. It seems they have support of some of the workers at the Fisheries Ministry. If this discrimination attitude is not halted, nothing good will come out of the seasonal closure" (FL-PI-3, personal communication, 10th June, 2019).

Therefore, though longer time for seasonal closure observance is key to replenishing the low stock of fishes, strict compliance to the ban must also be ensured to enjoy the full benefits (Scheer and Moss, 2017).

Misinformation and lack of information on government fishing policies among the ordinary fisher-folk

Ninety-eight% (22) of all the fisher-folks interviewed in this study, including four of the leaders of the local fishing groups, were not aware of the full government policy on the seasonal closure on fishing. They knew of only the seasonal closure on artisanal fishing. As such, they felt that they were discriminated against because of their impoverished state. They disclosed to the researchers that they saw many times the industrial trawlers and tuna operators working on the sea while they were asked to observe the closed fishing season. Some of them said to the researchers: "We see the boat fisher-folks (industrial trawlers) and tuna operators working though all of us have been asked to observe the seasonal closure on fishing. The authorities look on and do not prosecute them. Some of us would also revolt against the seasonal closure and go for fishing" (FF-2-FGD, personal communication, 21st May, 2019).

Their comments clearly show that they were not reliably informed of the government's policy on seasonal closures for fishing. However, the industrial trawlers and tuna operators have different periods that they would observe their seasonal closures. Tuna operators' seasonal closure was from January 1st to February 30th while industrial trawlers seasonal closure starts from August 1st to September 30th. Their view shows clearly that education on government policies regarding fishing should be intensified especially at the grassroots level. This is very crucial for these fisher-folks in helping in the implementation of the policies because lack of information and/or misinformation can propel many of them in usurping the policy directive on seasonal closures for fishing.

Making alternative arrangements for fishermen during the seasonal closure

The government of Ghana has shown her commitment in helping fisher-folks in their traditional business. One of such specific assistance is with the provision of subsidies on premix fuel for artisanal fishers (Sackey-Mensah, 2012). Interview with the fisher-folks show that they can wholeheartedly support the seasonal closure even if it is extended to two or three months only in condition that the government would offer them alternative sources of livelihood during the seasonal closure period. When the researchers asked them the kind of support they would expect from the government, these were some of the responses: "The government can support us with the setting up of cold stores for selling fishes during the seasonal closure period to help us cater for ourselves

and our families" (FF-1-FGD, Personal Communication, 5th June, 2019). "The government can support us with chemicals and other farming equipment to assist us in our farming activities during the seasonal closure period" (FF-2-FGD, personal communication, 21st May, 2019). "The government through some of the financial agencies could offer us soft loans with low interest rates to aid us engage in small-scale enterprises and/or trading to support ourselves and our families. Otherwise, during the closed seasons, we will be impoverished" (FF-3-FGD, Personal Communication, 28th May, 2019). "The government should make arrangements to offer us some allowance packages to help us fend for ourselves and our families during the seasonal closure" (FF-2-FGD, Personal Communication, 21st May, 2019).

Similar sentiments were expressed by the chief fisherman of Kokrobite in the Ga South Municipal Assembly in the Greater Accra Region of Ghana who requested the government of Ghana to make appropriate arrangements for alternative sources of livelihood for the fisher-folks before the implementation of the seasonal closure period on fishing (Business News, 2018). The workers at MOFAD concurred that such specific incentives and continuous support offered to the fisher-folks during the seasonal closure period would help them in supporting the policy as they would not be tempted in any way to breach the directive because of financial hardships. The demands of the fisher-folks and the workers at MOFAD in Ghana is not misplaced because similar plea and arrangements for alternative sources of livelihood were made for the fisher-folks in Myanmar during their annual three months seasonal closure on fishing (Global New Light of Myanmar, 30th May, 2019).

In thinking of the kind of alternative sources of livelihood that can be provided for the fisher-folks, the government of Ghana can pick lessons from what other countries are doing. For instance, in Sri Lanka, the government decided to diversify the income generating activities of small-scale fisher households such as promoting sustainable home gardening activities (RFLP, 2011). In addition, vocational training program on coconut oil processing was introduced since there are large coconut plantations in Myanmar (Haritha et al., 2013).

General challenges expressed by fisher-folks on bad fishing practices that need immediate redress

The major concern of about 23 out of the 25 (97%) of the fisher-folks was with the bad fishing practices that are carried out in the Albert Bosumtwi fishing harbour. They mentioned the use of light for fishing as well as the use of deadly chemicals such as DDT, Sodium cyanide, carbide and dynamite for fishing. Many of the fisher-folks stated that they noticed these bad fishing practices among the foreign nationals especially the Chinese. They said that the authorities look on as the foreign nationals engage in these unhealthy fishing activities. Some even said it may be because the Chinese fisher-folks have bribed the workers of MOFAD who are not applying the stricter punishments on them. However, when their colleagues engage in these same foul practices, they immediately cease their canoes.

When the workers of MOFAD were questioned on this, they dismissed it saying that the sanctions were applied on both local and foreign nationals, mentioning the prosecution of some Chinese who were found engaging in light fishing. Yet, over 50% of the participants in the study insisted that the fisher-folks who engage in these illegal fishing practices are not prosecuted. As a result, it is on the ascendency. One of the leaders of the fishing groups told the researchers: "Most times when we report such incidences, the culprits are freed because they have the support of someone in the fisheries department

or in government. If this favouritism attitude is not erased completely in the fishing industry, these illegal fishing practices would continue" (FL-PI-3, Personal Communication, 10th June, 2019).

Weak enforcement of fishing policies and sanctions as well as the frequent corruption among those in authority (Scheer and Moss, 2011) has been the constant bane behind the slow pace of development in the Ministry of Fisheries and Aquaculture Development in Ghana.

The Fisheries Ministry must liaise with the security agencies in the country and ensure the full implementation of the Regulations (10-21) of the Fisheries Regulation, 2010 (L. I. 1968) that aims at prosecuting all persons who engage in illegal, unreported and unregulated (IUU) fishing activities such as light fishing and the use of dynamites and poisons.

This fisheries act should be implemented to the fullest with no favour or whatsoever to anyone including governmental officials who hide behind the screens to support fisher-folks to engage in these unproductive activities in the fishing industry. One of the leaders of the fishing groups told the researchers that Ghana should learn from Togo and put up stricter measures in prosecuting all fisher-folks who engage in light fishing, aiding in completely rooting out these bad fishing practice in the country.

The researchers were told that the fisher-folks use light to attract the fishes. Also some fishers use the DDT and other chemicals in a bid to maximize their fish yield.

However, these practices have very dire consequences to the health of the aquatic ecosystems, fishes, the humans that consume the fishes and on the economic gains of the fish mongers (Curtean-Bănăduc et al., 2016). All the eighteen fish mongers and traders interviewed said that the use of the poisonous chemicals caused the fishes to rot speedily, few days after their catch, making them incur huge debts. Those who roast some of the fishes (Tilapia – *Oreochromis niloticus*) for sale said that when heat or smoke is exposed to the fishes caught using poisonous chemicals like DDT and cyanide; they break into pieces, negatively affecting their sales and prices. In terms of the health of the fishes, they look discoloured with broken and sunken eyes, making their consumption hazardous as buttressed Bentill (2014). Mak et al. (2005) mentions that when cyanide is used for fishing, fishes suffer chronic toxicity, exposing them to stress and damage with eventual death. In addition, the consumption of the fishes with large quantities of DDT can cause serious havoc to the nervous system (Bentill, 2014; Afoakwa et al., 2018).

Therefore, strict enforcement of sanctions against all forms of illegal fishing activities must be ensured by the Fisheries Ministry in collaboration with the law enforcing agencies in Ghana.

CONCLUSIONS

The Ministry of Fisheries and Aquaculture Development in Ghana has done well in implementing the closed season act which has been left behind for so many years despite it being part of the cultural fibre of the Ghanaian people. MOFAD in accordance with sections 76(3) and 84 of the Fisheries Act 2002 (Act 625) has been able to implement the seasonal closure for fishing in 2019 though with some considerable setbacks. This study aimed at assessing the impacts of the closed fishing season for artisanal fishing that was observed within the period of 15th May 2019 to 15th June 2019 in Ghana, with the Albert Bosumtwi fishing harbour in Sekondi, Western Region of Ghana as a case study. The study has shown that the projected benefits of the seasonal closure were not fully realized because of the relatively shorter period of observance, the lack of strict supervision, and the lack of effective dissemination of the government policies on the seasonal closure. For effective implementation of the seasonal closure for fishing in the coming years, the study contends that the Fisheries Ministry must ensure close talks through consultative forums with all the stakeholders in the fishing industry especially the grassroots fisher-folks so that government policies on seasonal closures for fishing could be well disseminated. Amicable dates that would aid in increasing the fish yield and sizes must be discussed during the consultative forums organized by the Fisheries Ministry. Also, very strict supervision approaches must be adopted by the Fisheries Ministry in prosecuting all fisher-folks and other persons who flout the seasonal closure. The sanctions must be stricter to serve as deterrent for others who would want to walk that unhealthy path. Moreover, the law enforcing agencies must assist the Fisheries Ministry in enforcing the stricter sanctions on fisher-folks who engage in bad fishing practices such as using light and other poisonous substances in fishing. When close measures are taken by the Fisheries Ministry in implementing these proactive suggestions, it would lead to better and more beneficial seasonal closure observance for artisanal fishing activities in Ghana.

REFERENCES

1. Abreu A. D., Salinas A. H. and Clusener-Godt M., 2016 – Sustainable management of the lake Bosomtwe in the Ashanti Region of Ghana, France: United Nations Educational, Scientific and Cultural Organization, 46.
2. Adom D., 2016 – Asante indigenous knowledge systems: repositories of conservation ethics for Ghana's biodiversity, sub-Saharan academic research publications (conference paper) (manuscript ID- UFUSokotoConf/2016/0029).
3. Adom D., 2018a – The human impact and the aquatic biodiversity of lake Bosomtwe: renaissance of the cultural traditions of Abono (Ghana)? *Transylvanian Review of Systematical and Ecological Research*, 20, 1, 87-110.
4. Adom D., 2018b – Traditional biodiversity conservation strategy as a complement to the existing scientific biodiversity conservation models in Ghana, *Environment and Natural Resources Research*, 8, 3, 1-24.
5. Anderson J. E., 2010 – Public policy making-An introduction (7th edit.), Boston MA: Wadsworth.
6. Anderson L. G., 2004 – The economics of fisheries management, 2nd revised edition, The Blackburn Press, Caldwell, New Jersey, 296.
7. Andre G. K., 2001 – The Jamaica fishing industry: brief notes on its structure, socio-economic importance and some critical management issues, 1-10.
8. Apetorgbor S., 2018 – Closed season brief, The USAID/Ghana Sustainable Fisheries Management Project (SFMP), Narragansett R. I.: Coastal Resources Center, Graduate School of Oceanography, University of Rhode Island GH2014_POL109_CRC, 10.
9. Arendse C. J., Govender A. and Branch G. M., 2007 – Are closed fishing seasons an effective means of increasing reproductive output? doi:10.1016/j.fishres.2007.01.001.
10. Arlinghaus R. and Cooke S. J., 2009 – Recreational fisheries: socio-economic importance, conservation issues and management challenges, 3-58.
11. Bentill N. L., 2014 – Danger: fishermen using DDT, carbide for fishing (General News) www.graphic.com.gh. (Accessed 21/04/2019).
12. Curtean-Bănăduc A., Burcea A. and Bănăduc D., 2016 – Persistent organic pollutants general considerations, in The impact of persistent organic pollutants on freshwater ecosystems and human health, ISBN 978-606-12-1412-9, 7-24, 152.
13. Pwaberi D. W., 2018 – Fishermen demand allowances before closed season fishing policy, The business news of Ghana, June 25, 2018, www.ghanaweb.com-663217.
14. Cambria F., 2016 – The importance of fisheries and aquaculture to development, fisheries, sustainability and development, 353-364.
15. Casey J. M. and Myers R. A., 1998 – Near extinction of a large widely distributed fish, *Science*, 281, 690-692.
16. Delgado C., Wada N., Rosegrant M. W., Meijer S and Ahmed M., 2003 – International Food Policy Research Center. Washington DC and World Fish Center: Penang, Malaysia.
17. Dogbevi E., 2015 – Ghana's fisheries sector said to generate more than GH 1b annually, http:www.gahanabusinessnews.com (Accessed 4/6/2019)
18. FAO, 2006 – State of world fisheries and aquaculture, Rome: Food and Agriculture Organization.
19. FAO, 1999 – Number of fishers doubled since 1970 http://www.fao.org/fi/highligh/fisher/c929.asp. Accessed 25/07/19.

20. Federal Register, 2004 – Rules and regulations, 69, 64, April 2nd, Department of Commerce, National Oceanic and Atmospheric Administration 50 CFR Part 660 (17329-17354) "Fisheries off west coast states and in the Western Pacific; Western Pacific pelagic fisheries; pelagic long line fishing restrictions, seasonal area closure, limit on swordfish fishing effort, gear restrictions, and other sea turtle take mitigation measures".
21. Global new light of Myanmar, 2019 – Editorial, finding alternative livelihood for fishermen during closed season is a must, May 30, http://www.myanmardigital.news (accessed 14/5/2019).
22. Halliday R. G., 1988 – Use of seasonal spawning area closures the management of haddock fisheries in the northwest Atlantic, *NAFO Scientific Council Studies*, 12, 27-36.
23. Haritha W., Champa A. and Claude F., 2013 – Promoting non-fisheries livelihoods in small-scale fisheries communities in Sri Lanka, 1-62.
24. Ibrahim A., 2019 – Was Fisheries Ministry coerced into accepting May 15 closed season? http://www.myjoyonline.com (accessed 7/04/2019).
25. Jim B. and Mark M., 2007 – Temporal and seasonal closures used in fisheries management: a review with application to Hawaii, 1-13.
26. Khan A. R., 2016 – Policy implementation: some aspects and issues, *Journal of Community Positive Practices*, XVI, 3, 3-12.
27. Landry S., 2017 – Policy implementation – A synthesis of the study of policy implementation and the causes of policy failure, OCP Policy Center, policy paper, 1-26.
28. Mak K. K. W., Yanase H. and Renneberg R., 2005 – Cyanide fishing and cyanide detection in coral reef fish using chemical tests and biosensors, *Biosensors and Bioelectronics*, 20, 2581-2593.
29. Mensah C. A., 2009 – Optimization of profit in the artisanal marine fishing: a case study of second fishing harbour, A research thesis submitted to college of science, KNUST, 1-78.
30. Ministry of Fisheries and Aquaculture Development, 2015 – Fisheries management plan of Ghana, A national policy for the management of the marine fisheries sector, vi-48.
31. RFLP, 2011 – Sri Lanka baseline survey report, Regional fisheries livelihoods programme for south and southeast Asia (GCP/RAS/237/SPA), project document2011/LKA/MIC/02.
32. Rhode Island Division of Fish and Wildlife, 2015 – Atlantic States Marine Fisheries Commission Tautog (Tautogaonitis) stock assessment peer review report, 283.
33. Sackey-Mensah K., 2012 – Fuel subsidy in Ghana's marine artisanal fisheries sector, https://www.unuftp.is/static/fellows/document/rebecca12prf.pdf (final report), (accessed 14/05/2019).
34. Sinclair M. and Valdimarsson G., 2003 – Responsible fisheries in the marine ecosystem, Wallingford, Cambridge: Food and Agriculture Organization of the United Nations.
35. Thiago D. and Mensah E., 2014 – Modernization of the fishing vessels registry and licensing system to enhance sustainable management of Ghana's fisheries, Ghana: final report WARFP.
36. USAID, 2016 – Sustainable fisheries management project, rebuilding depleted small pelagic stocks in Ghana, Closed fishing season proposal to the Ministry of Fisheries and Aquaculture Development, The Scientific and Technical Working Group, 1-12.
37. Watson R. A., David J. D. and Restrepo V. R., 1993 – Closed seasons and tropical penaeid fisheries: A simulation including fleet dynamics and uncertainty, *North American Journal of Fisheries Management*, 13, 326-336.
38. Zaney G. D., 2019 – Closed seasons-essential tool for reversing fish stock depletion, https://www.ghana.gov.gh (accessed 10/06/2019)