Chapter 9
Methodologies for the Assessment of River Ecosystem in Southern West Bengal, India

Abstract Southern eco-regions of the state West Bengal (**Lat. 22.0°–23.3° N; Long. 86.0°–88.3°E**), India, is a mosaic of different landscape types, endowed with undulating lateritic terrain with macro and micro gullies. The rate of infiltration is very high on the lateritic upland with dense vegetation cover. However, the upland surface composed of lateritic hard crust with jointed structures and granular materials is endowed with only sparse vegetation because of massive deforestation. Occasionally, the seepage waters from the vegetated uplands can generate a stream flow along the valley fill surface. Four major different aspects of riverine environment are required to be studied in order to gain a complete and holistic knowledge of the ecodynamics of river ecosystem in any area like Southern West Bengal, India.

These studies include long-term recording of physicochemical properties in respect of ongoing threats on river, existing status of biodiversity, and trophic interactions with an eye to compare the present research information with the past in order to understand the trend of ecological changes. Besides, all-round geomorphological and hydro-geological assessment processes have been given due importance for the dynamics and potentiality of riverine flows highlighting their connectivities to the ecosystems in order to devise conservation strategies giving due importance to people's participation. In order to achieve these goals, well-designed eco-monitoring of rivers of different parts of the world have to be conducted to generate baseline information which are to be subjected to existing statistical tools for achieving quantitative definite results. These results pertaining to the status of river environment are to be scientifically processed to arrive at proper decision so that the deteriorating trend of riverine environment may be arrested, restored, and environmentally managed in a sustainable manner and the benefits out of ecological services from the river may be utilized by the local peoples.

Keywords Taxonomic hierarchy · Evolutionary process leading to origin of new species · Traditional vs modern mode of classification · Analysis of different biotic indices · Methods of estimation of different ecological variables · Methods for biomonitoring · Determination of conservation categories of species · Pumping methods for water extraction · Conservation strategies: peoples participation

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9.1 Methodology to Study Varied Forms of Aquatic Fauna with Their Ecology

An array of interactions of different aquatic microbes, plants, and animals with the environment control water quality alongside performing ecological "services," such as production of biomass, decomposition, and nutrient cycling. Identifying species based on their functional roles in aquatic food webs constitutes an essential part of managing biotic communities, especially for undertaking ventures for aquaculture and fishery development. The research information through various ecological assessment procedures on the occurrence, distribution, and overall diversity of organisms starting from bacteria and protozoa to different macrophytes; microphytes; benthic, periphytonic, and planktonic invertebrates; and fishes have established the bioindicator potentialities of those biotic components pointing out the trends of eco-biological changes of the studied fluvial system. Such assessment also depends on the proper identification and recording of pollution-sensitive and pollution-tolerant taxa in order to determine bioindicator species and relevant biomonitoring tools using species diversity as an indicator of pollution with an aim at evaluating the acceptability of riverine water for the human use.

Identification of some species of algae and macrophytes and even faunal components possessing toxic substances is required for maintaining safe water quality. Taxonomic knowhow is also required for spotting and recording of bioinvasion in order to understand the influence of pest and invasive organisms. Finally, different conservation strategies are standardized for the protection of different threatened species alongside their habitats which are supposed to throw more light to shape the decisions for eco-management (**Tables 8.3 to 8.20; Figs. 8.1 to 8.6**).

9.1.1 The Taxonomic Hierarchies with Special Emphasis on Evolution of Species: Foundation of Biodiversity Studies

9.1.1.1 Taxonomic Hierarchy with Special Reference to Species Concept

The science of taxonomy is in a state of perpetual evolution. The initial idea of the taxonomic hierarchy was based on the conviction of descending orders in the classificatory scheme where the splitting of large groups into smaller ones (classes into subclasses) was made. Later, the proposition of taxonomy was moved to an ascending classification system where the related taxa are grouped into taxa of a higher order. The need of classification is twofold: **first,** to identify the organisms based on similarities and dissimilarities among themselves and, **second,** to group the related organisms to place them in proper hierarchy which reflect their evolutionary relationship. Classification of biological organisms deals with the identification and defining of different biological groups or taxa by assigning one scientific name to those organisms possessing at least one characteristic in common. A hierarchical, classification includes smaller groups within larger groups that do not overlap in living world, and each level of the hierarchy corresponds to the name of a taxon. Both these exercises, taxonomy and classification, play important roles for the understanding of biodiversity as being the living structural components in an ecosystem. The phylogenetic hierarchy is based on the evolutionary relationships of groups descending from common ancestors. The principle of classification in the evolutionary perspective upholds that two species are originated from an ancestral species in the process of evolution. Derivation of a group of species from a single common ancestor is designated as monophyletic taxa in contrast to the polyphyletic ones which comprise of those species resembling with one another in many respects but without experiencing direct descendence from a common ancestor.

Biologists consider the species as the fundamental unit of taxonomic division, and the scientific system for naming organisms is based on distinguishing species. An acceptable definition of biological species is "**a genetically distinctive group of populations constituted by the individuals having the power of free interbreeding in the natural ecological conditions after being reproductively isolated from all other members of such groups**" (McFadden and Keeton 1995). Species being the basic unit are grouped together into genera, genera into families, families into orders, and so on. These categories after having their evolutionary origin along rather different lines are roughly comparable from one group to the next. The family represents a coherent group formed by the assemblages of recognizable related genera. Similarly, the order is group of distantly related families. The class represents the major group accommodating varied forms of organisms belonging to different families and differs from other such classes in respect of both structure and way of life. The phyla differ among themselves more vividly and widely in terms of their organization and appearance.

However, many aquatic animals, plants, and microbes are unable for sexual reproduction, while members of many other species can reproduce with organisms that belong to different species as evident from the ability of some fishes to hybridize. The operational definition of species emphasizes the older and traditional concept of species by defining it as **"a group of organisms having close resemblance to other, with respect to their physical appearance by possessing almost similar morphology, physiology, behavior, and reproductive patterns"** (McFadden and Keeton 1995). Sometimes, difficulty arises when individuals of the same species display natural morphological diversity especially those living in different environments. Therefore, in order to undertake appropriate identification efforts, analyzing of such morphological variabilities of a large number of individuals inhabiting in different environmental conditions are required.

Generally, systematists are specialized for a specific group of organisms which highlights the characteristics required for differentiating one species from others. Species are considered as distinct only after the consensus among the majority of systematists studying the group of organisms regarding the distinctiveness of the species. The taxonomic identity based on the current scheme of identification provides a solid foundation for ecological information of a species, especially with the help of electronic search engines which tend to increase such abilities. Besides, the most important taxonomic methods recently use biological molecules, such as **DNA,**

RNA, lipids, and proteins, to ascertain proper status of a species (Graham and Wilcox 2000).

Recently, a very common approach of classifying microbial organisms to its distinct species level requires more than **30%** variabilities of **DNA** sequences or more than **5%** variation of ribosomal **rRNA** sequences (Buckley 2004). But all these methods do not highlight the theory of microbial evolution which advocates the roles of genome as to a coherent group of genes over evolutionary time at some arbitrary degree of **rRNA** similarity.

9.1.1.2 Evolutionary Process Behind the Origin of New Species

Evolution dealing with changes and relationships results in the creation of new species **which** is originated after the splitting of the existing population. The living world not being a static one gives rise to newer creation (species) with the vanishing of others. The possibilities for divergence and evolution are supposed to be higher and rapid in those animal populations where large numbers of offsprings with comparatively smaller-sized individuals are produced in comparison to those which produce fewer numbers and comparatively large-sized individuals having long span of life. The small populations, after being isolated geographically or ecologically, and the genetic variation coupled with selection play more effective roles in bringing about speciation in small community. Therefore, some groups show more species than others. For example, any insect population is having more individuals than a population of birds. The evolutionary processes responsible for the division, divergence, and evolution are the migration, habitat fragmentation, isolation, mutation, genetic drifts, and natural selection. Although animals with more fecundity coupled with shorter longivity have more possibility for evolution than animals with less fecundity and greater longevity, evolution must take longer, and environmental changes must be slower for such animals to the later category of animals to adapt themselves more efficiently. Evolution of species occurs continually and gradually by the agglomeration of so many small changes mainly orchestrated by the genetic shufflings and subsequent filtering by the natural processes. More specialized animals such as many of the mammals are capable of reaching to dominant positions in various habitats within certain period of time but are unable to face the radical changes causing their large-scale mortality.

9.1.2 Traditional vs Modern Mode of Classification

Traditional taxonomic schemes have distinguished among organisms using behavior, metabolic characteristics, and morphology. Traditional taxonomic classifications at the broadest level (kingdom and phylum) are probably not completely natural, and more research is necessary to untangle these evolutionary relationships. Modern approach in turn does not rely mainly on morphotaxonomical characteristics, but instead dependent on molecular, biochemical, and ecological methods.

9.1.2.1 Molecular Assessment Methods for Microbial Diversity in Natural Environments

Microbial ecologists have developed a variety of techniques to identify and determine the taxonomic and ecological status of species that are present in the natural environment along with the assessment of their rates of gene expression. Gene sequences for a tiny subunit of ribosomal **RNA (SSU rRNA, 16S rRNA)** can be extracted from very small samples. Ribosomes, an important cell organelle, function to synthesize proteins and the genetic code for ribosomal structure remains constant and very similar across the whole tree of life an representing **"highly conserved"** properties.

The desired fractions of ribosomal sequence (common with all microbial species) are being used as the **"primer"** of a polymerase chain reaction (**PCR**) for exponentially multiplying the number of replica of the identified **rRNA** genes, which are subsequently sequenced with standard methods. The **PCR** reaction is initiated with the breaking (denaturing) of **DNA** strands into two after increasing the ambient temperature followed by resynthesizing the complementary strands from each half of the two stranded molecules. Repetition of such breaking and synthesis considerably multiplies the newly formed copies of **DNA** from a very small sample. However, some demerits of this method lie with the possibility of biasness in taxonomic identification, the possibility of contamination, and the non-availability of most acceptable primers having universal acceptability for the complementation of the respective sequences common to all organisms (Forney et al. 2004).

After the success of exact amplification of pool **16S rRNA** "identity" genes from a mixed environmental sample, **DNA** fingerprinting techniques were discovered and applied for the appropriate monitoring and assessment of diversity. This molecular technique involves the amplification of subunit **rRNA** genes with **PCR** from a complex community, instead of separating them with regard to their sequence composition, thereby creating a "**fingerprint**" of the taxonomic characteristics of the sample. The desired goals of this method are achieved with the application of denaturing gradient gel electrophoresis (**DGGE**) or terminal restriction fragment length polymorphism (**T-RFLP**). The **DGGE** depends on a gel which possesses a chemical gradient that triggers the increased denaturation of the molecules in the process of their migration through the charged gel. A diversity of molecular and biochemical entities can be ascertained because of their of migration to different distances through the gel.

On staining the resulting bands of **DNA**, a ladder-like configuration of **DNA** helix is revealed that reflects diversity of the genomes. Terminal restriction fragment length polymorphism uses restriction enzymes, enzymes that cut **DNA** helix at specific sequences, in order to produce several smaller **DNA** fragments that are liable to be separated by gel electrophoresis. Owing to the prevalence of phylogenetic variations, **DNA** fragments exhibit different lengths in **DNA** sequences.

Analyzing of restriction polymorphism with a gel also result a pattern of bands, commonly designated as a "**fingerprint**," decoding of which enables to develop understanding on taxonomic composition of organisms, especially on diverse microbial communities. It also appears to be possible for separating the functional genes by combined application of targeted **PCR** of environmental genes and fingerprinting techniques. These methods applicable to eukaryotic species hold great promise in the pinpointed determination taxonomic identity of species.

9.1.3 Major Taxonomic Groups: Based on Molecular to Macro-anatomical Features

Three major groups of organisms have been proposed at the broadest level of classification: the Eukarya (eukaryotes), the Bacteria, and the Archaea (Woese et al. 1990). The Bacteria and Archaea were known formerly as the Prokaryota. Prior to the discovery of microscopic and chemical assessment techniques, unique cellular composition of bacteria could not be recognized, and during that period, organisms were classified only as animals (mobile) or plants (sedentary and green). After the establishment of light microscopy, the classification dividing organisms into animal and plant groups became difficult because many microbes were found to exhibit photosynthetic, motile, and sometimes simple behaviors (attraction to light or food).

The observation of those diverse microbial lifestyles obscured conventional distinctiveness between animals and plants. Invention of electron microscopy allowed definitive differentiation between organisms with complex inner architecture (eukaryotes) and those with more simple cells (then called prokaryotes). Recently, analysis of **rRNA** and other biological molecules has revealed that the Archaea originated from the Eukarya shortly (relative to the **4**-billion-year-old Earth) on their divergence from the Bacteria. Such analyses have also recommended the assignment of the status of super kingdoms instead of the traditional kingdoms for the Archaea, Bacteria, and Eukarya (Woese et al. 1990).

9.1.4 Classification Based on Nutritional Abilities

In the domain of aquatic ecology, taxonomy of organisms is based not only on phylogenetic relationships but also on their functional roles in communities and ecosystems. Organisms can be autotrophic (**self-feeding**) relying on carbon dioxide (**CO_2**) as the primary source of carbon to build cells in contrast to those of other heterotrophic organisms feeding on other organisms (predation, herbivory, parasitism, etc.) to acquire carbon (dissolved or particulate organic compounds or dead organisms) for cells from organic carbon. Some organisms also use both autotrophic and heterotrophic processes to obtain carbon. Heterotrophs that decompose organic carbon are sometimes called saprophytes or detritivores.

9.1.5 Classification of Organisms Based on Function Roles

A variety of additional classifications are used to describe the functional roles of organisms in aquatic food webs which are designated as functional feeding groups (Cummins 1973). Organisms that sieve particles from the water column are called filterers. Organisms that build nets or have morphological features that filter particles out of flowing waters are passive filterers, whereas those that actively pump water or create currents are active filterers. Aquatic organisms, mostly benthic fauna that acquire their nutrition from small organic particles, are called collectors. Shredders break up larger organic materials like decaying leaves for their nutrition, and scrapers remove biofilms from hard benthic substrata.

Functional feeding groups are somewhat similar to guilds, the concept based on which highlights organisms using the same resource in the same fashion (Root 1967). Members of the same functional group may use different resources. For example, some shredders may feed on decomposing leaves, whereas other shredders may feed on decomposing or living aquatic plants, but they all shred large organic materials. Functional and guild analyses can be more relevant than taxonomic considerations for relating organisms to ecosystem processes like nutrient cycling and energy flow. Consumers are often classified further by their position in the food web. For example, grazers or herbivores (primary consumers) eat algae, plants, or sometimes bacteria (primary producers). Carnivores or secondary consumers eat other animals, and top carnivores eat animals but are generally eaten by no larger animal. Thus, classification schemes based on modes of obtaining nutrition are one of the many ways to classify organisms.

9.1.6 Classification of Aquatic Organisms Based on Their Habitats

Additionally, organisms may be classified by the habitat they occupy (**Table 8.1**). Such classification can become useful as it allows an investigator to make predictions about abiotic and biotic conditions important to organisms. Aquatic organisms are broadly classified into two categories – first one exclusively live in water throughout their life span, and others require both water and sediments for their survival. The true aquatic one is known as pelagic while the latter one as benthic organisms.

The pelagic organisms are further classified as plankton (floating organisms) that requires the help of water movement for their own change of position and nekton that represents the free-floating animals (fish). Planktons are further classified as zooplankton (animals) and phytoplankton (plants) based on their ability to undertake nutrition. The benthic fauna in accordance with their sizes are distinguished as macrobenthos, meiobenthos, and microbenthos.

Macrophytes are large plants residing both in the water column and water–soil interphase of aquatic ecosystem. Microphytes are always in need of water, representing mostly the microscopic plants. Besides, another important category of organisms is present mostly in freshwater system, termed as periphyton, where organisms, both plants and animals, present remain attached with the hard structures within the water bodies.

9.1.7 Classification of Organisms Based on Species Interactions

Based on the types of interactions among themselves (interspecific interactions), organisms can also be classified into different categories in tune with different types of interaction schemes such as direct and indirect interactions (**Table 8.2**). Direct interactions occur between individuals of two species and involve no other; indirect interactions are mediated by other species. Exploitation is a general term for an interaction that harms one species and helps another. This term is not widely accepted yet, but includes interactions that may not be formally considered predation or parasitism. For example, an epiphyte that harms a macrophyte but receives benefit from living on its leaves is exploiting the plant. Mutualism is used to denote any positive reciprocal interaction. Others have used various terms to denote mutualism, including symbiosis, synergism, and protocooperation. Symbiosis highlights a close relationship instead of the active mode of interactions in between species, whereas synergism and protocooperation have not received widespread use outside of studies of animal behavior. Of all the interaction types found in macroscopic ecological communities, commensalism (positive on one, none on the other) and amensalism (negative on one, but no effect on the other) are likely the most common, followed by exploitation and then competition and mutualism (assuming that positive interactions are as likely as negative interactions (Dodds 1997; Dodds and Nelson, 2006)). In general, commensalism and amensalism have received almost no attention in the ecological literature; predation has received the most, followed by competition and mutualism.

9.1.8 Classification of Organisms Based on the Power of Tolerances of Ecological Parameters

The successful settlement and survival of a species within a community are controlled by a number of ecological factors which operate independently in association with one another, forming complex ecological conditions. Any factor or condition that exceeds the limits of tolerance is designated as limiting factor. Under stable conditions, the essential constituent available in amounts most closely approaching the minimum need to be the limiting one, a concept termed **Liebig's law** of the minimum. This has led to develop the concept of limits of tolerance which highlights and stresses upon the limiting effect of maximum as well as minimum constituents on diversity and distribution of organisms. This has been elaborately explained by the theory, known as **Shelford's law of tolerance** (Shelford 1913). Based on the discussion on **Liebig's law of minimum** and **Shelford's law of tolerance**, a good number of terminologies have surfaced for the general use in the subject ecology that use the prefixes **steno**- meaning "**narrow**" and **eury**- meaning "**wide**" **(Tables 8.1 and 8.2 and Fig. 8.1)** which are as follows:

1) **Steno and eurythermal:** Narrow and wide range of tolerance of temperature
2) **Stenohaline-euryhaline**: Narrow and wide range of tolerance of salinity
3) **Stenoecious-euryecious**: Narrow and wide range of tolerance of habitats

A tolerance model proposed by Connell and Slayter (1977) advocates that a species may invade a new habitat and becomes established within it independently irrespective of the presence or absence of other species. Some traditional and well-established marine species, such as sponges and jellyfish, are often encountered in small numbers from freshwater habitats. Some freshwater invertebrates (aquatic insects, arachnids, etc.) are considered as secondarily aquatic organisms after having evolution from the terrestrial forms which were earlier evolved from the marine ancestors. Secondarily adapted aquatic organisms colonized and adapted to freshwater habitats by possessing specialized morphological or physiological features that reflect their terrestrial ancestry. For example, aquatic insects mostly adapted to terrestrial system for their respiration with spiracles, trachea, etc., breathe in atmospheric air, and spend the bulk of their time underwater with some modifications of their morphoanatominal features to suit for aquatic environment.

9.1.9 Assessment of the Diversity and Assemblages of Freshwater Fauna

Invertebrates representing the most fascinating freshwater organisms by virtue of their abundance, diversity, and adaptive flexibility enjoy a diversified ecological niche and habitats in any freshwater ecosystems (Chakraborty et al. 2005). This group of living organism displays astonishing form of diversity of body forms, life cycles, and behaviors among all other aquatic fauna and flora. Owing to their abundance, diversity, and relatively fast growth rates among individuals and population, invertebrates have become ecologically very sensitive and productive in freshwater habitats, with the regulating effects on other groups of organisms (Wallace and Webster 1996; Thorp and Covich 2001; Dodds et al. 2004).

However, identification up to species level of several rare but interesting taxa along with larval forms of many known invertebrates poses real difficulty because of the lack of proper taxonomic keys. Vertebrates also depict higher abundance and diversity in freshwater habitats, although the major share of such diversity is made for only one group, the bony fishes (superclass Osteichthyes). However, most of the vertebrates those abound primarily in the freshwater environment are fishes, whereas other higher animal groups such as birds and mammals are partially aquatic. Some other vertebrate groups (frogs and salamanders) exhibit biphasic amphibious life cycles; a part of their lives is spent in water and the rest on lands.

Identification of vertebrates has appeared easier than invertebrates because the former are represented by fewer and larger animals, but still identification of species such as small-sized fishes (some minnows and darters) and larval forms of amphibians requires competency and expertise.

9.1.10 Assessment of Floral Assemblages in Freshwater River Ecosystem

Many plants in aquatic systems have been well characterized. Emergent wetland species generally are included in traditional plant taxonomic references (Michael 1968; Smith 1977; Sharma (1983, 1992, 1993, 1998); Pradhan & Chakraborty (2008); Halder Mallick and Chakraborty (2014); Halder et al. (2007); Sharma and Sharma (2010); Sharma et al. (1999); Sharma and Saini, (2016); Sinha (1992); Sladecek (1995); Suther et al. (2009). For more obscure mosses and liverworts, identification is more difficult, and even some larger groups such as sedges can be problematic to identify. Truly aquatic plants are only moderately diverse; and they not only act as an important structural component of the ecosystem but profusely contribute towards ecosystem function (Riemer 1984).

9.2 Analysis of Biotic Community: Types and Analysis

Biodiversity of an ecosystem is being recorded and quantified just by observing and counting taxa and estimating their frequency. These strategies typically distinguish estimating between alpha and beta diversities. The **alpha (α) diversity** was introduced by **R.H. Whittaker** in the year 1972 who referred it as the mean species diversity within the habitats at a local scale or within a particular habitat patch with its local taxon richness (usually species richness) and the number of taxa found in the community, weighted by abundance. A system with one very numerous species and a few rare ones is less alpha diverse than one in which the species are equally abundant. The **beta (β) diversity** is the variation of the species composition between two habitats. It takes into account the alpha diversity of the habitats and the number of unique species on each habitat. Beta diversity (and its relatives) is very important to conservation planning, because that planning typically involves the selection of an ensemble of sites to maximize the overall protection of biodiversity. The **gamma diversity** refers to the overall diversity for different ecosystems within the region, and therefore, it can be projected as the product of both alpha and beta diversities. The difference between one community and others already protected is often as important as the intrinsic richness of a community. The information about species richness on combining the information of abundance makes the way of calculating the Shannon Wiener Diversity Index and Simpson's Index.

9.2.1 Analysis of Different Biotic Indices

9.2.1.1 Deduction of Different Community Indices

Effect of environmental factors was assessed by comparing the community structure of different mollusks from different study sites. A community is a naturally occurring and interacting assemblage of plants and animals inhabiting in the same habitat in order to fix, utilize, and transfer energy to maintain the ecological stability of an ecosystem. Community structure analysis includes the following:

(a) **Relative abundance**: **Relative abundance (RA)** of different species in the community was determined by using the following expressions:

Relative Abundance (RA) = ni/N × 100 where ni = total number of individuals of in the species and N = total number of individuals of all the species. Dominance of species was ascertained on the basis of relative abundance. Species with RA, exceeding **5%**, were regarded as dominants, those between **2.5%** as subdominant, and remaining species as rare.

(b) **The species rank abundance (SRA)**: The species were ranked in order of abundance. The most numerically abundant species is ranked as one (Shaw et al. 1983).

Some additional analysis such as index of dominance (Simpson 1949), index of similarity (Odum 1950; Sorensen 1984) in between the study sites, species richness index or variety index (Menhinick 1964), species diversity index (Shannon and Weaver 1949), and species evenness index (Pielow 1966) are studied by using the following expressions:

(c) **Index of dominance (C) = $((ni/N)^2$ where ni = importance value for each species (number of individual) and N = total of importance value.**

(d) **Species richness or variety index (d) = $S/\sqrt{N}$ Or (d = SI/LnN) where S = number of species and N = total number of all species.**

(e) **Species diversity index (H^{-}) = − (Pi log Pi = − ((ni/N) log (ni/N) where ni = importance value for each species; N = total of importance values; and Pi = importance probability for each species (ni/N).**

According to Wilhm and Dorris (1966), when the value of diversity index exceeds **3** (>3), the quality of water would be clean; when this values ranged from **1** to **3**, the water quality would be moderately polluted; and when it is less than 1 (<**1**), the quality of water would be grossly polluted.

(f) **Evenness index (e) = H¯/log S where H¯ = diversity index and S = number of species.**

(g) **Index of similarity (%S) = where A = number of species in one study site; B = number of species in another study site; and C = number of species common to both study sites.**

9.2.2 Cluster Analysis: A Statistical Tool to Visualize the Relationship

Single-linkage clustering technique is the simplest form of hierarchical and agglomerative cluster analysis. This analysis is based on a matrix of similarity coefficients (Krebs 1999). The method is initiated to identify most similar pairs of samples, which are considered as the first cluster, and thereafter to determine the second most similar pair of samples or cluster having the highest similarity between a sample and the first cluster, whichever is greater. The cycle has to be repeated in steps until the samples reach to one big cluster.

9.2.3 MANOVA: Modified Form of ANOVA – Duncan Test

Multivariate analysis of variance (MANOVA) at **5%** level of significance is used to test the seasonal variation in overall species composition of biotic community, whereas analysis of variance (**ANOVA**) is computed to test for significant difference (P < **0.05**) of environmental parameters.

Duncan's post hoc tests are employed to check the differences in the abundance of individual species and physicochemical parameters among the seasons. **Analysis of similarities (ANOSIM)** is performed to find out the existing significant differences among the constituent species in a biotic community in different seasons. Similarity percentage analysis (**SIMPER**) is usually made to observe the percentage of similarity and percentage of major contributing species among seasons.

Nonmetric multidimensional scaling (nMDS) is done to allocate the similarity among the seasons in terms of species abundance with log**10** (1 + x) transformed data. For the assessment of the environment influence on biotic community structure, the Biota and Environmental Matching Routine (**BIOENV**) package is used to determine the best match between multivariate constituent species abundance pattern and ecological parameters such as temperature, **pH**, dissolved oxygen, salinity, alkalinity, etc. All ecological parameters are to be subjected square-root transformation and standardization before analysis. The best matches of biological and environmental parameters are measured using the **Spearman rank correlation**

coefficient. **Canonical correspondence analysis (CCA)** is calculated to find out the association between species and physicochemical parameters using the software **PAST** 3 (Paleontological Statistics).

9.2.4 Estimation of Different Heavy Metal Indices

9.2.4.1 Determination of Contamination Factor (CF)

Contamination factor (CF) for each metal was determined as

$$\mathbf{CF = Observed\ metal\ concentration\ (Cn)/Background\ concentration\ of\ the\ same\ metal\ (Bn)}.$$

9.2.4.2 Deduction of Pollution Load Index (PLI)

Pollution load index for each site for ecological study is calculated by the method and equation proposed by Tomlinson et al. (1980):

$$\mathbf{PLI} = \sqrt[n]{(\boldsymbol{CF1} \times \boldsymbol{CF2} \times \ldots\ldots.. \times \boldsymbol{CFn})}$$

where **CF** refers to the contamination factor and n is the number of parameters.

9.2.4.3 Calculation of Geoaccumulation Index (I_{geo})

The value of **geoaccumulation index (I_{geo})** for each metal is determined following Muller (1979):

$$I_{geo} = \log_2 \mathrm{C_n}/1.5 \times \mathrm{B_n}$$

where **Cn** is the observed concentration of metal in the sediment, **Bn** is the geochemical background concentration of that metal, and **1.5** is the correction factor for the background matrix due to lithogenic effect.

9.3 Biotic Indices and Their Applicability in the Assessment of Ecological Changes

A biotic index takes account the sensitivity of tolerance of individual species or groups to pollution and assigns them a value, the sum of which gives an index of pollution for a site (Gfetil and Ravera 1994; Karr (1981); Karr (1991); Karr (1999);

Sharma, 2001; Pradhan and Chakraborty, 2008; Lange and Lange, 1997; Kwok et al. 2007). The data may be qualitative (presence–absence) or quantitative (relative abundance or absolute density). These indices are deducted mainly to evaluate the organic pollution caused by organic pollutants. The saprobien system devised by Kolkwitz, 1935; Kolkwitz and Marsson, 1902 and Kolkwitz and Marsson (1908) is the earliest biotic index.

Polysaprobic, a-mesosaprobic, ß-mesosaprobic, and oligosaprobic zones from the higher organic enrichment to decreasing state in river are demarcated based on the intensity of pollutants and also by virtue of the trend of occurrences (the presence or absence) of indicator species in the said zones. Pantle and Buck (1995) also had developed the saprobien system by emphasizing the relative abundance of organisms in a biotic community.

9.3.1 *The Saprobic Index of Pantle and Buck*

Saprobien groups		Relative abundance	
	S value		h value
Oligosaprobic	1	Occurring accidentally	1
β-mesosaprobic	2	Occurring frequently	3
α-mesosaprobic	3	Occurring abundantly	5
Polysaprobic	4		

$$\text{Mean saprobic index } (S) = sh/h$$

1.0–1.5	Oligosaprobic	No pollution
1.5–2.5	β-mesosaprobic	Weak organic pollution
2.5–3.5	α-mesosaprobic	Strong organic pollution
3.5–4.0	Polysaprobic	Very strong organic pollution

In grossly polluted waters, where no macro-invertebrates are present, a **TBI** of zero is obtained. The maximum score in unpolluted water with a species-rich invertebrate fauna is **0**.

9.3.2 *Chandler Biotic Score (CBS)*

According to Chandler Biotic Score (1970), the abundance of organisms within the community, as well as the species richness, is of value in assessing the degree of pollution. This index has five levels of abundance, the score of each indicator species being weighted in relation to its abundance.

If a species, intolerant of pollution, is abundant, it is given a high score (**100**), whereas an abundant, pollution-tolerant species is given a low score (**4**). The allocation of scores is somewhat arbitrary. The lower limit of the score is zero, in which no macro-invertebrates are present, while there is no upper limit.

Comparison of physicochemical monitoring with biological monitoring

S. no:	Characteristics	Physicochemical monitoring	Biological monitoring
1	Pollutant concentration	Good	Poor
2	Assessment of intermittent, irregular pollution discharge	Not possible unless continuously monitored	Possible without continuous monitoring
3	Kind of pollution assessment	Good	Poor
4	Reliability (representation of data)	Poor	Good
5	Measure of ecological effect	Not possible	Possible
6	Monitoring	Relatively high	Relatively low

9.3.3 Advantages of Biological Assessment

1. The biological methods are quite quick and economical and can be integrated with other relevant studies.
2. Much less equipment are required, and large area can be surveyed in less time resulting in large amount of information suitable for assessment.
3. Provide cheaper option in comparison to physicochemical assessment, where chemical analytical equipment, manpower, and operation costs are very high. Biological assessment methods do not eliminate the need for chemical analysis of water samples; however, these may provide information, which may be integrated with physicochemical information. The integration of biological method with physicochemical method may provide a system, which is not too expensive, and generate necessary information with maximum efficiency.

9.3.4 Ecological Information Generated by Biological Assessment

Biological assessment relies on the fact that pollution of water body will cause changes in physicochemical environment of water and that those changes will disrupt the ecological balance of the system. The measure of extent of ecological upset will depict the severity of pollution. The biological systems used as water quality indicators should have the following characteristics:

1) The presence or absence of organisms acts as a function to denote water quality than any other ecological factors.
2) The biological system can be reliably used to assess the trend of changes of water quality, which are expressible in simplified form instead of sufficiently quantifiable level to undertake comparison with other such information.
3) Bio-assessment water quality should be conducted an extended period rather than at the time of sampling alone.
4) Bio-assessment focuses on the point of sampling rather than other watercourse as a whole.

9.3.5 Parametric and Nonparametric: Demystifying the Terms

Parametric and nonparametric represent two broad classifications of statistical procedures.

The most comprehensive, brief, and simple but universally acceptable definition of the term "**nonparametric**" is still wanting. It holds some general assumptions that are satisfied to a reasonable approximation. Parametric tests also rely on assumptions pertaining to the distribution of the underlying population from where the sample was taken.

The most common parametric assumption is that data are approximately normal. Nonparametric statistical procedures do not rely on the assumptions about the structural factors of the representative samples of the population. Although nonparametric tests depend on very few assumptions about the distribution of measurements in the population from which one can draw sample, this procedure suffers from two demerits. The first are with less rankings of the values in the data rather than using the actual data.

9.4 Analysis of Physicochemical Parameters of River Water

9.4.1 Physical Parameters

(i) **Temperature**: Distinct temperature layers exist in aquatic habitats. The metabolic rate of aquatic life increases at higher temperature, leading to the enhancement of dissolved oxygen (Saha et al. 2001). Temperature of the water sample was measured by mercury thermometer having **0.1**°C graduation.
(ii) **pH**: **pH** is defined as the negative of the logarithm to base 10 of the hydrogen concentration. Odum (1971) reported that water with low pH was found deficient in nutrients. pH of the water was calculated using Griph pH meter that was calibrated with pH buffer **4.0** and **7.0** before use. It consisted of glass membrane electrode.

The clean electrode was immersed into **100** ml beaker full of water sample. The solution was stirred, and the reading is taken after stabilization for about 2 minutes.

(iii) **Transparency:** Transparency is an expression of optical property. This was determined using **Secchi disc method**. It consists of a circular iron plate having **20** cm diameter with the surface painted with alternate black and white (Michael 1984).

Secchi disc transparency is expressed in centimeters. Initially the disc has been dipped slowly into the water until it just disappears. This depth was measured by noting the length of the rope (**L1**). Then the disc is lowered further down and slowly raises it until it reappears. This depth was measured (**L2**). Final disc depth was measured from the average of these two readings. This procedure was repeated thrice.

Transparency was measured using the following expression:

Secchi disc transparency (cm) = A + B/2

where **"A"** is depth in cm where **Secchi disc** disappears and **"B"** is depth in cm where Secchi disc reappears.

(iv) **Carbonate alkalinity**: The capacity of water to neutralize a strong acid is known as alkalinity.

(v) **Total alkalinity**: It is estimated by titrating the water sample with strong acid (**HCl**) using phenolphthalein indicator at high **pH** (**7** to **8**) and using methyl orange indicator at low **pH** (**4** to **5**). **100** ml of water sample was taken for each study (APHA 2005). From the titration values, the total alkalinity was calculated using the following equation:

$$\mathbf{TA}\ \text{as}\ \mathbf{CaCO_3},\ \mathbf{mg/l} = \frac{(\text{ml}\times\text{Normality})\ \text{of}\ \mathbf{HCl}\times 1000\times 50}{\text{ml of sample}}$$

(vi) **Calcium hardness**: Calcium hardness is determined with **EDTA.**

When the **pH** was adjusted to **12** by addition of 1 (**N**) NaOH, magnesium is precipitated as magnesium hydroxide. The Murexide indicator is used which indicates the end point by showing the sharp color change from pink to purple (APHA 2005; Trivedy and Goel 1984):

$$\text{Free}\ \mathbf{CO_2},\ \text{mg/l} = \frac{(\text{ml}\times\text{N})\ \text{of}\ \mathbf{NaOH}\times 1000\times 44}{\text{ml sample}}$$

(vii) **Magnesium hardness**: Magnesium hardness is the difference between total hardness and calcium hardness.

Magnesium hardness as $CaCO_3$ (mg/l) = Total hardness as $CaCO_3$ – Calcium hardness as $CaCO_3$

(viii) **Conductivity**: Conductivity is the capacity of the water to conduct electricity. It is an indirect measure of salt concentration, and it depends upon the level of ions and nutritional status. The conductivity of the water sample is measured using "**digital conductivity meter**" (Systronics Type 304) by dipping the conductivity cell in the sample contained in the beaker. At the time of measurement, the temperature of the sample is also noted. Conductivity is expressed in **μ** mho/cm.

The recent unit of conductivity has been named as Siemens **(S)** instead of mho.

(ix) **Total dissolved solid (TDS)**: The total amount of dissolved chemical species in water is called total dissolved solids. In general, freshwater has less than 1500 mg/l of **TDS** (Trivedy and Goel 1984).

(x) **Total dissolved solids (TDS)** are determined initially as the residue left after the evaporation of the filtered sample. Then the **250** ml water sample is filtered through **GF/C** filter paper and evaporated at **103** °C. **TDS** is measured in **gm/l**:

$$\mathbf{TDS}(\mathrm{gm/l}) = \frac{\mathrm{A - B \times 1000}}{\textbf{volume of sample taken (ml)}}$$

where, **A** = Final weight of the dish in **gm** and **B** = Initial weight of the dish in gm.

(xi) **Total suspended solid (TSS)**: Total suspended solids are the solids present in a suspended state in water. **TSS** is calculated using the following equation:

$$\mathbf{TSS}\ \text{in}\ \mathbf{mg}/\mathrm{l} = \frac{\mathrm{A - B \times 1000}}{\text{volume of sample}}$$

where, **A** = Final weight of filter paper and **B** = Initial weight of the paper before filtration.

9.4.2 Chemical Parameters

9.4.2.1 Organic Parameters

Dissolved Oxygen

It is measured using Winkler's iodometric method, the procedure of which is first conceived and established in the year **1988** by L.W. Winkler, in Hungary.

In this method, the oxidation of manganous hydroxide (bivalent form of manganese) is oxidized by the dissolved oxygen in the water, leading to the formation of tetravalent compound, the acidification of which liberates free iodine because of the oxidation of potassium iodide. Prior to that, a white precipitation of manganous hydroxide is formed out of the reactions of manganous sulfate with the alkaline iodide solution, which immediately gets oxidized by oxygen to a brown color compound.

The amount of free iodine, chemically equivalent to the amount of dissolved oxygen, is determined by titration with a standard solution of sodium thiosulfate (**0.005** M) using starch as an indicator. The water sample is filled in a **100** ml glass stoppered bottle avoiding any kind of bubbling. Then **1** ml of each $\mathbf{MnSO_4}$ and alkaline **KI** solution is added to it. The solution is shaking well. Then **2** ml of concentrated $\mathbf{H_2\ SO_4}$ is added to dissolve the precipitate.

50 ml of the solution is taken for titration. It is titrated against sodium thiosulfate solution using starch as an indicator. At the end point, initial dark blue color changes to colorless. Chemical reactions are as follows:

$$\mathbf{MnSO_4 + 2KOH = Mn\ (OH_2) + K_2SO_4; Mn(OH)_2 + O_2 = 2MnO(OH)_2}$$

$$\mathbf{2MnO(OH)_2 + 4H_22SO_4 = 2Mn(SO_4) + 6H_2O}$$

The number of moles of iodine liberated by this reaction is equivalent to the numbers of moles of oxygen present in the sample. The quantity of iodine is determined by titrating a portion of the solution with a standard solution of sodium thiosulfate:

$$\mathbf{2MnO\ (SO_4) + 4KI = 2MNSO_4 + 2K_22SO_4 + 2I_2}$$

$$\mathbf{4Na_2\ S_2O_3 + 2I_2 = 2Na_2S_4O_6 + 4NaI}$$

$$\text{Dissloved Oxygen (in mg/l)} = \frac{\textbf{Volumer of } \mathbf{Na_2S_2O_3} \textbf{ used for titration (in ml)} \times \mathbf{N(Na_2S_2O_3) \times 8 \times 1000}}{\textbf{Volume of sample taken for titration (in ml)}}$$

where N = **Normality of thisosulfate**
8 = **Equivalent wt of oxygen**.

Chemical Oxygen Demand (COD)
COD of the water sample is determined using titrimetric method. **20** ml of water sample is taken in a **250** ml of **COD** flask. **10** ml of **0.025** N potassium dichromate solutions is added.

A pinch of $\mathbf{Ag_2SO_4}$ and $\mathbf{HgSO_4}$ is also added which was followed by **30** ml of $\mathbf{H_2SO_4}$. Then the solution was refluxed for **2** h. The solution is cooled. Finally, it is titrated with **0.1** N ferrous ammonium sulfate in presence of Ferroin indicator (Trivedy and Goel 1984). The blank test is performed. It is measured using the following equation:

$$\mathbf{COD, mg/l} = \frac{(\boldsymbol{b} - \boldsymbol{a}) \times \mathbf{N\ \ of\ \ K_2Cr_2O_7 \times 1000 \times 8}}{\mathbf{sample\ \ volume\ \ (ml)}}$$

where **a** = ml of titrant with sample
b = ml of titrant with blank.

Biochemical Oxygen Demand (BOD)
Biochemical oxygen demand (**BOD**) is estimated as mentioned in following method:

In this method, three oxygen bottles were filled with water to be analyzed. All three bottles were numbered. To the first bottle, Winkler's reagent is added immediately on collection. Two other bottles are stopped without trapping any air bubbles. These untreated bottles are placed in the dark in an incubator at **20** °C and incubated for **5** days. It is calculated by measuring the difference of the dissolved oxygen concentration between the sample and after incubating it for **5** days at **20** °C.

9.4.2.2 Inorganic Parameters

Total Kjeldahl Nitrogen

It is estimated by digestion and distillation method (Trivedy and Goel 1984). **40** ml of water sample is taken in Kjeldahl flask for digestion. **4** ml of conc. $\mathbf{H_2SO_4}$, **10** drops of $\mathbf{CuSO_4}$, **6** gm of solid $\mathbf{K_2SO_4}$, and **1** ml of **10% NaCl** solution were added in it. The solution was diluted to some extent. Then the distillation is performed. Finally titration is carried out using the distillate with 0.01 NHCl until the color changes from blue to faint pink. This is estimated using the following equation:

$$\text{Kjeldahl Nitraogen (mg/l)} = \frac{(a-b)\times \mathbf{0.01}\times \mathbf{1000}\times \mathbf{14}\times \mathbf{d}}{\textbf{volume of sample distrilled}}$$

where **a** = Volume of **HCl** used with sample
b = Volume of **HCl** used with blank
d = dilution factor.

Phosphate Content

Phosphate is an essential element for the entire living organism.

Total phosphate content in water sample was measured spectrophotometrically (Systronics-**20**). The sample was digested in the presence of **4** ml $\mathbf{H_2SO_4}$, **10** drops $\mathbf{CuSO_4}$ solution, and **6** gm of solid potassium sulfate. The solution was diluted and 1 drop of phenolphthalein was added to it. It was neutralized by titrating with 5 N **NaOH**. At the end point, the solutions turn pink, which disappears after addition of ammonium molybdate. The concentration of phosphorous was determined from the standard curve (Trivedy and Goel 1984).

Chloride Content

Chloride content of the water is an important pollution index.

Higher values of chloride may be attributed because of decomposition of organic matter, whereas the minimum values are due to consumption of ions by the macrophytes (Trivedy and Goel 1984). It was done by titrimetric method involving direct titration of the solution with $\mathbf{AgNO_3}$ (**0.02** N) using $\mathbf{K_2CrO_4}$ as an indicator. The chloride content was calculated using the following equation:

$$\text{Chloride (mg/1)} = \frac{(\textbf{Volume} \times \textbf{Noemality})\ \textbf{of}\ \mathbf{AgNO_3}\ \textbf{required} \times \mathbf{35.5} \times \mathbf{1000}}{\textbf{volume solution taken (ml)}}$$

Salinity

Salinity of the water is determined using the following empirical equation:

$$\textbf{Salinity (g/l)} = \mathbf{0.03} + \mathbf{1.805} \times \textbf{Chlorides (mg/l)}\ \text{(Trivedy and Goel 1984)}$$

9.4.2.3 Microbial Parameters

Coliform (Total and Fecal)

The most probable number of coliforms in a water sample can be estimated using the multiple tube fermentation techniques (Trivedy and Goel 1984). This technique involves inoculating the water sample at several dilutions in a suitable liquid medium. All are placed in an incubator at **35 °C** for **30 min** for at least **48 h**. After the incubation period, they are examined for gas production by coliform organisms. The density of bacteria is calculated on the basis of positive and negative combination of tube using **MPN tables**. Total coliform value is expressed in the form of **MPN/100 ml**. Since the coliforms in water may be derived from the sources other than the fecal, so the separate test for fecal coliform has to be performed. They are supposed to inoculate in lactose and incubate for **24 h** at **44 °C**. Finally the confirmatory test is performed:

$$\mathbf{MPN/100\ \ ml} = \frac{\mathbf{MPN\ \ table\ \ value \times 10}}{\mathbf{starting\ \ dilution}}$$

9.5 Analysis of Bottom Soil Parameters

9.5.1 Soil Temperature (°C)

Using soil thermometer.

9.5.2 pH

pH of soil was determined with the help of a glass electrode digital **pH** meter (**EC**, **pH 5652**) using a **soil/water ratio** of **1:2.5** as proposed by Jackson (1973).

9.5.3 Salinity (o/oo)

The salinity of a soil suspension was determined using Knudson's method (Strickland and Persons 1968).

9.5.4 Organic Carbon o/o

Organic matter of the soil was determined by Walkley and Black's (1934) rapid titration method. The organic matter of the soil was digested with excess of

$\mathbf{K_2Cr_2O_7}$ and $\mathbf{H_2SO_4}$**.** The residual unutilized matter ($\mathbf{K_2Cr_2O_7}$) was then titrated against ferrous ammonium sulfate.

Calculation was made using the formula:

$$\mathbf{o/o\ \ Organic\ \ Carbon} = \frac{\mathbf{3.951}}{\boldsymbol{gm}}(\mathbf{1 - T/S})$$

where

gm = wt. of sample.
S = ml of ferrous solution with blank titration
T = ml of ferrous solution with sample solution

9.5.5 Soil Texture (^{o}/o)

Textural composition of soils was estimated by means of mechanical analysis following standard methods (Black 1965; Jackson 1967; Strickland and Parsons 1968). For textural analysis, **20 gm** of shade dried sample was first digested with **6%** $\mathbf{H_2O_2}$, till the sample was free of organic matter.

The soil was then treated with dilute **HCl** to remove the free calcium carbonate and washed and shaken thoroughly with **NaOH** to bring complete dispersion. The suspension was transferred to a **1000 ml** cylinder. After **4** min, **20 ml** of sample was pipetted out from **10 cm depth** and dried to constant weight to obtain the weight of silt and clay (**X gms.**).

The pipetting was repeated in similar manner after **6 h** to get the weight of clay alone (**Y gms.**).

$$\mathbf{Chloride\ \ (mg/l)} = \frac{\mathbf{(Volume \times Normality)\ \ of\ \ AgNO_3\ \ required \times 35.5 \times 1000}}{\mathbf{volume\ \ of\ \ solution\ \ taken\ \ (ml)}}$$

Percentage of sand, silt, and clay in the soil was determined by using the following calculation:

$$\mathbf{\%\ \ of\ \ clay = Y \times 250}$$
$$\mathbf{\%\ \ of\ \ slit = (X - Y) \times 250}$$
$$\mathbf{\%\ \ of\ \ sand = 100 - (X \times 250)}$$

9.6 Eco-monitoring and Biomonitoring a Tool for Eco-assessment of Ecosystem Health

In view of the ongoing perturbations and eco-degradations in most of the ecosystems of the world, the ecosystem health is being assessed in respect of the community structure (species richness, species composition, food chains and food webs, trophic interactions, etc.) and ecosystem functioning (productivity, energy flows, nutrients cycling, etc.). Eco-management strategies are designed and executed giving due importance to the existing human perceptions and actions, state of community structure, and ecosystem functioning and management response (Fairweather 1999). Identification and application of some ecological indicators have been found to contribute better diagnosis of the environmental problems so that effective steps can be taken to combat the deteriorating ecosystem health (Stark 1993; Chakraborty et al. 2005; Maity et al. 2013; Chakraborty et al. 2021).

The concept of ecosystem health of rivers, after being enunciated as a social construct, can be evaluated in a number of ways, starting from the assessment of abiotic interactions and resultant processes (nutrient budgeting and sedimentation processes), ecodynamics of species interactions and flows of matters and energy, and proper realization of societal expectations and involvement. A healthy ecosystem is one that the community believes to be healthy, and different social groups hold different views and ideas about this (an angler is satisfied on getting preferred fish species, peoples regularly taking baths are happy if they do not develop any diseases, etc.) (Begon et al. 2006).

Environmental monitoring is meant for programed process of measurement and collection of information about the existing status of environment and can be done by physicochemical and biological methods. Physicochemical monitoring deals with quantitative estimation of physical and chemical parameters of environment. On the other hand, employing of biological parameters for assessing environmental perturbation is termed as biomonitoring. The appropriate monitoring systems are required to recognize and predict the ecological changes caused by human-mediated hazardous activities. As life is the best indicator of environment, several biomonitoring methods have been devised using biological criteria for successfully predicting the impact of several human activities, especially the human-contributed pollutants, well in advance since they present effective and reliable method of evaluating the effect of all those unwanted substances on living organisms. Biomonitoring of the environment is possible by studying the mode of responses of living organisms against the ecological changes (bioindicator species), and their constituent biochemical and molecular components (biomarkers) represent biomonitoring (Sanyal et al. 2015). Employing of biological parameters for assessing environmental perturbation is termed as biomonitoring which has now become a growing subject for research to assess pollution (Bartram and Balance 1996).

Biomonitoring of aquatic ecosystems through the evaluation of biodiversity and their interaction in the natural habitat is one of the important tools for monitoring ecosystem health. The use of indicator organisms in the assessment of water quality depends upon an in-depth knowledge of the ecological tolerance of the concerned organisms. A biological indicator representing a useful biological measure is sensitive enough and can be used for diagnosis, control, prevention, and reclamation. Biomonitoring, the systematic use of living organisms for the assessment of ecological changes, includes several ecological bio-criteria such as molecular, population, community, and ecosystem. This mode of eco-assessment generates complete spectrum of information on holistic water resource management in riverine system. However, the changes in lotic aquatic ecosystems characterized by rapid eco-hydrological variabilities pose difficulty in estimating those parameters, as they cannot reflect the integration of various environmental factors and long-term sustainability of river ecosystems because of their instantaneous nature (Pradhan et al. 2003; Sanyal et al. 2015).

A water quality index (**WQI**) is a numeric expression used to evaluate the quality of a given water body. It is a technique which provides a single number that expresses overall water quality at a certain location and time based on several water quality parameters:

$$\mathbf{SPV} = \frac{\sum_{i=1}^{n}\left(\mathbf{log}^{\mathbf{10\ Pb/n}}\right)}{\mathbf{N}}$$

where

SPV is species pollution values.
Pb is comprehensive pollution values.
n is the number of chemical parameters,
N is the number of study sites.

$$\mathbf{CPV} = \frac{\sum_{i=1}^{n}\mathbf{SPVi}}{\mathbf{n}}$$

where

CPV is the community pollution value.
n is the number of species in a community.

9.6.1 Initiation and Application of Biological Monitoring Program (BMP)

Realizing the urgent need of biological monitoring, the International Union of Biological Sciences (**IUBS**), in its **XXI** General Assembly, held in Ottawa, Canada, in 1982, decided to initiate a worldwide program for identifying and applying biological indicators in environmental monitoring particularly to evaluate the effects of hazardous substances on ecosystems. These programs are with the following objectives:

1. To encourage environmental researchers and managers to develop, standardize, and apply biomonitoring methods indicative of hazardous substances of the environment
2. To generate baseline information of existing methodology of bioindicators
3. To initiate exchange of experience-based knowledge among several like-minded organizations across the globe
4. To publish reference lists along with relevant research information on bioindicators in forms of papers, brochures, practical manuals, etc. for distribution mostly as awareness building program.
5. To promote interdisciplinary actions and develop international collaboration in standardization and execution of acceptable and agreed methods
6. To encourage the scientific organizations in sharing new results concerned with bioindicators among themselves
7. To organize special regional or international symposia, workshops, and seminars for the sharing and dissemination of knowledge

9.6.2 Selection and Application of Bioindicators for Environmental Monitoring

The term bioindicators encompasses a wide spectrum of organisms serving as indicators of environment by way of using or employing the entire organisms through their presence or absence, or utilizing their phenotype features and physiological uniqueness where any of which can serve as an index of their environmental status. Biomonitoring with a bioindicator indicating the general pollution status of the environment, without throwing any light on the exact physical or chemical factors responsible for such environmental quality deterioration, is to be supplemented with appropriate physical and chemical methods to understand the exact reasons for such happenings.

Therefore, different microbes, plants, animals, cell organelles, organs, individuals, populations, biotic communities, and ecosystems displaying different levels of sensitivity can be successfully employed as ecological indicators (bioindicators) to assess and predict environmental change in a timely manner.

9.6.2.1 Microbial Systems

Microbes being fast detectors of the ecological changes by virtue of their sensitivity specifically to some substances can detect harmful substances and also take part in decomposition of pollutants. Alteration of microbial communities and reduction of species diversity can be the result of the presence of specific toxic agents. Bacteria like *Salmonella typhimurium* and fungi such as *Neurospora* and *Aspergillus* have been proved to be very efficient in monitoring genetic effects of physical and chemical agents. Several bacteria such as *E. coli*, *Vibrio* spp., *Aeromonas* sp., *Pseudomonas*, *Clostridium*, *Streptococcus*, etc. have been used for the assessment and prediction of changes in marine environment induced by human activities. Cyanobacteria are used as bioindicators of soil pesticides. Some filamentous fungi, yeasts, actinomycetes, and bacteria are used to monitor oil pollution (oil spillage).

9.6.2.2 Lower Plants: Fungi and Algae

The susceptibility or resistance towards a hazardous substance in the environment varies with different plants species. For example, lichens act as ideal monitoring agents due to their susceptibility and resistance to different environmental effects. There are some lichens which can thrive only in the unpolluted air, whereas others are resistant even to the most polluted systems. Different species of *Lecanora* act as good indicators of a broad spectrum of environment, while lichen thalli can indicate the presence of $\mathbf{SO_2}$ and fluorine in atmosphere. Lichens are also utilized for survey of long life nuclides like cesium **137** and strontium 30, released from nuclear explosions. Various algae such as *Ulva* and *Enteromorpha* have been used as effective bioindicator in monitoring the water quality of rivers and estuaries. Algal species, such as *Cladophora* and *Stigeoclonium*, have shown their efficiency as indicators of heavy metal pollution of water. Some other algae, such as *Dunaliella tertiolecta*, *Skeletonema costatum*, *Criosphaera carterae*, *Amphidinium carterae*, *Cyclotella cryptica*, *Pavlova lutheri*, etc., have been tested for their efficacies as indicators of oil pollution (oil spillage).

9.6.2.3 Applicability of Animal Systems for Biomonitoring

Individual species of an animal, its different organs, or the whole of the biotic community provide data on the accumulation of toxic persistent chemicals in animals. The bioaccumulation and bio-magnification of nondegradable substances through the food chains ultimately reach to the human beings with magnified toxicity as the top representative of the food web which are indicated by selecting a suitable species for routine study. Fish, zooplankton like daphnia, benthic gastropod, aquatic insects, etc. are used to monitor heavy metal and pesticide pollution levels in water. Zooplanktons as rotifers and cladocerans are used as indicators of freshwaters. Earthworms are good bioindicators of soil radioactive pollution.

9.6.2.4 Molecular Biology and Physiology of Living Organisms for Biomonitoring

Cellular and subcellular components have exhibited their flexibility and adaptability towards specific environmental changes and perturbations, representing an excellent components of bioindicators. Both short- and long-term toxicity experimental protocols have been developed in vitro as well as in vivo to monitor changes caused by different environmental agents. Grover et al. (1985) presented an account of monitoring environmental chemicals by chromosomal aberrations in plants. Many animals manifest behavioral responses against environmental changes after detected by their sense organs. An undesirable chemical of the ecosystem imposes severe threats not only to the species populations but also to several organs (endocrine, renal, cardiac, neural, muscular, and digestive) disrupting their functioning as revealed from the observations of the changed morphological, biochemical, or physiological properties.

9.6.3 Rotifers: The Tiniest Zooplanktonic Fauna as Bioindicator Organisms – A Case Study from the Riverine Networks of Southwest Bengal, India

Detection of pollution status by physicochemical ways is not always easy, but sometimes it appears to be very difficult in the remotest areas and expensive too. According to the International Organization for Standardization (**ISO**), environmental monitoring is meant for programed process for measurement and collection of information about the existing status of environment and can be done by both physicochemical and biological "**methods.**" Biological monitoring being an integral part of water quality monitoring includes two of the following categories:

1. The bioassays (early warning or alarm systems, eco-toxicological tests, bioaccumulation tests, eutrophication tests) that are mostly experimental
2. Bio-assessments (analysis through the biological communities) that are observational in approach

Both in turn are linked to the choice of environmental policy makers concerning the updating of "**water quality criteria**" and "**effluent standards**." Biomonitoring or application of biological variables in environmental monitoring activities has often resulted in different interpretations relating to "**biological variables**" and caused a lot of confusion on "**activities**" relating to these aspects (Zwart and Trivedi 1995). A biological indicator is meant to give a useful biological signals having some dimensions, which may be sensitive enough and can be used for diagnosis, control, prevention, and reclamation (Ghetti and Revera 1994). It is possible to judge the nature and degree of pollution of any water body based on the occurrence, abundance, and composition of the inhabiting particular biotic organisms.

Among different groups of zooplankton, due to high population turnover rates, rotifers have appeared to be the most sensitive to changes in water quality. Their community structure not only allows estimates of the level of pollution but also can indicate the trend of general conditions over time (Sladecek 1983). Rotifera, being an important faunal component of freshwater lotic as well as lentic zooplanktonic community, have attracted the attention of several workers globally, with respect to their significance as bioindicators of water quality and also as an indicator of saprobity (Pradhan et al. 2003).

A study has recorded a total of **46** species of Rotifera from **9** study sites in the freshwater riverine network systems of Southwest Bengal, India, formed by the rivers Dwarkeswar, Shilabati, and Kansai (Pradhan and Chakraborty 2006). All the documented Rotifera species were categorized as per the established scheme for bioindicator species, viz., eutrophic species, oligotrophic species, acidophilic species, mixohaline species, alkaline mesotrophic species, taxa preferring special water, temperate species, worm stenothermal species, cold stenothermal species, and eurythermal species. The physicochemical parameters of different study sites where the rotiferan bioindicator species inhabit were compared with the international standards for permissible limit to find out the relationship between the intensity of pollution and occurrence of rotifers. Rotifera comprised of an important faunal component of littoral and limnetic invertebrate communities in freshwater environments. Rotifera has been considered as good indicators of saprobity (= organic pollution manifested in **BOD5′** dissolved oxygen content and specific communities of indicator species). Hakkari 1972; Radwan 1976; Fuller et al. (1977), Maemets (1983) and Sladecek (1983), advocated for the significance of bioindicator species of in monitoring the water quality, trophic status and environmental toxicity.

In fact, on applying rotiferan zooplankton as bioindicators for the first time, Kolkwitz and Marsoon (1902) set up "**saprobien system**" to define the quality of surface waters mainly on the presence of indicator species, and this system is still wildly used forming the basis for a series of biological indices (De Pauw et al. 1992). Subsequently, Kolkwitz (1935) listed some species as polysaprobic, alpha mesosaprobic, beta-mesosaprobic, and oligosaprobic. Wetzel (1959) listed two polysaprobic species as tamesosaprobic and four species as oligosaprobic. Sladecek (1983) provided an excellent account of **625** species of Rotifera after recording from Czechoslovakia as indicators of water quality making relevant remarks on saprobity, saprobic valence, indicative weight of different species, saprobic index, and pollution. In addition, other notable contributions had dealt the role of Rotifera as bioindicator highlighting their relationships with **pH** (Berzins and Pejler 1987), temperature (Berzins and Pejler 1989a), trophic degree (Berzins and Pejler 1989b), oxygen content (Berzins and Pejler 1989c), water color (Berzins and Pejler 1989d), and substrate and habitat (Pejler and Berzins 1989, Pejler and Berzins 1993; Giri and Chakraborty (2012); Giri et al. (2005); Giri et al. (2008)).

In this study, the temporal and spatial distribution patterns were studied in relation to major ecological parameters pertaining to riverine ecosystem. All the documented Rotifera species were categorized as per the established scheme for bioindicator species, viz., eutrophic species, oligotrophic species, acidophilic species, mixohaline species, alkaline mesotrophic species, taxa preferring special water, temperate species, worm stenothermal species, cold stenothermal species, and eurythermal species. On the basis of observation of diversity index, the range of pollution in rivers and streams can be assigned into three undermentioned categories (Wilhm and Dorris 1968): **H^{-} (Shannon index: condition of water of diversity) >3** clean water; **1–3** moderately polluted, and **<1** heavily polluted. In the present study, the rotiferan population registered a highly significant inverse relationship with water current which corroborated the findings of Reinhard (1931) and Eddy (1934).

Hofmann (1977) opined that temperature exerts a significant influence on population dynamics of rotifer not only because of its direct control on embryonic development but also because it is an important characteristic of the determinative situation of the environment. The correlation between Rotifera and temperature showed also significant positive relationship in most of the study areas. The **pH** governed the distributional transport and fate of heavy metals in an aquatic system (Whitton and Say 1975). The alkaline **pH** was favorable for the growth of aquatic vegetation (Westlake 1975). Comparatively lower **pH** during summer months was supposed to be due to higher decomposition activities of organic matter coupled with higher temperature and lower water depth. In this study, **pH** did not show any definite seasonal trend, and **pH** values ranged from **6.1** to **7.9**, and thus in most cases, it remained to either in acidic or in alkaline range, and Rotifera exhibited both significant and insignificant direct and indirect correlations with **pH** as revealed from correlation coefficient analysis (Giri et al. 2003; Pradhan et al. 2003, 2008; Pradhan and Chakraborty 2006).

According to Berzins and Pejler (1987), **pH** had no direct effect on rotifers even though it appeared to be as an important parameter in explaining the distribution of different species. Besides species-specific study, it was quite difficult to draw any definite trend between different zooplankton groups and **pH**. Species-wise study of different rotifer species revealed that different species displayed different relationships with **pH**. **Alkalinity** of the water by possessing hydroxyl ions capable of combining with the hydrogen ion neutralizes a strong acid (Trivedy and Goel 1984). The species with well-developed lorica such as *Brachionus* and *Keratella* built higher population during the period when the alkalinity was high (Dhanpathi 2000), but in the present observation, although the water conditions were neither acidic nor alkaline, the genus *Brachionus* and *Keratella* exhibited positive relationship with alkalinity. Sharma (1992) stated that the Rotifera fauna of West Bengal included various acidophilic species, **viz**., *K. cochliaris* and *B. patulus*, whereas *B. bidentata*, *B. rubens*, and *Lecane lunaris* have been regarded by him as alkalophilic element. Several indicator species of Rotifera recorded from Indian inland waters were categorized by Sharma (1996). Based on the affinity for specific water bodies following categories of Rotifera have been made.

1. **Eutrophic species**: Those species which are likely to inhabit in highly nutrient-containing water bodies, **viz.**, *Brachionus angularis*, *B. bidentata*, *B. calyciflorus*,

B. caudatus personahis, *B. falcatus*, *B. rubens*, *Keratella tropica*, *Asplanchna priodonta*, *L. curvicornis curvicornis*, *Lecane (Monostyla) bulla*, *L. (M.) lunaris*, *Polyartltra vulgaris*, *Pompholyx sulcata*, and *Filinia longiseta.* Most of these species were designated as eutrophic indicators in India and elsewhere in the world (Sladecek 1983; Saksena 1987; Sharma 1996). Out of these rotiferan species, *Brachionus angularis*, *B. calyciflorus*, *B. rubens*, and *Filinia longiseta* have been reported to inhabit in hypereutrophic water body (Sharma 1996).

2. **Oligotrophic species**: Those species which are likely to inhabit in low nutrient-containing water bodies, **viz.**, *B. falcatus*, *Keratella cochlearis*, *Keratella tropica*, *Lepadella (Lepadella) ovalis*, *L. (L.) leontina*, *L. (L.) nana*, *L. (M.) decipiens*, and *Asplanchna priodonta*.
3. **Acidophilic species**: Those species which are likely to inhabit in acidic water bodies, **viz.**, *B. quadridentatus* and *Ellc allis dilatata*.
4. **Alkaline mesotrophic species**: Those species which are likely to inhabit in alkaline and moderately nutrient-containing water bodies, **viz.**, *Brachionus angularis*, *B. bidentata*, *B. caudatus personatus*, *B. rubens*, *B. calyciflorus*, *B. falcatus*, *B. forficula*, *Keratella tropica*, *Lecane (L.) curvicornis curvicornis*, *Lecane (Monostyla) bulla*, *L. (M.) lunaris*, *Polyartlzra vulgaris*, *Pompholyx sulcata*, and *Filinia longiseta.*
5. **Worm stenothermal species**: Those species which are likely to live in narrow range of worm water, **viz.**, *B. bidentata*, *B. forfiella*, *B. falcatus*, *Keratella tropica*, *Beaucllampiella elldactylota*, and *L. (M.) stenroosi.*
6. **Eurythermal species**: Those species which are like to live in wide range of temperature variation, **viz.**, *Brachionus angularis*, *B. calyciflorus*, *B. rubens*, *Lepadella (Lepadella) ovalis*, *L. (L.) hastate*, and *Polyarthra vulgaris.*

Pejler (1983) mentioned that along a trophic scale, the number of planktonic rotifer species successfully increased up to mesotrophic condition, after which the numbers declined till hypereutrophic phase. On the basis of scales as developed by Wilhm and Dorris (1968), nine different study sites located on three freshwater rivers, through six seasons of two consecutive years, showed Shannon index of diversity of rotiferan community between **1** and **3**. Based on such information, the water of such water bodies can be regarded as moderately polluted (Pradhan and Chakraborty, 2008; Pradhan et al, 2003).

9.6.4 Biomonitoring by Aquatic Insects

Ecological changes in an ecosystem because of anthropogenic activities can be assessed from taxonomic, functional, and phylogenetic diversity, by the computation of different community indices such as richness (Astorga et al. 2011; Ligeiro et al. 2013; Brasil et al. 2019), by the recording of species composition Montag et al. 2019), by the abundance of individuals (Paiva et al. 2017), by beta diversity (Cunha and Juen 2017; Brasil et al. 2017), and by functional diversity (Péru and Dolédec

2010). In addition to the community-level approach, it is also possible to assess the changing environmental condition by the presence or absence of species in the course of population studies. Some groups like aquatic insects, such as Ephemeroptera, Coleoptera, Hymenoptera, Plecoptera, Hemiptera, and Trichoptera, have revealed differential power of tolerance in the disturbed or polluted aquatic systems losing the number of species or individuals (Siegloch et al. 2017). Thus, it is important to identify which environmental factors can affect or benefit aquatic insects, since environmental monitoring with the help of aquatic insects is based on the distribution of species and their ability to respond to different environmental conditions (Roque et al. 2008). Freshwater environments in the tropics, the most threatened landscape of the world, differ ecologically from those in temperate zones in their physical, chemical, and biological attributes (Kwok et al. 2007) and are now in need of proper protection and effective conservation. Eco-monitoring of the environmental changes in the rivers and streams with the help aquatic insect community commands more attention from environmental managers. The establishment of direct relationship between aquatic insect communities and environmental predictors has become important to undertake a multi-scale analysis between the lotic freshwater systems, riparian zone, and regional landscape. Conventional biotic indices such as richness index, composition of species, and abundance or density of individuals along with the knowledge base of functional and phylogenetic diversity of aquatic insects can be used to measure changes in ecosystem services and loss of evolutionary lineages.

Three different scales have been noted at which environmental alterations due to the interventions of human beings that occur and affect aquatic insect communities. These scales are as follows: (**i**) impacts are limited at the regional level and changes are brought about due to changes in the land use in a region that drains wastewater into an freshwater system (Allan and Johnson, 1997; Allan et al. 1997; Allan 2004); (**ii**) environmental changes are caused by the impacts from the riparian zone, located along the margins of freshwater systems, such as deforestation-mediated ecological disturbances, erosion, reduction in the supply of allochthonous nutrients, etc. (Naiman and Decamps 1997); and **(iii)** impacts on directly receiving wastewater such as disposal of sewage in the river or stream (Martins and Pereira 2017). All these scales individually or synergistically cause significant changes in aquatic biota and, consequently, in ecosystem services (Allan 2004). Based on the baseline research information of the impact of the environmental changes on the ecology of aquatic insects (variations in soil use, scale of change, diversity metrics, and taxonomic groups), it is possible to throw light on the present ecological status of the riverine ecosystem and also to predict future environmental consequences. Several background information such as (**i**) climate region (tropical or temperate), (**ii**) local (physicochemical variables of the water, channel structure) and regional (changes in the land use, growth, and extent of riparian zone) environmental predictors, (**iii**) groups of entomofauna (Hemiptera, Ephemeroptera, Trichoptera, Odonata, Coleoptera, Diptera, etc.), and **(iv)** different indices of diversity (species richness, evenness, relative abundance of individuals, etc.) are required for the biomonitoring program of the insects.

A combined analysis of predictors at a local and regional scale (instream and landscape) has appeared to contribute effectively to the relationships between the environmental predictors with aquatic insect communities. The influence of the landscape characteristics (width of riparian vegetation, relief, and type) and stream characteristics (water quality parameters, volume and currents of water, size, width, etc.) affects the ecological conditions (concentrations of nutrients, increase in water temperature, degradation of riparian forest, and an increase in the flow rate of sediment) and, consequently, the aquatic communities in a stream (Allan and Johnson 1997; Steinman and Denning 2005; Macedo et al. 2013).

Besides, for the evaluation of the roles of aquatic insects in the biomonitoring of the riverine ecological changes, an important aspect is the selection of the most suitable taxonomic group based on their sensitivity, tolerance, and resistance of organisms to environmental variations and ecological stresses for pollution which vary based on the environmental conditions (Martins and Pereira, 2017). Among these groups, Ephemeroptera, Plecoptera, and Trichoptera (**EPT**) are used as the most acceptable groups to play as bioindicators of lotic freshwater systems (Vinson and Hawkins 2003).

9.6.5 Eco-biomonitoring of a Transboundary River in India by Molluskan Community Indices: A Case Study from the Riverine System from the Southwest Bengal, India

In order to become an ideal bioindicator, an organism must have some suitable characteristics (Hilty and Merenlender 2000; Zheng and Liu 2010; Füreder and Reynolds 2003) as mentioned below:

1. Taxonomic simplicity in order to enable even nontechnical person to recognize and identify the species
2. Wide range of regional, national, and even worldwide distribution
3. Preference towards local habitats with low mobility
4. Well-documented ecological attributes
5. Occurrence in higher density
6. Suitability for its use both in field and laboratory experimental studies
7. Higher sensitivity to ecological changes

In a recent ecological study, emphasis on detailed environmental assessment of water, soil, diversity, density, distribution, and community interactions of benthic mollusks have been made at five different contrasting ecozones (study sites **I**, **II**, **III**, **IV**, and **V**) on Subarnarekha River, a major transboundary river of India during six seasons of **2** consecutive years (July 2012 to June 2014). Major physicochemical parameters (**pH**, temperature, dissolved oxygen, hardness, etc.) and (6) heavy metals of water and soil have been estimated through six different seasons of **2** consecutive years. Heavy metal pollution of rivers is mostly caused by industrial, domestic, urbanized, and agricultural wastes. The persistence toxicity of heavy metals and their bioavailability have established them as potential pollutants. Major heavy metals such as **Hg**, **Pb**, **Cr**, and **Cd** by virtue of their toxic effects even at minimum concentrations in the bioavailable form can enter the food chain and produce a range of metabolic and physiological disorders (Zheng and Liu 2010; Loviov 1999). However, metals (**Fe** and **Zn**) which are needed for the normal development of living beings can be detrimental if their concentrations exceeded above their threshold values. Metals after being reached to the river water with municipal or industrial bind with particulate matters and assuming more weight settle down to the bottom to become a part of the sediments (Suthar et al. 2009). The contamination of aquatic and soil environments with such toxic materials impose serious threats to aquatic ecosystems, agriculture, and human health (Masindi and Muedi 2018).

The Subarnarekha River, a major transboundary river in the Eastern India, traverses through different landscape areas (mines, industrial field, agricultural field, forest, etc.) of three states of India, viz., Jharkhand, Odisha, and West Bengal, before ending to **Bay of Bengal** at the border of the two states of Eastern India, West Bengal and Odisha. As the consequence of the extensive mining and mineral processing activities for the industries, devastating environmental degradation has resulted in the upstream of this river.

During monsoon, the open and exposed earthen material flows into the river as runoff water and thereby increase the load of suspended solids and heavy metals in the water. Application of biological organism as an indicator of community or environmental changes has been proved to be the most effective in providing explanation of the cause and effect of pollution in recent years (David and Philips, 1970).

The trend of occurrence in respect of concentration of heavy metals was found to be in tune of **Fe>Cu>Zn>Pb>Cr>Cd** at **SI** to **SV** except **SII** where such trend was exhibited as **Cu>Fe>Cr>Zn>Pb>Cd**. The pollution load index and geoaccumulation index have revealed different modes of pollution loads in the surface of bottom sediments. A number of biotic indices like species diversity index and dominant index were found to be maximum during postmonsoon season, whereas species richness index and species evenness index were recorded maximum during monsoon season. Macrobenthic invertebrates inhabiting in the bottom of the freshwater bodies can play an important role in detecting the quality of water body by acting as a reliable bioindicator due to their longevity, site-specific habitats, and least mobility (Zheng and Liu 2010).

Among benthic invertebrates, mollusks play an important role as bioindicators due to their susceptibility to contaminants (Loviov 1999) and their power of tolerance against altered ecological conditions (Edmondson et al. 2010; Gupta and Singh 2011). Macrobenthic invertebrates, especially mollusks with higher species diversity and distribution, are being used in the evaluation of effect of stress based on their community behavior, density distribution, and environmental sensitivity (Sharma and Saini 2016). This group of bottom-dwelling animals sharing a major portion of benthic population and belonging to the higher strata of benthic food chain systems can frequently reflect any effect on benthic community in response to environmental contamination, geographical changes, and similar other natural or man-made modifications. Organisms belonging to this group are mostly sedentary, colonial, and ecosystem-specific. By virtue of these qualities, benthic organisms are considered ideal for environmental impact assessment and have been accepted and utilized in pollution investigation throughout the world. The present study was based on seasonal variation of concentrations and mode of contamination of heavy metal in sediments and water from different sites of Subarnarekha River of India with an emphasis on determining the roles of benthic mollusks for biomonitoring of the ecological changes in a river ecosystem (Pakhira and Chakraborty 2016, 2018; Chakraborty et al. 2021)).

9.6.6 Different Biotic Indices in Temporal and Spatial Scales

In an intra-community assemblage, species or species groups normally controlling the energy flow and strongly affecting the prevailing environment of all other species in a community are known as ecological dominant (Chakraborty and Choudhury 1994). The degree to which dominance concentrates in any species or species groups can be expressed by an appropriate index of dominance which tends to show inverse relationship with species diversity index which in other way usually exhibit direct variation with species richness index (Odum 1971). Among the five study sites, the dominance index was found to be maximum at **SI** followed by **SII**, **SIV**, SV, and SIII.

The species diversity index was recorded highest at **SV** followed by **SIII**, **SIV**, **SII**, and **SI**. The maximum richness index was found at **SV** (**1.83**) followed by SIII (**1.47**), **SIV** (**1.28**), **SII** (**1.04**), and SI (**0.67**). The maximum evenness index was derived at SIII (**0.925**) and that of minimum was seen at **SI** (**5.29**). The maximum values of dominant index were found during postmonsoon season, whereas minimum values were recorded during monsoon season. Maximum species diversity index was observed in monsoon season in all study sites except **SIV** and registered maximum in postmonsoon season, whereas minimum species diversity index was noted in pre-monsoon season in all study sites excluding **SIV** where minimum was found in monsoon. The maximum species richness index was found in monsoon, and minimum was noted in postmonsoon for all the study sites. Species evenness index showed maximum during monsoon season for **SI**, **SIII**, and **SV** and during postmonsoon for **SII** and **SIV** while minimum was value was recorded during monsoon at study sites **I**, **III**, and **V** and minimum during monsoon season at study sites **II** and **V** (Pakhira and Chakraborty 2016, 2018; Chakraborty et al. 2021).

9.6.7 *Different Indices Based on Heavy Metals*

9.6.7.1 Contamination Factor (CF)

Contamination factor is used to assess the pollution load of the sediments with respect to heavy metal pollution. **Contamination factor (CF)** values of different heavy metals recorded at different study sites displayed different results after being influenced by the prevailing ecological variables. There are four grade ratings on the basis of **CF** values (Hakanson 1980). All study sites displayed low **CF (CF < 1, Class 1)** to moderate **CF (CF 1 = CF < 3, Class 2)** during different seasons, indicating unpolluted to moderately polluted nature of the sediments (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.2 Pollution Load Index (PLI)

Pollution load index is an effective tool for assessing and comparing the sediment quality. According to Mohiuddin et al. (2010), **PLI = 0** indicates perfection, **PLI = 1** indicates baseline level of pollutant, and **PLI > 1** represents progressive deterioration of sediment. All the study sites revealed the **PLI** value as greater than one which reflects the polluted nature of the sediments. The maximum and the minimum **PLI** values as recorded from **SII** and **SV**, respectively, were due to the discharge of industrial effluent and anthropogenic activities carried out at the upstream region of the river (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.3 Geoaccumulation Index (Igeo)

The geoaccumulation index was introduced by Muller (1979) for determining the extent of metal accumulation in the sediments. It consists of seven grade classification system of sediments from unpolluted to extremely polluted nature of sediments. Geoaccumulation index values obtained for different metals at different study sites are presented. Among the five study sites, **SI** showed **1 < Igeo <2** representing moderate polluted nature of the sediment. **SII** revealed **0 < Igeo <1** reflecting the unpolluted to moderate polluted nature of the sediments, and **SIII**, **SIV**, and **SV** showed **Igeo <0** representing the unpolluted nature of the sediments (Pakhira and Chakraborty 2018; Chakraborty et al. 2021).

9.6.7.4 Justification of Considering Mollusks as Bioindicators

Biomonitoring gives the direct evidences of ecological changes that occurred in the aquatic ecosystem due to environmental pollution. There are several ways to find out the information on the biomonitoring of aquatic metal pollution which gives the potential effects and actual toxicities. In this study, different community indices of mollusks like index of dominance, species richness index or variety of indices, species diversity index, species evenness index, different heavy metal indices such as contamination factor, pollution load index, and geoaccumulation index have been used for biomonitoring and assessing the ecological status of Subarnarekha River.

The maximum values of contamination factor, pollution load index, and geoaccumulation index were found in the upstream region (**SI** and **SII**), and such intensity of heavy metal concentrations was seen gradually decreasing at the rest of the study sites (**SIII**, **SIV**, and **SV**) located in the downstream of this river. From the earlier observations of Muller (1981), it can be inferred that industrialization and mining practices in the upstream region might increase the values of contamination factor, pollution load index, and geoaccumulation index, and also those anthropogenic activities were principally responsible for the higher existence of heavy metals in the downstream region.

These findings have been substantiated by the biotic indices as maximum species diversity indices from **study site V** have confirmed the inverse relationship of pollution stress with biotic diversity. Therefore, alongside recording the molluskan species in the entire stretch (around **240 km**) of Subarnarekha River, different eco-geo-biological indices have appeared to throw more insights on assessing the ongoing environmental perturbations in a lowering aquatic ecosystem mainly heavy metals (Pakira and Chakraboty 2018; Chakraborty et al. 2021).

9.6.8 Biomonitoring of Wetlands by Zooplankton: A Case Study from the East Kolkata Wetland, West Bengal, India

Wetlands, one of the most productive life-support systems across the globe, have become a threatened landscape mostly because of a multitude of human activities. A recent study conducted on four selected wetlands of East Kolkata Wetlands (**EKW**), a Ramsar Site of the state of West Bengal, India, with five study sites, **viz.**, **study site I**, **study site II**, **study site III**, and study **site IV**, had verified and tested the scopes and utility of application of a biotic index developed based on the qualitative distribution of **3** major taxa of zooplankton (Rotifera with **5** genera and **11** species, Cladocera with **6** genera, and Copepoda with **4** genera) for biomonitoring.

The biotic indices like **CPV** and **SPV** have been calculated. Computation of index of similarity has revealed maximum similarity between study **site** I and study **site IV** for total zooplankton, Rotifera, Copepoda, and Cladocera as **58.8%**, **60%**, **66.67%**, and **85.71%**, respectively. As population density of total Rotifera exhibited highest density at the eco-restored wetlands (study **site III** and study **site IV**), ecological stabilities with least disturbances in the water body are reflected by the dominance of both Cladocera and Copepoda (**study site I**). The community pollution value (**CPV**) calculated from the distribution of zooplanktonic species indicates the higher intensity of pollution (Jiang 2006, Guo et al. 2010) at **SII** by **study site III**, study site IV, and **study site I** during July **2008**–June **2011**. The species pollution value (**SPV**) was computed based on the basic ecological information on zooplanktonic taxa. Also pointed out was the differential pollution loads of different wetlands (Sanyal et al. 2015).

9.6.9 Biomonitoring of Aquatic Ecosystems with Molecular Markers: A Case Study from the Southwest Bengal, India

Monitoring of global warming-mediated devastating ecological effects on freshwater wetland ecosystems through a long-term eco-biological studies of a freshwater benthic molluskan species have revealed that changes in biochemical entities bear a direct relationship with the ongoing ecological changes from molecules to ecosystem (Maity Dutta et al. 2014, 2018). Adverse ecological conditions due to the continuous rise in temperature tended to impose stress on the aquatic faunal components including the benthic fauna by causing reactive oxygen species and oxidative stress-mediated damages to cells, and the affected fauna in response evolve a variety of defense mechanisms to overcome both external and internal environmental challenges by metabolic changes in order to maintain cellular homeostasis (Fabbri et al. 2008; Mizrahi et al. 2014). It has been experimentally established that the ecosystems having higher biodiversity can adjust more temperature-mediated stress than those with less biodiversity (Wood et al. 2017). After being stressed, **reactive oxygen species (ROS)** are continually generated as consequences of normal metabolic pathways, and degradation of **ROS** levels is controlled by delicate cellular control mechanisms (Halliwell and Gutteridge 2007). All information pertaining to the temperature stress have advocated in favor of cellular adaptation which is supposed to have been caused by the antioxidants and some drug-metabolizing enzymes which in turn trigger the cells to produce antioxidant enzyme systems and free radical scavengers like nonprotein thiols and reduced glutathione (**GSH**) which are considered as common biomarkers used in environmental monitoring (Doyotte et al. 1997; Regoli et al. 1998; Chainy et al. 2016).

Emphasizing heat shock protein 70 (**HSP70**) as one of the potential biomarkers for environmental stress in fishes, mollusks, etc. (Wepener et al. 2005; Liu and Chen 2013; Maity Dutta et al. 2014; da Silva Cantinha et al. 2017), a recent study on screening and identifying some biochemical entities including **HSP70**, catalase (**CAT**), superoxide dismutase (**SOD**), reduced glutathione (**GSH**), and glutathione reductase (**GR**) has established their efficacies as dependable biomarkers as a measure to evaluate the impact of the temperature-induced stress on *Bellamya bengalensis* (Lamark 1882), a highly representative freshwater benthic molluskan gastropod in (Maity Dutta et al. 2014). Earlier studies on population density and reproduction potentiality of this gastropod species have revealed stress withstanding ability (Raut 1981). Owing to increasing concern of global climate change, temperature rise is of great interest to any aquatic environment developing extreme stressful ecological states to the poikilothermous animals like gastropod mollusks.

This study had unearthed some interesting facts relating to potentiality of the molecules and the anti-oxidative metabolic network as the biomarker in the studied two contrasting ecozones: a natural and an eco-restored forest-wetland ecosystem, named Gurguripal, in the District of Midnapore (West), of the state of West Bengal, India, in the eastern part of India. **10–20**-fold increases in **CAT**, **SOD**, and **HSP70** protein expressions paralleling to their increased enzymatic activities were recorded after exposing the faunal component (benthic mollusk: *Bellamya bengalensis* (Lamark 1882)) in different temperature stresses. The reduced **GR** coupled with increased glutathione peroxidase (**GPx**) has pointed out distinctly on the oxidative damage of cells as evident by an increase of malondialdehyde (**MDA**) level within the damaged tissues leading to higher mortality. Changes in **SOD** and **CAT** activities indicate more activation of physiological processes which scavenge the **ROS** generated because of its exposure to heat stress. However, when mortality increased at different time points, these enzyme activities exhibited a decreasing trend at higher temperature stresses (**36 °C–72 h** and **38 °C–72 h**) and thereby failed to repair the damaged tissues from the action **ROS** and there resulted higher mortality of the animals.

The systematic extrapolation of the findings of this experimental study subjecting the gastropod mollusk at different temperature stresses has reflected changes in the **HSP** and antioxidant functions which have generated scopes for the better understanding of the climate change- and global warming-related adaptive responses in the biological systems. The **HSP70** exerting its important role in the adaptive mechanism play a fundamental role of **HSPs** in the regulation of protein synthesis, protein folding and targeting, and kinetic partitioning between folding and thereby make them very dependable regulators within the cell (Roberts et al. 2010).

Based on this study, it is hypothesized that heat can exert stress alone or in association with some prevailing physicochemical parameters in an aquatic ecosystem. The synergistic effects of these factors are magnified with the change of time and with the degree of exposure of such stresses. But withstanding such stresses for a certain period of time, the adaptive ability of the organism against stress get exhausted, and the stressed animal ultimately succumb to death. It is also accepted that global warming- and climate change-mediated stresses on living organism help explain the roles of several cellular organelles, thereby recognizing some biomolecules as biomarkers in monitoring the ecological changes of aquatic system (Maity Dutta et al. 2014, 2018).

9.6.10 *Monitoring and Assessment of Thermal Stress by Hsp70 and MnSOD of Freshwater Gastropod* **Bellamya bengalensis** *(Lamark 1882): A Case Study from the Southwest Bengal, India*

The atmospheric temperatures are expected to rise by **1.4–5.8 °C** by the end of this century as a result of global warming (Parry et al. 2007). The exposure of organisms to temperature stress activates radical in oxidative stress, especially in the presence of heat. Global climate change-mediated environmental pollution can lead to an increase in the temperature of water bodies, which in turn alter several physicochemical expressions of different heat shock proteins (**HSPs**) (Piano et al. 2002; Dieterich et al. 2013). **HSPs** being ubiquitous chaperones help refold stress-induced denatured proteins (Nollen and Morimoto 2002; Wang et al. 2013) and also are considered as important biomarkers in organisms exposing themselves to ongoing pollution or thermal stress in nature (Hofmann et al. 2000; Metzger et al. 2012; An et al. 2014). Besides, heat-induced generation of reactive oxygen species (**ROS**), i.e., **superoxide**, $\mathbf{H_2O_2}$ and $\mathbf{OH}^-$ radicals, has been implicated in stress-related molecular response and acclimatization (Verlecar et al. 2008). Superoxide dismutase (**SOD**) is the chief regulator of **ROS** and a producer of $\mathbf{H_2O_2}$ from $\mathbf{O_2}$ (Fridovich 1995; Landis and Tower 2005). Both of these proteins are primitive and universal in their structure and actions in organisms (Monserrat et al. 2007).

Hsp70 being a molecular chaperone help in proper folding of proteins so that the biomolecules can maintain stability and thereby act as an important mitochondrial transporter protein (Hofmann et al. 2000). However, manganese superoxide dismutase (**MnSOD**) also acts as a scavenger of superoxide which is commonly occurring free parameters like salinity, heavy metals, biological oxygen demand (**BOD**), chemical oxygen demand (**COD**), etc. of the aquatic environment (Ficke et al. 2007; de Bij et al. 2006). Scavenging of superoxide is one of the most important stress adaptations because the presence of $\mathbf{O_2}$ and $\mathbf{H_2O_2}$ can also lead to the formation of the highly reactive and damaging hydroxyl radical (**OH·**) (Halliwell and Gutteridge 1986). The free radicals can perturb structures of all cellular components such as membranes and resulting mutagenic **DNA** breakage (LaVerne and Pimblott 1993).

The crucial balance between the exogenous prooxidant factors and the antioxidant defense system of an organism may be evaluated to assess the impact of the environmental stressors on the ecological system (Andersen et al. 2006). **SOD** and **Hsp70** have been after being exposed to thermal stress (Liu and Post 2000; Banerjee et al. 2009). The combined effects of water temperature and other environmental factors have been shown to influence on the expression of **Hsp70** (Wang et al. 2012; Izagirre et al. 2014). In a recent study (Maity Dutta et al. 2018), a freshwater molluskan species, *Bellamya bengalensis* (Lamark 1882) (Gastropoda: Viviparidae), was selected as a test animal to evaluate the impact of the physicochemical properties of water, environmental pollution, and heat stress in two wetlands [**study site I** (**SI**) and **study site II** (**SII**)], one eco-restored, devoid of human interference (**SI**) and the other wetland sustaining human impacts (**SII**).

Besides biomarker (**SOD and Hsp70**) expression studies, the survivability, mortality, and stress adaptability in this experimental species were evaluated during summer and winter seasons. The research findings of this study have improved the understanding of the use of suitable biomarkers in a commonly occurring aquatic fauna so that ecological consequences because of global environmental stresses can be assessed. Assessment of mode of expression of biomarkers such as **70-kD** heat shock proteins (**Hsp70**) and manganese superoxide dismutase (**MnSOD**) in response to the heat stress on the freshwater molluskan species *Bellamya bengalensis* (Lamark 1882) explains the molecular basis of adaptive response manifested by the studied species against increased experimental temperatures (**32–40 °C** for a period of **24–72 h**). Simultaneously performing the immunoblotting of **MnSOD** and **Hsp70** from their digestive glands and the recording of mortality rate of *B. bengalensis* at regular intervals during the period of heat stress have revealed the relationship of stresses and the biomarkers.

The expression of **Hsp70** was observed minimum at lower thermal stress, which showed a rising trend with the increase of temperature. The higher **Hsp70** levels do not show direct and positive relation with the survival of the concerned animals. In contrast, recognizing the expression levels of a universal free radical scavenger like **MnSOD** levels as a potential bioindicator of adaptive response of the animal species like *Bellamya bengalensis* towards its survivality. The mortality rate of *B. bengalensis* from **SII** was found to be always less from that of **SI** animals in similar experimental condition. Both the **Hsp70** and **MnSOD** levels also showed no significant alteration in response to elevated temperature for animals collected from **SI** during the summer except the **Hsp70** expression at **38 °C** which was increased by **1.8–2.7** fold at different periods of exposure. The **Hsp70** expression in *B. bengalensis* from **SII** also demonstrated a gradual increase in **Hsp70** levels over the control in winter. However, the upregulation of **Hsp70** in treatment at **SII** never exceeded by a **2.5**-fold increase at both **36 °C** (**48 h**) and **38 °C** (**48 h**). The expression of this protein exhibited higher results with respect to control, but the duration of the dependent response was not prominent.

In contrast, snails collected from **SII** during the summer had demonstrated a significant upregulation of both **Hsp70** and **MnSOD** and had an almost 4-fold increase (**36 °C** for a span of **48 h**) and a **2.5**-fold increase (**38 °C** of the duration of **48 h**), respectively. It can be concluded that longer durations at higher temperatures result in reduced protein expression in the present study. **MnSOD** levels showed a considerable increase during an exposure of **24** and **48 h** over untreated controls for both sites and seasons. **MnSOD** levels of *Bellamya* exhibited markedly higher levels at **SII** than at **SI** in winter. Moreover, the increase of **MnSOD** was sustained through **72 h** of treatment when maximum mortality was observed. In summer, the expression of **Hsp70** of studied animals from both **SI** and **SII** did not indicate any alteration in protein levels. The basal levels of **Hsp70** protein in control (laboratory stress unexposed) snails of both sites were found to be notably higher in summer than that of winter. As a result, a further expression of this protein was found not to be very significant due to the laboratory temperature exposure to these snails. The study depicts more acceptable results from the observation field-derived component in comparison to laboratory-derived data on the stressed animals. Though these seasonal protein expression variations are mainly attributed by the temperature change, we have to take into account the interactive role of other physicochemical variables of the corresponding environment.

Owing to the higher incidence of mortality in *Bellamya* after being subjected to elevated temperature at **40 °C** in specimens collected in winter, **Hsp70** and **MnSOD** levels could not be measured. Response to stress is a key factor for survival of an organism (Storey 1996; Gidalevitz et al. 2011). This study also revealed the susceptibility of *B. bengalensis* inhabiting at both sites to mortality by thermal stress. However, at **SII**, which has been used regularly for domestic purpose (washing, bathing, etc.), results in greater stress adaptation in aquatic animals. Probably for this reason, water **pH**, alkalinity, **TDS, TSS, BOD**, and **COD** were recorded as consistently higher in **SII** compared to **SI**. The higher **BOD** and productivity in **SII** were likely also responsible for the lower **DO** concentration in this site. In addition, unlike **SI, SII** is a closed and isolated water body which does not experience the water recirculation and passage with other water bodies. The time- and temperature-dependent changes in stress responses were less prominent at **SII** than **SI** during summer.

But the responses **SI** and **SII** in winter were found to be similar. Both the increase in **MnSOD** and **HSP70** appeared to be time-dependent at different temperatures during winter. Since the basal values of both proteins were higher in summer compared to winter, further elevation of temperature in laboratory condition resulted little change in *B. bengalensis* collected during summer. This observation indicates that natural temperature changes due to seasonal variations in association with the corresponding physicochemical parameters had measurable effects on **Hsp70** and **MnSOD** expressions. The responses generated due to the seasonal variation were similar to the results noticed in laboratory temperature experiments. It reveals the ubiquitous impact of heat stress adaptation in these animals.

The increase in both **MnSOD** and **Hsp70** is interpreted as adaptive changes against heat stress. In summer, there is a comparatively small difference between the ambient water temperatures of both sites and the temperature applied for inflicting thermal stress to *Bellamya bengalensis*. As a result, the impact of the thermal stress alone is much lower in summer in comparison to that of winter. It was further observed that when exposed to elevated thermal stress, the snails did not have mortality probably due to their preadaptation to apparently polluted water. In this context, it can be inferred that the heat shock response can be induced in *B. bengalensis* through induction of **Hsp70** when the thermal stress is substantial. At lower thermal stress levels, induction of **Hsp70** was found to be at minimum levels, whereas higher **Hsp70** levels did not show any relation to survival or adaptation. The **MnSOD** levels, as an indicator of survival in the studied species, reflect variability in the tolerance level from lower-intensity stresses to poor quality water condition. Thus, measurement of **MnSOD** levels is supposed to serve as the potential biomarker in a freshwater bioindicator species *B. bengalensis*.

The significance of the present study focuses on the dependent biomarkers to predict environmental stresses imprinted on a bioindicator species. It is noticed in the present experiment that the **SII** animals were acclimatized and adapted to an array of pollutants and thereby expressed more tolerance prior to their utilization in the heat stress experiments. It can be hypothesized that the preadaptation to a certain degree of cumulative stress may provide some resistance against adverse stress condition. In the future, the best possible laboratory experimental schedule resembling natural environmental condition may open further scope for the understanding of natural stress adaptation. In view of the present scenario for global warming, extrapolation of this research outcome may provide the groundwork for further studies to explore the strategy of natural and long-term stress adaptation against sustained environmental threats (Maity Dutta et al. 2018).

9.7 Documentation of Biological Components

9.7.1 Collection and Recording of Macrophytes

Macrophytes constituting an important green biomass of any freshwater ecosystem can be collected from the main flow of water to the top of the banks of the river and adjoining water bodies, the length of which from main riverine course vary from **50** to **100 m** based on water volume. Investigations were made at a monthly interval through three seasons of **2** years (2000–2002). All the macrophytic vegetations were grouped into three categories, **viz.**, aquatic, semiaquatic, and terrestrial. Coefficient of similarity among different categories, **viz.**, aquatic, semiaquatic, and terrestrial plants, of different study sites were calculated using the Sorensen's similarity index.

$$\mathbf{SSI} = \frac{\mathbf{2C}}{\mathbf{A} + \mathbf{B}} \times \mathbf{100}$$

where

C = Common species from two sites
A = Total number of species from **1st** site
B = Total number of species from **2nd** site

Identification of plant species was made in consultation with standard literatures (Blasco 1977), monographs, and relevant floras.

9.7.2 Collection and Recording of Zooplankton and Other Aquatic Fauna

The zooplankton samples can be collected by filtering **100** l of water through the bolting nylon cloth (NO. -**25**, mesh size -**54** μ) and were preserved in **5%** buffered formalin (APHA 2000). The zooplankton species are identified following Edmondson (1959), Brooks (1959) Needham and Needham (1962), Michael and Sharma (1988), Battish (1992), Sharma (1993), Reddy (2001), and Sharma (2001). All the drawing and photographs of Rotifera are made using a phase contrast microscope (Model No. – **Carl Zeiss**, Germany – 912311). Mollusks, aquatic insects, and crustaceans are also collected from different collection sites manually by hand picking or by nets dragging over the vegetation. Other bottom-dwelling species are sorted out by using a metallic sieve having the mesh size of **0.5** mm and preserved in alcohol; sometimes buffered formaldehyde was used in the field. Careful visual observations are made during collection to find out the fauna. Identifications of collected specimen were done with the help of standard methods (Subba Rao 1989, Mitra and Kumar 1988) and subsequently confirmed by the scientists of Zoological Survey of India, Kolkata.

9.7.3 Diversity of Freshwater Ichthyofauna

Fishes are collected from various aquatic subsystems like rivers, streams, wetlands, etc. and directly from the fishermen as well as from the local markets, viz., Midnapore, Jhargram, Ghatal, Garbeta, Bankura, Arambag, Dehati, Khirai, Sonakonia, Kolaghat, and Khakurda, located at four districts of Southwest Bengal (**22–23.3°N; 86–88.3°E**) during different seasons like pre-monsoon (March–June), monsoon (July–October), and postmonsoon (November–February). Indigenous naming of different fishes is determined through focus group discussion (Mukherjee 1995). Collections are made randomly using bag nets, dragnets, cast nets, gill nets, seines, long line, different types of indigenous traps, etc. Fish species brought in the local markets from outside places were not taken into consideration. The specimens were preserved in **4%** buffered formalin immediately after collection and subsequently identified with the help of some standard literatures (Day 1878; Shaw and Shebbeare 1937; Jayaram 1999; Sen 1985; Beavan 1990; Talwar and Jhingran 1991; Menon 1999).

9.7.4 Fishing Technologies for Inland Water Bodies of Southwest Bengal

Four districts of Southwest Bengal are crisscrossed by several large rivers, their rivulets, canals, creeks, etc., which together with other adjoining wetlands constitute the inland water bodies. In the present study, six major rivers, viz., Subarnarekha, Dwarkeswar, Shilabati, Rupnarayan, Kansai, and Keleghai, and their adjoining water bodies were thoroughly investigated during different months, seasons, and years. Three seasons were pronounced in this area, **viz.**, pre-monsoon (less precipitation), monsoon (maximum precipitation), and postmonsoon. Collection and documentation of information relating to different fishing technologies were done through the participatory interaction with the stakeholders with a set of preformulated questionnaire in a village-level group meeting and by physical verification (Mukherjee 1995).

9.7.5 Participatory Methods: A Tool for Bio-assessment and Conservation

The participatory methods help in the involvement of local communities or stakeholders because it is they who do their own analysis through such methods, explain their findings and propose action on that basis. The method are both "**verbal**" and "**visual**" and involve the use of signs, symbols, objects, models, measures, etc. These methods are simple and handy and can be used by all.

9.7.5.1 Participatory Rural Appraisal (PRA) Techniques

A tool-based on people's perception, a "**basket of techniques**," adopted to interact with local communities, to understand them, and to learn from them, can be designated as **PRA** method.

This method facilitates better interaction with the local communities for indigenous knowledge-building exercise. This is also an alternative means of data collection and analysis. By means of this method, different kinds of data collection, identification, and mobilization of intended groups and provocation of their participations are possible, and furthermore, there are opening of various ways in which intended groups can participate in decision-making, project design, execution, and monitoring. **PRA** is a fruitful strategy where we can concentrate on people, their livelihoods, and their interrelationships with socioeconomic and ecological factors as it involves the participation of local community.

9.7.5.1.1 Questionnaire Survey

This type of survey involves investigation or enquiry about the people where they are treated as passive entities as they are not involved or they cannot influence the sense and direction of the ongoing enquiry. A picture-based questionnaire survey was conducted to evaluate the knowledge of the adjacent villagers regarding the declining of natural resources and the problem of developing eco-potentialities. Before conducting the interviews and taking necessary photographs, the verbal consents of the willing persons were taken. The questionnaire survey was conducted to explore two dimensions of people's cognizance through questionnaire to find out background information on socioeconomic status of the respondent (**viz.**, gender, age, and level of education of the respondents as enumerated in completed school years) in order to explore the effect of these variables on the knowledge of respondents (Kasina 2007) and questionnaire to attempt to extract the perception of respondents with respect to the possible causes of reduction of eco-potentialities. After taking the age profiles of the respondents in account, **30** willing participants of age 40 years and above were considered as the "**principal informants**" to categorize the commonly identified problems of bioresource declination.

Selected participatory rural appraisal techniques were carefully designed and applied to extract primary information relating to the conservation status of fishes. The techniques like (**a**) trend analysis, (**b**) fish magnitude value, (**c**) matrix ranking, and (**d**) rank-based quotient are being elaborated below.

9.7.5.1.2 Trend Analysis

The trend analysis is for depicting the nature of decline of a species over decades through applying participatory rural appraisal techniques. It has been done to analyze the nature of increasing or declining numbers of the target fish population over decades. In this analysis, the experience profiles of the stakeholders were also taken into consideration. In this method of trend analysis, the local people were interviewed to understand the trend of different variables from a historic perspective. The method helps in providing a background to any issue through trend analysis (Mukherjee 1997). For trend analysis, **75** respondents were put to an interactions in order to identify and assess the decadal decline of different fish species (**17**) in terms of time and visibility of the target species in the near and around surroundings. The scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canal, tributaries, and rivers) reduced drastically from **1960** to **2000.**

9.7.5.1.3 Fish Magnitude Value (FMV)

It was calculated from a participatory approach where both the geographical and temporal dimensions were considered. **Fish magnitude value (FMV)** was designed and calculated from the vertical and horizontal logics. In this case, both the geographical distributions and temporal dimensions were taken into consideration. Calculation of the fish magnitude value was considered in conformity with the **IUCN** guidelines (IUCN 2001; Anon 2001).

The contention was that fish species had declined not only over a geographical space but also over the time. This is an innovative technique relying basically on the perceptual assessment by the fishermen of different age groups (**60** to **70** years old). This assessment is related to the decline of different fish species not only overtime but also over distribution, e.g., the fishermen assessed what have been the availability **vis-à-vis** biomass (**Kg**) of a fish species in a given decade (**60s**) in terms of scores designed by themselves and these score values were multiplied by the visibility range **vis-à-vis** the extent of their occurrence (**Km^2**), to help determine the status of that species in that decade. This type of calculation over decades would delineate by what percentage the decline has been occurring since the benchmark decade. To avoid the biases in the perceptual assessment made by an individual farmer, the total score value of a group was divided by the number of members of that very group to have an interpolated value in the form of a mean:

$$\mathbf{Mean\ of\ FMV} = \frac{\mathbf{Yield} \times \mathbf{Area\ of\ Occupancy}}{\mathbf{Number\ of\ respondents}}$$

9.7.5.1.4 Matrix Ranking

This unique method could be used to derive local perceptions and to quantify the perception so as to draw a logical inference on the reason and way of the superiority of one ecosystem over another. By applying this method, one can have an excellent estimation through a participatory mode of different attributes or values for different sites. Different attributes and criteria which were mentioned in a matrix scoring exercise were ranked according to their relative importance either on the basis of fixed scoring (say scoring out of ten). Perceptions of rural people could be revealed through an exercise in matrix scoring.

A number of causal factors were found to be instrumental for the declining of fish population from their natural habitats (irrigation canals, tributaries, wetlands, floodplains, and rivers) of Southwest Bengal. Group meetings with local fishermen community of some selected villages such as Kolaghat, Khakurda, Bankura, Arambag, Sonakonia, Dehati, Midnapore, Ghatal, Garbeta, and Khirai were organized to collect information related to factors responsible for declining of fishery resources.

Mostly the male members of the community assembled in the meeting place at a time. The set of criteria was discussed by the fishermen community. They were also requested to add to the list and to score on the set of criteria generated. Habitat destruction, nonrestricted nylon thread fishing gears, ichthyotoxic materials derived from local plants and also chemicals used for agriculture, fishing during breeding seasons, water pollution by wastes from human settlements and industries, fish diseases (epizootic ulcerative syndrome and others), excessive and nonjudicious use of water, human population explosion, occurrence of flood, introduction of exotic fish species, siltation, and fish bodies without being endowed with scales were found to be the major problems for the declining of fishery resources. To initiate the process of scoring by individuals, the criteria were written on piece of paper in vernacular (such criteria were read out loudly and understood by the participants, although many of them could not read or write) and arranged in a column on the ground. Each person was given a handful of stone chips (ten stone chips) and asked to score each criterion as much or as little as he wished to. It was free scoring as explained to the participants, where relative importance of a criterion would get indicated by putting more stone chips to more important ones and less stone chips to those which were relating less important.

9.7.5.1.5 Rank-Based Quotient (RBQ)

To calculate the interpolated values of different quality responses at both the vertical and horizontal dimensions is deliberately intercepted in this type of approach. At first, the individual choices for ranking against the relative position in the rank were calculated and then multiplied it by the rank values, and then the total values had been divided by the total number of members in the participatory groups. This approach is a unique concept to eradicate the flamboyancy of quality responses (Patra et al. 2005). To calculate rank-based quotient (**RBQ**) of each problem, the formula of Sabarathnam (1988); Sabarathnam and Sengottaiyan (1996) was used.

It was made to re-rank the identified causes in terms of their vertical and horizontal dimensions. Ranking was done with the help of **Rank-Based Quotient (RBQ)**. A focus group was formed. They were put to a discussion in identifying ten causal factors. It was made to rank the identified causes in terms of their vertical and horizontal dimensions:

$$\mathbf{RBQ} = \frac{\sum \mathbf{fi}(\mathbf{n}+\mathbf{1}-\mathbf{i})}{\mathbf{N}*\mathbf{n}} \times \mathbf{100}$$

where,

fi = frequency of respondents reporting the problem under ith rank,
I = rank of problems,
N = total number of respondents,
n = total number of problems.

In order to gather information about the factors responsible for a sharp decline in the eco-potentialities of wetlands over the decades, a meeting involving 60 local people was organized. After identifying some problems through participatory interactions, they were categorized, sorted, and screened. In these interactions, the number of participants was 20 for each focus group, and three such groups were created for necessary interactions to generate adequate data. Successful application of this type of participatory tool **(RBQ)** had already been practiced over decades to assess and document the nature and degree of decline of a score of selected bioresources.

9.7.5.1.6 Market Survey and Assessment of Fish Production

The data on average monthly landing of **17** siluroid fishes at the major fish markets of the study areas during **1997** to **2001** had been collected and presented. In this process, **eight** focus groups comprising of **five** fish retailers in each group having an age profile of above **50** years were taken into consideration from different landing centers. They were asked to present an account of fish landings at the respective markets in terms of **kg/month** for the last **5** years trickling from 1997.

9.7.5.1.7 Categorization of Fishes: A Prime Step for Conservation

The International Union for Conservation of Nature and Natural Resources **(IUCN)** categorizes the taxa in a given scheme depending upon the different criteria (**IUCN** 2001, Red List Categories and Criteria, **Version 3.1**). In the present work, the species was categorized specifically following the percentage of population size reduction and mean decline on market landing.

The percentage of population size reduction was calculated on the basis of **FMV** and was compared with the percentage given in the list. For critically endangered (**CR**), decline on FMV was **80%**, and mean decline on market landing was **60%**. For endangered (**EN**), decline on **FMV** was **70%**, and mean decline on market landing was **40%**.

For vulnerable (**VU**), decline on **FMV** was **50%**, and mean decline on market landing was **30%**. For near threatened (**NT**), decline on **FMV** was **<50%**, and mean decline on market landing was **15%**. The **IUCN** standardizes the percentage of population reduction over decades, which have been taken into consideration with the value of **FMV** (Patra et al. 2004; Patra et al. 2005; Mishra et al. 2009).

9.7.5.1.8 Causal Analysis: Understanding Cause and Effect

The perception of the outcomes through **PRA** method application cannot be done as that of the results of some laboratory-based research. The best way to disclose the benefits is an adequate discussion of the said outcome in the community.

Representation of a **PRA** process involves some diagrams, maps, ranking, flowcharts, etc. presenting and eliciting the local knowledge and experiences. The causes of decline or even extinction of bioresources in a given ecosystem can better be represented in a form of flow analysis which is known as causal diagram. The relationship between cause and effect of an event, process, or entity can be delineated by this method (Tables 9.1, 9.2, 9.3, 9.4 and 9.5).

Table 9.1 Some terms used to classify aquatic organisms by habitat

Habitat	Description
Benthic	On the bottom
Emergent	Emerging from the water
Endosymbiotic	Living within another organism
Epilithic	On rocks
Epigean	Above the ground
Epipelic	On mud
Epiphytic	On plants
Epipsammic	On sand
Hygropetric	In water on vertical rock surfaces
Hyporheic	In groundwater influenced by surface water
Lentic	In still water
Littoral	On lake shores, in shallow benthic zone of lakes
Lotic	In flowing water
Neustonic	On the surface of water
Pelagic	In open water
Periphytic (biofilm, Microphytobenthos)	Benthic, in a complex mixture including algae
Profundal	Deep in a lake
Symbiotic	Living very near or within another organism
Stygophilic	Actively use groundwater habitats for part of life cycle
Stygobitic	Specialized for life in groundwater
Torrenticole	Adapted to live in swiftly moving water

Table 9.2 Classification of interactions between two species (A and B)

Effect of A on B	Effect of B on A	Name of Interaction
Positive	Negative	Exploitation (includes predation and parasitism)
Negative	Negative	Competition
Positive	Positive	Mutualism
None	Positive	Commensalism
None	Negative	Amensalism
None	None	Neutralism

PRA teams consisting of people associated with the consumption, production, and maintenance of resource diversity and having of heterogeneous experiential profiles, social and economic backgrounds, etc. were structured to chalk out this type of analysis. The diversity created in the group composition was meant to identify, assess, and enumerate different causes, viz., biotic, abiotic, and social, from multiple realities (Tables 9.6, 9.7, 9.8, 9.9, 9.10, 9.11, 9.12, 9.13, 9.14, 9.15, 9.16, 9.17, 9.18, 9.19 and 9.20).

Table 9.3 Fish-stupefying plants used in Southern West Bengal, India

Sl no.	Scientific name	Local name	Family	Part(s) used	Habit
1	Bassia latifolia	Mahua	Sapotaceae	Oil cake of fruit	Tree
2	Casearia graveolens	Pimpri	Samydaceae	Bark	Small tree
3	Excoecaria agallocha	Gengwa	Euphorbiaceae	Latex	Small tree
4	Moringa oleifera	Sajne	Moringaceae	Root and bark paste	Tree
5	Nicotiana tabacum	Tamak	Solanaceae	Crushed plant	Herb
6	Polygonum hydropiper	Panmarich	Polygonaceae	Crushed plant	Shrub
7	Polygonum orientale	Panmarich	Polygonaceae	Crushed plant	Shrub
8	Pongamia pinnata	Karanj	Fabaceae	Oil cake	Tree
9	Sapindus mukorossi	Ritha	Sapindaceae	Fruit powder	Tree
10	Strychnos nux-vomica	Kuchila	Loganiaceae	Dried seed powder	Tree
11	Tamarindus indica	Tetul	Fabaceae	Dried seed powder	Tree
12	Tephrosia purpurea	Ban-nil	Fabaceae	Crushed plant	Herb
13	Tridax procumbens	Bisalyakarani	Asteraceae	Fresh leaf juice	Herb
14	Vangueria spinosa	Moyena kanta	Rubiaceae	Crushed fruit	Small tree

Table 9.4 A model of classifying streams by discharge patterns and relationship to aquatic communities

Drying frequency	Flood and discharge frequency/predictability	Stream type	Effect on biota
Often	Rare–frequent	Harsh intermittent	Strong
Low	Frequent	Intermittent flashy	Strong
Low	Infrequent	Intermittent runoff	Strong
Rare	Frequent unpredictable floods, low discharge predictability	Perennial flashy	Strong
Rare	Frequent predictable floods, low discharge predictability	Snow and Rain	Strong–intermediate
Rare	Infrequent floods, low discharge predictability	Perennial runoff	Strong–intermediate
Rare	Infrequent floods, high discharge predictability	Mesic groundwater	Weak
Rare	Infrequent predictable floods, high discharge predictability	Winter rain	Seasonally strong
Rare	Infrequent predictable floods, high discharge predictability	Snowmelt	Seasonally strong

Table 9.5 Characteristics of regional (top-down) vs local (bottom-up) strategies

	Regional (top-down)	Local (bottom-up)
Scale	Reach to network 1000 to 50,000 km river length 5000 to 500,000 km^2 (or greater)	Site to reach to small river basin 10 to 100 km river length 100 to 2000 km2
Management objectives	Assess geomorphic/ecological/identify/ chemical conditions of river reaches develop actions Target/prioritize actions	Diagnosis of trajectory, causes of change how it works Project design Pre-and post-project appraisal
Data sources	Satellite and airborne imagery LiDAR regional surveys	Historical maps, photos, surveys, accounts
	GIS national layers	Field measurements
	Network of stream gauges and SSC measures	Hydraulic modeling
	National-designed field campaigns (RHS)	In situ/ex situ experiments

9.7.5.1.9 Eco-assessment of Fishing Practices

Extensive survey has been made in different study sites of Southwest Bengal through different months and seasons in order to document the ongoing fishing technologies, which are being practiced. This has strong bearings on the conservation strategies to be undertaken for the protection of aquatic organisms. Different types of crafts, gears, and other traditional fishing technologies have already been documented. Due to the lack of restriction of mesh size, juveniles and many unwanted but ecologically important aquatic organisms are caught and destroyed leading to both economic and ecological losses.

Nylon threads used for making different gears also pose harmful effects during fishing operation as these damage different soft parts of both target and nontarget aquatic organisms. Application of the extracts of ichthyotoxic plants as a part of indigenous fishing technology should be reviewed with a holistic approach in order to save the steady state of environmental balance (Mishra et al. 2001, 2002, 2003).

9.7.5.1.10 Identification and Assessment of Anthropogenic and Environmental Stresses (Through RBQ Method)

A number of causal factors were found to be instrumental for the declining of fish population from their natural habitats (irrigation canals, tributaries, and rivers) of Southwest Bengal, India (Patra et al. 2005; Mishra et al. 2009).

Group meetings with local fishermen community of some selected villages, viz., Khakurda, Bankura, Arambag, Sonakonia, Dehati, Midnapore Sadar, and Khirai, were organized to collect information related to factors responsible for declining of fishery resources. Mostly the male members of the community (**Nos 30**) assembled in the meeting place at a time.

Table 9.6 Methodologies on environmental flows: global perspectives

Country	No. of EFMs (% of GT 207)	Total no. types (max 6)	No. of hydro (% of GT 61)	No. of hydraulic (% of GT 23)	No. of habitat sim (% of GT 16)	No. of holistic (% of GT 58)	No. of combin (% of GT 14)	No. of others (% of GT 35)
USA	77 (37%)	5	20 (33%)	19 (50%)	29 (50%)	–	8 (23%)	1 (7%)
Australia	37 (18%)	6	11 (18%)	1 (4%)	6 (10%)	11 (69%)	6 (17%)	2 (14%)
UK	23 (11%)	6	10 (16%)	1 (4%)	1 (2%)	1 (6%)	3 (9%)	7 (50%)
Canada	22 (11%)	4	9 (15%)	1 (4%)	10 (17%)	–		2 (14%)
South Africa	20 (10%)	5	6 (10%)	–	2 (3%)	5 (31%)	4 (11%)	3 (21%)
New Zealand	20 (10%)	5	8 (13%)	2 (9%)	6 (10%)	–	3 (9%)	1 (7%)
Spain	14 (7%)	4	8 (13%)		4 (7%)	–	1(3%)	1 (7%)
Italy	11 (5%)	5	4 (7%)	1 (4%)	1 (2%)	–	4 (11%)	1 (7%)
France	10 (5%)	3	3 (5%)		6 (10%)	–	1 (3%)	–
Portugal	10 (5%)	4	7 (11%)	1 (4%)	1 (2%)	–	1 (3%)	–

Numbers of environmental flow methodologies (**EFMs**) of different types and proportions of global totals for the 10 countries for which the highest total numbers of methodologies were recorded

Abbreviations: *GT* global total, *hydro* hydrological, *hydraulic* hydraulic rating, *habitat sim* habitat simulation, *combin* combination. A slash indicates on recorded application of the specific methodology type

Table 9.7 Identification of causal factors responsible for depletion of *Nandus nandus* (N = 30)

Sl no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Sluggish behavior	9		4				7		2		50.81	2
2	Attack of disease (epizootic ulcerative syndrome)	10			12	2						64.02	1
3	Use of nonrestricted nylon thread fishing gears		3		3	5			2			24.42	8
4	Occurrence of flood and siltation				10	7		7		2	3	43.88	3
5	Fishing during breeding seasons			5		3		6		7		29.7	7
6	Ichthyotoxic materials (plants/chemicals)	1		1		7	6		3	5		30.75	6
7	Pesticides used for agriculture			5	3			6	5	7	1	37.95	5
8	Excessive and nonjudicious use of water	1		1			6		5	5		21.51	9
9	Introduction of exotic fish species			2		4		4	1		2	17.49	10
10	Habitat destruction			11	2				5			38.61	4

The set of criteria was discussed by the fishermen community who were also requested to add to the list and to score on the set of criteria generated. Habitat destruction, usage of nonrestricted nylon thread fishing gears, application of ichthyotoxic materials (plants and chemicals), fishing during breeding seasons, water pollution, siltation, multifarious water use, human population pressure, sluggish behavior of some fish, fish diseases (epizootic ulcerative syndrome and others), and introduction of exotic fish species are the major problems for the declining of fishery resources. To initiate the process of scoring by individuals, the criteria were written on piece of paper in vernacular (such criteria were read out loudly and understood by the participants, although many of them could not read or write) and arranged in a column on the ground.

Table 9.8 Identification of causal factors responsible for depletion of *Puntius sarana* (N = 30)

Sl no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**10**			**12**			**7**				**69.96**	**1**
2	Water pollution by wastes from human settlements			**9**			**6**	**4**	**5**		**2**	**41.97**	**3**
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**8**
4	Introduction of exotic fish species	**3**			**4**			**2**	**8**			**29.7**	**5**
5	Fishing during breeding seasons				**10**			**7**		**2**	**3**	**34.64**	**4**
6	Ichthyotoxic materials (plants/ chemicals)	**1**		**1**						**5**		**9.24**	**10**
7	Pesticides used for agriculture	**9**	**4**	**4**				**4**				**57.42**	**2**
8	Attack of dis-ease (epizootic ulcerative syndrome)		**5**			**6**			**7**			**27.12**	**6**
9	Sluggish behavior			**1**	**2**	**5**			**5**			**22.11**	**9**
10	Occurrence of flood and siltation		**5**				**6**		**7**	**1**		**26.07**	**7**

Each person was given a handful of stone chips (**ten stone chips**) and asked to score each criterion as much or as little as he wished to. It was free scoring as explained to the participants, where relative importance of a criterion would get indicated by putting more stone chips to more important ones and less stone chips to those which were relating less important. Ranking were done with the help of **rank-based quotient** (**RBQ**). A focus group was formed.

They were put to a discussion in identifying ten causal factors and extract their relative value on the declining trend of fish population in general and also five selected species (two critically endangered, **viz.**, *Nandus nandus* and *Puntius sarana*, and three endangered, viz., *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha*) in particular.

Table 9.9 Identification of causal factors responsible for depletion of *Eutropiichthys vacha* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**	**1**			62.37	2
2	Water pollution by wastes from human settlements			**5**				**6**		**7**	**1**	26.07	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**			**5**	**5**		22.11	8
4	Introduction of exotic fish species			**5**	**3**			**6**		**7**		32.67	6
5	Fishing during breeding seasons		**4**	**11**	**2**				**5**			50.49	3
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	34.64	5
7	Pesticides used for agriculture				**12**	**2**		**4**				36.96	4
8	Excessive and nonjudicious use of water	**1**		**1**			**6**		**3**	**5**		21.51	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation	**15**		**2**			**6**	**4**			**2**	70.02	1

Then, they were also made to assess the extent of the impact area and the intensity of the problems so as to finally attain the village magnitude value, which were subsequently ranked to provide a holistic idea of the problem.

9.7.5.1.11 Decade-Wise Trend Analysis of Selected Fish Species

In this method of trend analysis, the local people were interviewed to understand the trend of different variables from a historic perspective. The method helps in providing a background to any issue through trend analysis (Mukherjee 1997).

Table 9.10 Identification of causal factors responsible for the depletion of *Ompok pabo* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**				61.38	1
2	Water pollution by wastes from human settlements	**1**		**1**			**6**		**3**	**5**		21.51	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**	**6**		**5**	**5**		31.41	6
4	Introduction of exotic fish species							**6**		**7**		12.54	8
5	Fishing during breeding seasons			**11**	**2**	**5**			**5**			48.51	3
6	Ichthyotoxic materials (plants/ chemicals)			**5**	**3**			**6**		**7**	**1**	33	5
7	Pesticides used for agriculture	**15**		**2**					**1**			55.77	2
8	Attack of disease (epizootic ulcerative syndrome)			**2**				**4**	**1**		**2**	12.21	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation				**10**	**2**		**7**		**2**	**3**	38.6	4

The scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canal, tributaries, and rivers) reduced drastically between **1960** and **2000**. About **175** fishermen participated to deliver their knowledge about the decade-wise declining trend of **27** selected fish species of Southwest Bengal. Although a total of **103** freshwater fishes have been recorded from different water bodies of Southwest Bengal, India, to generate information relating to the quantum of production **vis-à-vis** catch from natural water bodies, a number of markets (**6**) located near the harvesting sites were selected for continuous market survey. A total of **52** species of fishes were found to constitute bulk of fish resources of those markets.

Table 9.11 Identification of causal factors responsible for depletion of *Ailia coila* (N = 30)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**10**			**12**			**4**				**66**	**1**
2	Water pollution by wastes from human settlements			**9**		**2**				**2**		**29.03**	**6**
3	Use of nonrestricted nylon thread fishing	**1**		**1**			**6**		**5**	**5**		**21.51**	**8**
4	Introduction of exotic fish species gears		**4**	**4**				**7**				**31.68**	**5**
5	Fishing during breeding seasons	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**7**
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	**34.64**	**4**
7	Pesticides used for agriculture	**15**		**2**				**4**	**1**		**2**	**61.71**	**2**
8	Excessive and nonjudicious use of water							**6**		**7**		**12.54**	**9**
9	Sluggish behavior		**3**						**2**			**10.89**	**10**
10	Occurrence of flood and siltation		**3**	**11**	**2**				**5**			**47.52**	**3**

Out of these **52** species of fishes, **27** species were picked up based on their present availability against overexploitation coupled with environmental degradation and also to study their conservation categories. It was found from the information based on the decline of **FMV** after **2000**, the population of *Nandus nandus* experienced maximum decline (**86.15%**) followed by Puntius sarana (**83.78%**) which suffered an abrupt decline between **1960** and **2000**, and the decline of **FMV** after last decay in other species would have been as follows: *Rita rita* **62.82%**, *Batasio batasio* **41.76%**, *Lepidocephalus guntea* **48.13%**, *Mystus cavasius* **70.48%**, *Mystus vittatus* **63.20%**, *Ompok pabda* **74.64%**, *Ompok pabo* **79.46%**, *Wallago attu* **61.07%**, *Ailia coila* **76.13%**, Clupisoma garua **63.65%**, *Eutropiichthys vacha* **78.00%**, *Pangasius pangasius* **43.88%**, *Bagarius bagarius* **33.94%**, *Clarias batrachus* **41.27%**, *Arius gagora* **47.65%**, *Heteropneustes fossilis* **32.23%**, *Notopterus nopterus* **60.55%**,

Table 9.12 Segregated figure on decadal fish magnitude value (FMV) for 27 selected fish species

SL. no.	Local name	Scientific name	1960	1970	1980	1990	2000	Mean	SD
1	Rita	*Rita rita*	236.50	203.70	169.06	101.46	37.72	149.69	80.14
2	Batasi, tengra	*B. batasio*	196.30	180.70	90.00	35.20	20.50	104.54	81.09
3	Gento	*L. guntia*	183.80	163.20	123.50	93.50	48.50	122.50	54.16
4	Pat tengra	*M. cavasius*	296.20	262.33	214.50	61.66	18.20	170.58	123.70
5	Dorakata tengra	*M. vittatus*	232.13	200.70	175.60	107.60	39.60	151.13	77.38
6	Nayna	*N. nandus*	156.00	132.50	78.60	32.50	4.50	80.82	64.20
7	Swarna punti	*P. sarana*	148.50	120.60	58.50	18.50	3.00	69.82	63.24
8	Pabda	*O. pabda*	191.87	163.50	128.50	48.50	12.30	108.93	76.21
9	Pabda	*O. pabo*	266.80	253.50	220.70	66.20	13.60	164.16	116.17
10	Boal	*W. attu*	190.50	170.00	110.00	65.50	25.50	112.30	69.24
11	Banspata	*A. coila*	174.30	112.50	89.60	77.50	18.50	94.48	56.53
12	Fultusi	*C. garua*	158.50	123.40	109.60	89.40	32.50	102.68	46.62
13	Bacha	*E. vacha*	185.70	157.80	122.50	93.20	20.50	115.94	63.81
14	Pangas	*P. pangasius*	259.80	231.70	208.40	119.20	66.90	177.20	81.08
15	Baghar	*B. bagarius*	87.20	68.80	54.30	38.60	25.50	54.88	24.33
16	Magur	*C. batrachus*	254.30	224.50	176.50	104.20	61.20	164.14	80.80
17	Goar aar	*A. gagora*	313.33	282.07	278.09	253.09	132.50	251.82	70.05
18	Singi	*H. fossilis*	287.53	253.40	230.00	166.00	112.50	209.89	70.24
19	Pholui	*N. nopterus*	287.80	266.66	225.30	86.05	33.95	179.95	113.29
20	Shol	*C. striatus*	211.12	174.15	154.50	112.20	71.50	144.69	54.29
21	Mourola	*A. mola*	279.60	252.30	213.90	111.50	59.80	183.42	94.05
22	Koi	*A. testudineus*	257.50	226.13	188.70	90.80	35.16	159.66	93.64
23	Lata	*C. punctatus*	224.20	196.16	152.50	64.13	27.66	132.93	84.45
24	Pangkal	*M. pancalus*	217.13	182.00	151.40	84.60	47.50	136.53	69.66
25	Arr tengra	*A. seenghala*	310.50	250.40	215.60	150.00	89.20	203.14	86.20
26	Cheng	*C. orientalis*	255.10	225.14	190.86	97.20	49.00	163.46	87.24
27	Ilish	*T. illisa*	254.30	224.50	190.00	83.06	44.60	159.29	91.09

Table 9.13 Quantum of production of fishes during the year 2000–2002 (from market survey, expressed in Kg/year) in main landing centers of six rivers and their associated water bodies

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Kelegha)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
1	*Labeo rohita*	Rui	225	237	212	201	290	302	170	171.5	–	–	165	167
2	*Labeo calbasu*	Kalbasu	125	119	95	88.5	131	128	102	98.5	–	–	90	88
3	*Labeo bata*	Bata	320	298	75	79	250	248	82	81.5	–	–	79	76
4	*Labeo boga*	Bangan	173	174	50.5	49.5	167	177	75	16	–	–	78	76.5
5	*Cirrhinus mrigala*	Mrigal	92	72	75	78.5	103	108.5	82	81	–	–	84.75	81.5
6	*Catla catla*	Catla	252	267	115	98	305	288.5	117	112	–	–	105	102
7	*Puntius sophore*	Puthi	280.6	264	202.7	160	288	267	235.8	237.5	–	–	230	219.5
8	*Puntius ticto*	Puthi	175.8	157	55.7	61	180.8	165.5	180.7	123	–	–	185.75	181.5
9	Puntius sarana	Swarna-puti	–	–	2	1.5	1	–	–	–	–	–	–	–
10	*Hypophthalmichthys molitrix*	Silver carp	200.7	210.5	172.4	189.5	310.75	297	173.8	177	–	–	153.75	155
11	Cyprinus carpio	Cyprinus	55	58	35	54	62	64	42	41.5	–	–	39	37.5
12	*Ctenopharyngodon idella*	Grass carp	105	111	90.5	110	110	117.5	100.8	88.5	–	–	98	97.5
13	*Mystus bleekeri*	Golsha tengra	405	387	290	287	432	429	328	281	–	–	281	277
14	*Mystus cavasius*	Pat tengra	190	178.5	35	32.5	180	167.5	105.5	97	–	–	125	119
15	*Mystus gulio*	Nuna tengra	54	47	61.5	52.8	35	28.5	54	51.5	–	–	–	–
16	*Mystus vittatus*	Dorakata Tengra	69.5	62	71.5	69	65.5	49.2	62	58.5	–	–	–	–
17	Aorichthys aor	Arr	215	210.5	115	113.5	70	71	175	168	76.5	78	45	43

(continued)

Table 9.13 (continued)

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Kelegha)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
18	*Aorichthys seenghala*	Arr tengra	405	378.5	–	–	202	197.5	–	–	129.5	126.5	–	–
19	*Ompok bimaculatus*	Puffta	310	303.5	–	–	180	173	170	161	–	–	–	–
20	*Ompok pabda*	Pabda	78	71	32	27	19	17.5	14	12.5	–	–	–	–
21	*Ompok pabo*	Pabo	51.5	45.5	47	39.5	53	49	37	33.5	–	–	–	–
22	*Wallago attu*	Boal	303	276	226.5	219.8	398	384	189	188	185	183	175	173.5
23	*Ailia coila*	Kajri	155	141	–	–	75	69	–	–	–	–	–	–
24	*Clarias batrachus*	Magur	50.80	42.5	62	58	55	52.5	40	39	–	–	42	41
25	*Heteropneustes fossilis*	Singi	60.3	56.5	40	39	65	61	51	43	–	–	52	52
26	*Clupisoma garua*	Fultusi	295	263	–	–	75	72	–	–	–	–	–	–
27	*Pangasius pangasius*	Pangas	–	–	–	–	85	80	–	–	320	314	–	–
28	*Rita rita*	Rita	103.5	96.5	–	–	10.5	9	14.5	13	–	–	0.5	–
29	Batasio batasio	Batasi tengra	62	57.5	–	–	51	49	37	35.5	–	–	–	–
30	*Channa striatus*	Shol	85	76	51.5	49	86.8	78.5	58	57	–	–	52	48.2
31	*Channa punctatus*	Lata	322	312.5	180	177	355	312	175	165	–	–	245	240
32	*Channa orientalis*	Cheng	65	57	53	45.5	85	84	54.5	535	–	–	82	80
33	*Notopterus chitala*	Chital	210	199	77	71	192	191	69.5	64	–	–	73.5	71
34	*Notopterus notopterus*	Pholui	300.7	267	185	166	370	368	196	191.5	–	–	193	185.5
35	*Gudusia chapra*	Khira	–	–	–	–	–	–	–	–	1900	–	–	–
36	*Tenualosa ilisha*	Ilish	–	–	–	–	35	33.5	–	–	2800	–	–	–

37	*Securicula gora*	Ghora chela	42	37	–	–	–	–	–	–	–	–	–	–
38	*Chela cachius*	Chela	175	147.5	95	90.5	185	166	173	168.5	–	–	170	168
39	*Polynemus paradiseus*	Tapsya	–	–	–	–	–	–	–	–	2200	–	–	–
40	*Nandus nandus*	Nayna	–	–	0.5	–	1.5	1	–	–	–	–	–	–
41	*Bagarius bagarius*	Baghar	–	–	2	2	0.5	–	–	–	–	–	–	–
42	*Eutropiichthys vacha*	Bacha	25.5	24	5	4.5	10	9.5	21.5	19	–	–	–	–
43	*Arius gagora*	Goar arr	14	13.5	8	8	7	6.5	12	9.5	–	–	–	–
44	*Esomus danricus*	Jongia	280	276	197	190	292	291	283.75	280	-	–	203.3	200
45	*Amblypharyngodon mola*	Mourola	302	297	275	276	312.75	310	265.7	263	–	–	225.7	212
46	*Xenentodon cancila*	Kankley	307	289	150	148	285.7	283	179.3	172	–	–	182	181.5
47	*Glossogobius giuris*	Bele	103	78	75	76	119.8	117	103.7	98	–	–	97	96
48	*Anabas testudineus*	Koi	112	81	52	68	170	171	62	61	–	–	67	65.5
49	*Macrognathus pancalus*	Pangkal	175	167	90	91	187	195.5	93	89	–	–	97	96
50	*Setipinna* spp.	Paasa	–	–	–	–	–	–	–	–	1100	1078	–	–
51	*Lates calcarifer*	Vetki	378	372.5	412	410.5	64	62.5	105	104	–	–	–	–
52	*Anguilla bengalensis*	Ban	137	133	76	74.8	58.5	57	108	109	54.5	53	–	–
53	Prawns and shrimps	Chingri or kucho chingri	675	689.5	2000	1978	975	1021	670	654.5	1450	1377.2	630	541
	Total		8519.9	8100.5	6145.3	6034.4	8042.1	7879.7	5268.05	5449.5	10215.5	3209.7	4346.25	4172.2

Table 9.14 Decade-wise trend analysis of selected 27 freshwater fishes of South West Bengal

SL. no.	Local name	Scientific name	1960	1970	Decline %	1980	Decline %	1990	Decline %	2000	Decline %	Mean decline	Category
1	Rita	*Rita rita*	236.50	203.70	13.87	169.06	17.01	101.46	39.99	37.72	62.82	33.42	VU
2	Batasi tengra	*B. batasio*	196.30	180.70	7.95	90.00	50.19	35.20	60.89	20.50	41.76	40.20	NT
3	Gento	L. guntia	183.80	163.20	11.21	123.50	24.33	93.50	24.29	48.50	48.13	26.99	NT
4	Pat tengra	*M. cavasius*	296.20	262.33	11.43	214.50	18.23	61.66	71.25	18.20	70.48	42.85	VU
5	Dorakata tengra	*M. vittatus*	232.13	200.70	13.54	175.60	12.51	107.60	38.72	39.60	63.20	31.99	VU
6	Nayna	*N. nandus*	156.00	132.50	15.06	78.60	40.68	32.50	58.65	4.50	86.15	50.14	CE
7	Swarna Punti	*P. sarana*	148.50	120.60	18.79	58.50	51.49	18.50	68.38	3.00	83.78	55.61	CE
8	Pabda	*O. pabda*	191.87	163.50	14.79	128.50	21.41	48.50	62.26	12.30	74.64	43.27	VU
9	Pabda	*O. pabo*	266.80	253.50	4.99	220.70	12.94	66.20	70.00	13.60	79.46	41.85	EN
10	Boal	*W. attu*	190.50	170.00	10.76	110.00	35.29	65.50	40.45	25.50	61.07	36.89	VU
11	Banspata	*A. coila*	174.30	112.50	35.46	89.60	20.36	77.50	13.50	18.50	76.13	36.36	EN
12	Fultusi	C. garua	158.50	123.40	22.15	109.60	11.18	89.40	18.43	32.50	63.65	28.85	VU
13	Bacha	*E. vacha*	185.70	157.80	15.02	122.50	22.37	93.20	23.92	20.50	78.00	34.83	EN
14	Pangas	*P. pangasius*	259.80	231.70	10.82	208.40	10.06	119.20	42.80	66.90	43.88	26.89	NT
15	Baghar	*B. bagarius*	87.20	68.80	21.10	54.30	21.08	38.60	28.91	25.50	33.94	26.26	LC
16	Magur	*C. batrachus*	254.30	224.50	11.72	176.50	21.38	104.20	40.96	61.20	41.27	28.83	NT
17	Goar aar	*A. gagora*	313.33	282.07	9.98	278.09	1.41	253.09	8.99	132.50	47.65	17.01	NT
18	Singi	*H. fossilis*	287.53	253.40	11.87	230.00	9.23	166.00	27.83	112.50	32.23	20.29	LC
19	Pholui	*N. nopterus*	287.80	266.66	7.35	225.30	15.51	86.05	61.81	33.95	60.55	36.30	VU
20	Shol	*C. striatus*	211.12	174.15	17.51	154.50	11.28	112.20	27.38	71.50	36.27	23.11	LC
21	Mourola	*A. mola*	279.60	252.30	9.76	213.90	15.22	111.50	47.87	59.80	46.37	29.81	NT
22	Koi	*A. testudineus*	257.50	226.13	12.18	188.70	16.55	90.80	51.88	35.16	61.28	35.47	VU

23	Lata	*C. punctatus*	224.20	196.16	12.51	152.50	22.26	64.13	57.95	27.66	56.87	37.40	VU
24	Pangkal	*M. pancalus*	217.13	182.00	16.18	151.40	16.81	84.60	44.12	47.50	43.85	30.24	NT
25	Arr tengra	*A. seenghala*	310.50	250.40	19.36	215.60	13.90	150.00	30.43	89.20	40.53	26.05	NT
26	Cheng	*C. orientalis*	255.10	225.14	11.74	190.86	15.23	97.20	49.07	49.00	49.59	31.41	NT
27	Ilish	*T. illisa*	254.30	224.50	11.72	190.00	15.37	83.06	56.28	44.60	46.30	32.42	NT

FMV decline after 2000 in case of critically endangered (**CE**) **= > 80 [2** species]; endangered (**EN**) **= 75–80** [**3** species]; vulnerable (**VU**) **= 50–75** [**9** species]; near threatened (**NT**) = 40–50, [**10 species**]; least concern (LC) **= <40** [**3 species**]

Table 9.15 Identification of causal factors responsible for depletion of fishes (N = 30)

SL. no.	Causal factors	Ranking by farmers										RBQ Values	Re-ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Ichthyotoxic materials (plants/ chemicals)		**5**						**1**			**16**	**VI**
2	Habitat destruction	**16**		**3**								**61.33**	**I**
3	Fishing during breeding seasons	**10**						**1**				**34.63**	**II**
4	Introduction of exotic fish species			**5**							**1**	**13.63**	**X**
5.	Occurrence of flood and siltation.		**9**									**27**	**IV**
6	Water pollution by wastes from human settlements				**2**			**1**		**1**		**6.65**	**IX**
7	Pesticides used for agriculture	**4**		**6**	**4**							**38.6**	**III**
8	Excessive and nonjudicious use of water		**7**				**2**					**24.3**	**V**
9	Use of nonrestricted nylon thread fishing gears		**6**									**18**	**VII**
10	Human population explosion		**1**		**4**							**12.3**	**VIII**

RBQ = $\sum^{n}$ **fi (n + 1−i)/Nn × 100**
where *N* total number of fishermen or key informants, i.e., **30**; ***n*** number of ranks, ***i*** rank position; and *fi* frequency of **i**

Channa striatus **36.27%**, *Amblypharyngodon mola* **46.37%**, *Anabas testudineus* **61.28%**, *Channa punctatus* **56.87%**, *Macrognathus pancalus* **43.85%**, *Aorichthys seenghala* **40.53%**, *Channa orientalis* **49.59%**, and *Tenualosa illisa* **46.30%**. Decadal mean of **FMV** of different other species would have been as follows*: Rita rita* **149.69**, *Batasio batasio* **104.54**, *Lepidocephalus guntia* **122.50**, *Mystus cavasius* **170.58**, *Mystus vittatus* **151.13**, *Nandus nandus* **69.82**, *Puntius sarana*

Table 9.16 Quantum of production of fishes during the year 2000–2002 (from market survey, expressed in Kg/year) in main landing centers of six rivers and their associated water bodies

SL. no.	Name of fishes	Common name	Midnapore (Kansai) 2000–2001	Midnapore (Kansai) 2001–2002	Dehati (Keleghai) 2000–2001	Dehati (Keleghai) 2001–2002	Rohini (Subarnarekha) 2000–2001	Rohini (Subarnarekha) 2001–2002	Dhadika (Shilabati) 2000–2001	Dhadika (Shilabati) 2001–2002	Kolaghat (Rupnarayan) 2000–2001	Kolaghat (Rupnarayan) 2001–2002	Bankura (Dwarkeswar) 2000–2001	Bankura (Dwarkeswar) 2001–2002
1	*Labeo rohita*	Rui	225	237	212	201	290	302	170	171.5	–	–	165	167
2	*Labeo calbasu*	Kalbasu	125	119	95	88.5	131	128	102	98.5	–	–	90	88
3	*Labeo bata*	Bata	320	298	75	79	250	248	82	81.5	–	–	79	76
4	*Labeo boga*	Bangan	173	174	50.5	49.5	167	177	75	16	–	–	78	76.5
5	*Cirrhinus mrigala*	Mrigal	92	72	75	78.5	103	108.5	82	81	–	–	84.75	81.5
6	*Catla catla*	Catla	252	267	115	98	305	288.5	117	112	–	–	105	102
7	*Puntius sophore*	Puthi	280.6	264	202.7	160	288	267	235.8	237.5	–	–	230	219.5
8	*Puntius ticto*	Puthi	175.8	157	55.7	61	180.8	165.5	180.7	123	–	–	185.75	181.5
9	*Puntius sarana*	Swarna-puti	–	–	2	1.5	1	–	–	–	–	–	–	–
10	*Hypophthalmichthys molitrix*	Silver carp	200.7	210.5	172.4	189.5	310.75	297	173.8	177	–	–	153.75	155
11	*Cyprinus carpio*	Cyprinus	55	58	35	54	62	64	42	41.5	–	–	39	37.5
12	*Ctenopharyngodon idella*	Grass carp	105	111	90.5	110	110	117.5	100.8	88.5	–	–	98	97.5
13	*Mystus bleekeri*	Golsha tengra	405	387	290	287	432	429	328	281	–	–	281	277
14	*Mystus cavasius*	Pat tengra	190	178.5	35	32.5	180	167.5	105.5	97	–	–	125	119
15	*Mystus gulio*	Nuna tengra	54	47	61.5	52.8	35	28.5	54	51.5	–	–	–	–
16	*Mystus vittatus*	Dorakata Tengra	69.5	62	71.5	69	65.5	49.2	62	58.5	–	–	–	–

(continued)

Table 9.16 (continued)

SL. no.	Name of fishes	Common name	Midnapore (Kansai)		Dehati (Keleghai)		Rohini (Subarnarekha)		Dhadika (Shilabati)		Kolaghat (Rupnarayan)		Bankura (Dwarkeswar)	
			2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002	2000–2001	2001–2002
17	Aorichthys aor	Arr	215	210.5	115	113.5	70	71	175	168	76.5	78	45	43
18	*Aorichthys seenghala*	Arr tengra	405	378.5	–	–	202	197.5	–	–	129.5	126.5	–	–
19	*Ompok bimaculatus*	Puffta	310	303.5	–	–	180	173	170	161	–	–	–	–
20	*Ompok pabda*	Pabda	78	71	32	27	19	17.5	14	12.5	–	–	–	–
21	*Ompok pabo*	Pabo	51.5	45.5	47	39.5	53	49	37	33.5	–	–	–	–

Table 9.17 Identification of causal factors responsible for depletion of fishes (**N** = **30**)

SL. No.	Causal factors	Ranking by farmers I	II	III	IV	V	VI	VII	VIII	IX	X	RBQ Values	Re-ranking of causal factors
1	Ichthyotoxic materials (plants/ chemicals)		**5**						**1**			**16**	**VI**
2	Habitat destruction	**16**		**3**								**61.33**	**I**
3	Fishing during breeding seasons	**10**						**1**				**34.63**	**II**
4	Introduction of exotic fish species			**5**							**1**	**13.63**	**X**
5	Occurrence of flood and siltation		**9**									**27**	**IV**
6	Water pollution by wastes from human settlements				**2**			**1**		**1**		**6.65**	**IX**
7	Pesticides used for agriculture	**4**		**6**	**4**							**38.6**	**III**
8	Excessive and nonjudicious use of water		**7**				**2**					**24.3**	**V**
9	Use of nonrestricted nylon thread fishing gears		**6**									**18**	**VII**
10	Human population explosion		**1**		**4**							**12.3**	**VIII**

RBQ = $\sum^{n}$ **fi (n + 1−i)/Nn × 100**
where *N* total number of fishermen or key informants, i.e., 30, *n* number of ranks, *i* rank position, and *fi* frequency of i

69.82, *Ompok pabda* **108.93**, *Ompok pabo* **164.16**, *Wallago attu* **112.30**, *Ailia coila* **94.48**, *Clupisoma garua* **102.68**, *Eutropiichthys vacha* **115.94**, *Pangasius pangasius* **177.20**, Bagarius bagarius **54.88**, Clarias batrachus **164.14**, *Arius gagora* **251.82**, *Heteropneustes fossilis* **209.89**, *Notopterus nopterus* **179.95**, *Channa striatus* **144.69**, *Amblypharyngodon mola* **183.42**, *Anabas testudineus* **159.66**, *Channa punctatus* **132.93**, *Macrognathus pancalus* **136.53**, *Aorichthys seenghala* **203.14**, *Channa orientalis* **163.46**, and *Tenualosa illisa* **159.29**.

Table 9.18 Identification of causal factors responsible for depletion of *Eutropiichthys vacha* (N = 30)

SL no.	Causal factors	Ranking by farmers I	II	III	IV	V	VI	VII	VIII	IX	X	RBQ values	Ranking of causal factors
1	Habitat destruction	**9**	**4**	**4**				**7**	**1**			62.37	2
2	Water pollution by wastes from human settlements			**5**				**6**		**7**	**1**	26.07	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**			**5**	**5**		22.11	8
4	Introduction of exotic fish species			**5**	**3**			**6**		**7**		32.67	6
5	Fishing during breeding seasons		**4**	**11**	**2**				**5**			50.49	3
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	34.64	5
7	Pesticides used for agriculture				**12**	**2**		**4**				36.96	4
8	Excessive and nonjudicious use of water	**1**		**1**			**6**		**3**	**5**		21.51	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation	**15**		**2**			**6**	**4**			**2**	70.02	1

For trend analysis, **175** respondents were put to an interactions in order to identify and assess the decadal decline of different fish species (**27**) in terms of time and visibility of the target species in the near and around surroundings. Decade-wise trend analysis of **27** selected freshwater fishes of Southwest Bengal generated mean decline value based on which the following conservation categories have been determined, taking into consideration the guidelines put forward by the **IUCN** (2001) regarding the different conservation categories. In this work five different conservation categories have been made based on the following criteria (Patra et al. 2005): **critically endangered** (**CE**), the decline of **FMV** after last decay should be **>80**; endangered (**EN**), the decline of **FMV** after last decay should be **75–80**; vulnerable (**VU**), the decline of **FMV** after last decay should be **50–75**; near

Table 9.19 Identification of causal factors responsible for depletion of *Ompok pabo* (**N** = **30**)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**9**	**4**	**4**				**7**				61.38	1
2	Water pollution by wastes from human settlements	**1**		**1**			**6**		**3**	**5**		21.51	7
3	Use of nonrestricted nylon thread fishing gears	**1**		**1**		**5**	**6**		**5**	**5**		31.41	6
4	Introduction of exotic fish species							**6**		**7**		12.54	8
5	Fishing during breeding seasons			**11**	**2**	**5**			**5**			48.51	3
6	Ichthyotoxic materials (plants/chemicals)			**5**	**3**			**6**		**7**	**1**	33	5
7	Pesticides used for agriculture	**15**		**2**					**1**			55.77	2
8	Attack of disease (epizootic ulcerative syndrome)			**2**				**4**	**1**		**2**	12.21	9
9	Sluggish behavior		**3**						**2**			10.89	10
10	Occurrence of flood and siltation				**10**	**2**		**7**		**2**	**3**	38.6	4

threatened (**NT**), the decline of **FMV** after last decay should be **40–50**, and least concern (**LC**), the decline of **FMV** after last decay should be <**40**.

9.7.5.1.12 Fish Magnitude Value (FMV): Assessment of Trend of Decline of Biodiversity

Fish magnitude value (**FMV)** has been designed and calculated from the vertical and horizontal logics. In this case, both the geographical distribution and temporal dimensions were taken care of while calculating the fish magnitude value (Patra et al. 2005; Mishra et al. 2009).

Table 9.20 Identification of causal factors responsible for depletion of *Ailia coila* (**N = 30**)

SL no.	Causal factors	Ranking by farmers										RBQ values	Ranking of causal factors
		I	II	III	IV	V	VI	VII	VIII	IX	X		
1	Habitat destruction	**10**			**12**			**4**				**66**	**1**
2	Water pollution by wastes from human settlements			**9**		**2**				**2**		**29.03**	**6**
3	Use of nonrestricted nylon thread fishing	**1**		**1**			**6**		**5**	**5**		**21.51**	**8**
4	Introduction of exotic fish species gears		**4**	**4**				**7**				**31.68**	**5**
5	Fishing during breeding seasons	**1**		**1**		**2**	**6**		**3**	**5**		**25.47**	**7**
6	Ichthyotoxic materials (plants/ chemicals)				**10**			**7**		**2**	**3**	**34.64**	**4**
7	Pesticides used for agriculture	**15**		**2**				**4**	**1**		**2**	**61.71**	**2**
8	Excessive and nonjudicious use of water							**6**		**7**		**12.54**	**9**
9	Sluggish behavior		**3**						**2**			**10.89**	**10**
10	Occurrence of flood and siltation		**3**	**11**	**2**				**5**			**47.52**	**3**

The contention was that fish species had declined not only over a geographical space but also over the time. Scoring by villagers showed low amidst a declining trend, and population of indigenous fish species in the natural habitats (irrigation canals, rivers, and its tributaries) has been reduced drastically between **1960** and **2000**.

The research outcome of trend analysis is used to depict the nature of decline of a species over decades through applying **participatory rural appraisal** (**PRA**) **techniques**. This is an innovative technique relying basically on the perceptual assessment by the fishermen of different age groups (**60** to **70** years old) about the decline of different fish species not only over time but also over distribution, **e.g.**, the fishermen assessed what have been the availability of a fish species in a given decade (**60s**) in terms of scores designed by themselves, and this score value [**yield Kg/**area of occupancy (**Km**)] was multiplied by the visibility range **vis-à-vis** the extent of their occurrence, say visible in **5–7** Km radii area, and this ultimately helps calculating the status of that very species in that decade.

This type of calculation over decades would delineate by what percentage the decline has been occurring since the benchmark decade. To avoid the biases in the perceptual assessment made by an individual farmer, the total score value of a group was divided by the number of members of that very group to have an interpolated value in the form of a mean:

$$\textbf{Mean of FMV} = .\textbf{Yeild X area of occupancy}.$$

Number of responding fish farmer. It was scintillating to observe that total fish magnitude values have been plunged abruptly for all the species under study between the decades of **1990** and **2000**. So special research thrust is to be organized to isolate the critical factors responsible for such an abrupt decline of all these local fish species.

The problems related to why fish population has gone a sharp decline over the decades were **12** in number [habitat destruction, use of nonrestricted nylon thread fishing gears, application of ichthyotoxic materials derived from local plants and chemicals used for agriculture, fishing during breeding seasons, water pollution by wastes from human settlements and industries, siltation, excessive and nonjudicious use of water, human population explosion, occurrence of flood, attack of disease (epizootic ulcerative syndrome), sluggish behavior of some fishes, and introduction of exotic fish species], among which in each cases, ten problems were restricted for the detection of causal factors responsible for depletion of fishes.

9.7.5.1.13 Plants Used for Stupefying Fish in Southern West Bengal, India

Fish harvesting with the help of toxic plant extract has been an age-old practice in various parts of the world. However, the techniques employed and plants/plant parts being used vary from country to country.

This practice of fish catching following traditional methods has recently attracted the attention of both scientists and entrepreneurs all over the world. A large number of plants used for stupefying fish from different Indian states have been reported by various workers, from the southern part of the state West Bengal, India, comprising of erstwhile three contiguous districts: Bankura, Midnapore [undivided; now Midnapore (East) and Midnapore (West)], and Hooghly (**22–23.3° N; 86–88.3° E**). Biogeographically, the whole area is a mosaic of different landscape types ranging from highly fertile alluvial plains to densely covered dry deciduous forests crisscrossed by six principal rivers **viz.** Dwarakeswar, Kansai, Keleghai, Rupnarayan, Silabati, and Subarnarekha – having a vast tract of seasonally or annually flooded riverine waterlogged depressions that support **104** fish species both migratory and local (Table 9.20).

A large cross section of rural fishing community, tribal and non-tribal, both having main agrarian economy, subsists on these aquatic ecosystems for livelihood during the lean periods of the year. To facilitate fish capture and to obtain good quantity of fish, they use local plants as fish-stupefying agent or fish poison.

These people love and enjoy fishing, often spending the whole day with their families even collecting a negligible amount of fish. For stupefying fish, selection of suitable site is very important (Mishra et al. 2009). In most of the cases, shallow water bodies, especially with slow-running water, is preferred over flowing streams since chances of plant parts used being swept away are greater in these lotic systems. The selected plants or plant parts are crushed directly in or near water body or crushed outside and thrown into the water.

The effect of fish poison makes fish perplexed momentarily, thus restricting its movement all of a sudden and finally forcing it to float on water surface, and thus capturing is facilitated and done. People's observation about stupefied fish is that plant-based ichthyotoxins cause damage to the eye and nerve. Fishes losing consciousness thus become sluggish and move uncertainly. Similar observations were also reported by present and earlier workers. This preliminary study (Mishra et al. 2002, Mishra et al. 2003a, b) during the six (**6**) seasons of two (**2**) consecutive years (**2000–2001**) reveals **14** ichthyotoxic plant species under **13** genera covering **11** dicot families (Table 9.3).

9.8 Conservation Strategy: Common People's Participation

There is an urgent need for conservation and revival of fishes whose populations have significantly declined. Possible conservation measures include eco-restoration, protective and preventive measure, in situ and ex situ conservation, and creation of mass awareness.

9.8.1 Conservation and Endangered Ecosystems Act

Sustainable bioresource management aims at maintaining a sound balance between optimum utilization of bioresources and simultaneous renewal of the same.

This should take into account the merit and demerits of resource utilization of the past and present, so that the need of the moment is satisfied and carrying capacity of natural resources is kept in reserve for fulfilling the future requirements. While sustainable bioresource management includes a broad spectrum of components, viz., better education; improved access to basic needs such as water, food, and shelter; etc., the viable ecosystems are seen as the basic life-support system. Successful ecosystem management for enhancing fish production usually depends upon the creation of partnership between the different users, managers, and beneficiaries. Thus, for sustainable development of common property resource, it is essential to involve local communities and other stakeholders.

It is often easier and more appropriate to work with existing groups of stakeholders rather than trying to create new interest groups. A mechanism should be sought for bringing together representatives of the various categories of stakeholders for participatory rural appraisal (**PRA**) to identify constraints and differences, resolve conflicts, review progress, make collaborative management decisions, etc.

The salient aspect of the approach is the local communities, their members are the experts, and the outsider is the learner one. Conservation is broadly defined as the management of a natural resource in such a way to provide assurance for the maximum benefit to the human being in the near future. Conservation embraces several components such as preservation, protection, maintenance, sustainable utilization, and eco-restoration.

9.8.1.1 Need for the Conservation

Natural resources are unlimited, this concept is no longer valid. All natural resources are finite in quantity and can be so overutilized or abused as to reach a point, where they are for all practical purposes no longer renewable. Therefore, all the so-called waste materials coming out from the utilization of natural resources should be recycled for its reuse.

It should always be remembered that biotic resources are, in fact, the object of human exploitation to meet the basic necessities of life and living. The exponentially growing human population is not only consuming the resources increasingly but also degrading the quality and disturbing the natural process of resource recycling.

Problems relating to conservation are the outcome of the following factors: rapid increase of human population, increasing industrialization and urbanization, degradation of environmental quality, excessive consumption of resources, and various types of pesticides used in agriculture for obtaining higher yield of food grain and vegetables in many states of India as well as in West Bengal, India.

A survey on the availability of pesticides used in the three districts in West Bengal indicates that chlorinated hydrocarbon pesticides are more frequently used by the farmers than any other category of pesticides. The chlorinated hydrocarbons are not easily broken down by the bacteria, other water quality parameters, and processes, but they are retained in soil, organic debris, bottom biota, aquatic insects, plankton, and fishes (Jhingran 1988). The simulated studies showed that several types of pesticides and inorganic fertilizers reduce the growth of fish even at sublethal levels and also reduce the frequency of fishes as well as the hatching success of the fertilized eggs of the fish (Konar 1977).

Sediment load represents one of the important aspects of hydrology of stream. These were probably due to dissolved solid, suspended solid, and bed load, **i.e.**, sand and clay deposition in the river bed. The relative importance of these categories depends on geological structure and climatic conditions of these areas where the river or drainage basin was situated (Michael 1988). The runoff from agricultural fields and denuded forests results in siltation of the riverine beds.

Dwarkeswar, Kansai, and Keleghai rivers and their tributaries were subjected to this kind of sedimentation load and siltation, which besides diminishing the flow of water results in the destruction of breeding grounds of fishes and benthic fauna, migration of fishes, and decline in overall productivity of these rivers and their associated water bodies.

In the abovementioned ecological background, the Ninteen (**19**) study sites belonging to 6 rivers, it was revealed that water of Midnapore (**SI**) in Kansai River, Khirai (**SIII**) and its associated water bodies, Dehati (**SIV**) and its surrounding wetlands in Keleghai, Garbeta (**SIX**) in Shilabati River, Rajgram (**SXIV**) and its associated water bodies, and Chandur (**SXVII**) and its adjoining water bodies in Dwarkeswar River were in good condition than other study sites.

The water quality of the Dwarkeswar River was assessed with the help of physicochemical as well as biological parameters. The results of this monitoring approach were presented as a case study of biological monitoring application in conjunction with physicochemical monitoring. It was observed from such study that the water quality of Dwarkeswar River at Rajgram and Chandur with their associated other water bodies was quite better than other sites of these river. The same results were noticed at different study sites, **viz.**, **SI**, **SIII**, **SIV**, and **SIX** with their associated water bodies.

With the help of participatory rural appraisal (**PRA**) method, decade-wise trend analysis (from **1960** to **2000**), and fish magnitude value (**FMV**), it was confirmed that there has been severe decline in the freshwater fish fauna in Southwest Bengal in general and other food and game fishes in particular. Out of **103** species of fishes, **27** species were recognized as highly depleted fish population, among which *Nandus nandus* was subjected to abrupt decline between **1960** and **2000** (mean decline **86.15%**) followed by **Puntius** sarana (**83.78%**). The decline of **FMV** after 2000 in other species would have been as follows: *Rita rita* **62.82%**, *Batasio batasio* **41.76%**, *Lepidocephalus guntia* **48.13%**, *Mystus cavasius* **70.48%**, *Mystus vittatus* **63.20%**, *Ompok pabda* **74.64%**, *Ompok pabo* **79.46%**, *Wallago attu* **61.07%**, *Ailia coila* **76.13%**, *Clupisoma garua* **63.65%**, *Eutropiichthys vacha* **78.00%**, *Pangasius pangasius* **43.88%**, *Bagarius bagarius* **33.94%**, *Clarias batrachus* **41.27%**, *Arius gagora* **47.65%**, *Heteropneustes fossilis* **32.23%**, *Notopterus nopterus* **60.55%**, *Channa striatus* **36.27%**, *Amblypharyngodon mola* **46.37%**, *Anabas testudineus* **61.28%**, *Channa punctatus* **56.87%**, *Macrognathus pancalus* **43.85%**, *Aorichthys seenghala* **40.53%**, *Channa orientalis* **49.59%**, and *Tenualosa illisa* **46.30%** (Table 9.12).

Several anthropogenic activities in and around the riverine tracts such as large-scale water abstraction for channel irrigation; development of hydroelectric projects; construction of dams, reservoirs, and barrages; siltation; large-scale deforestation coupled with soil erosion and dumping and releasing of pollutants especially from the from industrial, agricultural, and municipal activities; using of pesticides and inorganic fertilizers; and such others have all had destructing effects on the fish stock of these rivers. Depth and width of channel and water current appeared to be very important factors of the environment.

Overexploitation coupled with loss of fish seeds were also other important factors for the decline of these fish genetic resources. All these factors led to the need for formulating out strategies of judicious exploitation of commercially important fish species, protection of these stocks from any sort of stress including pollution of the water and soil for improvement of the inland fishery, and conservation of the rich fish germplasm resources of this area.

9.8.1.2 Enactment of Endangered Ecosystems Act

The Endangered Ecosystems Act is a formal recognition of the importance of saving species which are threats of varied intensities. Alongside achieving some success, this act bears some lacunae as it does not pinpointedly address the major reasons that led to make species endangered, namely, the ecodegration or even loss of crucial ecosystems.

Thus, a level of diversity higher than biodiversity has appeared to be more effective in maintaining ecosystem diversity. Ecosystem diversity holds on several other ecosystems within short ranges, such as rivers with floodplains, associated wetlands, and even riparian forests on the bank of rivers, ensuring protections of such chain of ecosystems means protecting many threatened species.

Noss and Scott (1997) considered that critically endangered ecosystems suffer more than **98%** decline in the area which was formerly occupied normal diversity of organisms. They are of opinion that much could have been done to reduce the loss but continued pressures, especially the form the economic continue the pattern of transformation of many of the endangered ecosystems.

And all these have necessitated the enactment of Endangered **Ecosystem** Act, mainly with an aim at protecting the endangered species along with protecting endangered ecosystems in order to arrest further damage, recovering of eco-degraded critical ecosystems, and promoting more eco-monitoring and surveillance to generate useful baseline research information for better eco-management, protection, and conservation.

9.8.1.3 Threatened Categories

The earlier method of grouping of fishes into different categories, **viz**., threatened, extinct, endangered, vulnerable, and rare, has been put to different criticisms and thrown into a stressed situation for their subjective nature and abstractive dimension. The **IUCN Council** adopted the latest version in this regard (IUCN 2001; Red List **Categories and Criteria**, Version **3.1**) as a result of comments from the **IUCN** (IUCN 1994) and Species Survival Commission (**SSC**) memberships (IUCN 1998) and from a final meeting of the Criteria Review Working Group in February 2000, and the version incorporated changes of the earlier categories into nine categories, viz., extinct, extinct in the wild, critically endangered, endangered, vulnerable, near threatened, least concern, data deficient, and not evaluated. Critically endangered,

endangered, and vulnerable species belong to "**threatened**" category, and all the nine categories as per the **IUCN Version 3.1** have been defined as follows: the Endangered Species Act **(ESA)** of **1973**, reauthorized again in 1988, states that a species is endangered when it has been pushed to a point where it suffers an imminent danger of becoming extinct if protection is provided.

The act also provides provisions for the protection of the threatened species which are judged to be in jeopardy, but not on the brink of extinction. After assigning the status of threatened or endangered to a species, laws specify several penalty measures, such as substantial fines, for killing, damaging, and illegal trading of the species or its parts.

Extinct (EX) A taxon (species) is designated as extinct only after confirmation of the death of the last surviving individual of that species. The confirmation implies the failure of recording of the species after an exhaustive surveys on the habitats of that species eat appropriate times (diurnal, seasonal, annual), and also by framing survey schedule in tune of taxon's life cycle and life form.

Extinct in the Wild (EW) A taxon (species) is considered as extinct in the wild when any individual under the same species is not recorded from its from its population or habitat but only seen in the cultivated or domesticated forms.

Critically Endangered (CR) A taxon (species) appears to be critically endangered only when the best available evidence indicates that it meets any of the criteria (IUCN 2001) for critically endangered species, and it is going to be at an extremely high risk of extinction category in the wild if the causal factors continue operating.

Endangered (EN) A taxon (species) is named as endangered when the best available evidence indicates that it meets any one of the criteria (IUCN 2001) for endangered species because of the reduction of its numbers to a critical levels along with the drastic destruction of its habitats that the species is deemed to be in immediate danger of extinction.

Vulnerable (VU) A taxon (species) is assigned the treatment status as vulnerable only when it meets any one of the criteria for vulnerable based on existing available evidences (IUCN 2001), and it tends to move into the endangered category with in a short time if the causal factors continue operating.

Near Threatened (NT) A taxon (species) is appeared to be in the category of near threatened after completion of its evaluation against the criteria that does not qualify for the categories of critically endangered, endangered, or vulnerable now, and therefore, it is presumed that this species is likely to qualify for a threatened category in the near future.

Least Concern (LC) A taxon (species) is least concern when it does not fit to any threatened categories because of its higher abundance in its natural habitats.

Data Deficient (DD) A taxon (species) is data deficient because of the availability of dearth baseline research information regarding its abundance, distribution, and population in order derive at conclusion regarding the to make a direct or indirect assessment of its risk of extinction.

Not Evaluated (NE) A taxon (species) is denoted as not evaluated when no evaluation against the criteria for a threatened species is possible.

Based on the **PRA** (**participatory rural appraisal**) method, which includes several subcomponents such as **FMV** (**fish magnitude value**), **decade-wise trend analysis** (from 1960 to 2000), and **RBQ** (**rank-based quotient**) analysis, it has been possible by the research survey conducted in the Southwest Bengal of India to determine the conservation category of these **27** fish species which still enjoy considerable demand in the market by virtue of their nutrient status and palatability (Mishra et al. 2009).

Out of these **27** species, **2** species were ranked as critically endangered (**CE**), **3** species were categorized as endangered (**EN**), **9** species were remain as vulnerable (**VU**), **10** species were determined as near threatened (**NT**), and **3** species were listed as least concern (**LC**). From the **RBQ** analysis dealing with probable reasons for the causes of depletion of abundance of fishes were highlighted (Tables 9.7, 9.8, 9.9, 9.10 and 9.11) (Mishra et al. 2009).

A species has at least any of the following criteria:

1. Decline in the modes of occurrence and abundance of species in a striking rate
2. Absence of species in the geographic areas and habitats earlier inhabited by the species
3. Considerably lower presence of the total number of alive species having breeding potential
4. Expected proportionate declining of the density of the species in tune with the projected decline of the population along with the continuation of habitat destruction
5. Increased probability of extinction of the depleted population of the species within a specific number of years or future generations of the species

9.8.1.3.1 Rank-Based Quotient (RBQ): An Innovative Approach to Identify the Causal Factors of the Decline of Species Population

RBQ analysis was constructed mainly for five threatened fishes (two critically endangered, **viz.**, *Nandus nandus* and *Puntius sarana*, and three endangered, viz., *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha*). In case of *Nandus nandus*, attack of disease (epizootic ulcerative syndrome) has considered as the most important factor followed by sluggish behavior, occurrence of flood and siltation, habitat destruction, pesticides used for agriculture, application of ichthyotoxic materials (plant products or synthetic chemicals), fishing during breeding seasons, use of nonrestricted nylon thread fishing gears, excessive and nonjudicious use of water, and introduction of exotic fish species. In case of *Puntius sarana*, habitat destruction has been considered as the most important factor followed by pesticides used for agriculture, water pollution by wastes from human settlements, fishing during breeding seasons, introduced exotic fish species, attack of disease (epizootic ulcerative syndrome), occurrence of flood and siltation, use of nonrestricted nylon thread fishing gears, sluggish behavior, and usage of ichthyotoxic materials (plant chemicals) for the depletion of this fish species.

RBQ values of *Ompok pabo*, *Ailia coila*, and *Eutropiichthys vacha* revealed that habitat destruction, occurrence of flood and siltation, pesticides used for agriculture, and fishing during breeding season are the first four causal factors for their depletion. In order to ensure conservation of all those rapidly depleting fish population, an attempt has been made for the artificial production of fish seeds employing updated induced breeding technology for two species of fish, **viz.**, *Puntius sarana* and *Mystus cavasius*, as a part of in situ conservation measure.

It has been possible to produce a good number of fish juvenile of this two threatened fishes and distribute to the farmers for their subsequent culture and propagation. Positive response was found for *Mystus cavasius* with a single dose of "**Ovatide**" with a single dose of **3 ml**/Kg to female and single dose of **1.5 ml/Kg** to male, and this appeared to be very significant for commercial seed production (Mishra et al. 2001).

Such program involving local fisherman along with their existing infrastructure may be further extended if different government agencies and research institutes can take up the responsibility to restore these natural resources. Therefore, this research venture with the financial assistance of the Department of Science and Technology and **NES**, Government of West Bengal, India, has taken into consideration the assessment of the environmental status of habitats of freshwater fishes, documentation of floral and faunal diversity including fishes, quantum production of fishery resources, studies on the biology of two threatened fishes, evaluation of the stress factors responsible for the depletion of fishery resources with the active participation of local people, assessment of conservation categories of selected fishes, and application of recent technology for the mass-scale production of seeds of already threatened fishes for their propagation and conservation.

9.8.2 Research Outcomes Based on PRA Methods

The research outcomes of research work for a period of **3** years, it was possible to document the diversity of flora (**113** species) and fauna (**254** species) of different freshwater wet-lands, rivers and their associated water bodies of Midnapore (West and East), Bankura and Hoogli districts of Southwest Bengal.

Physicochemical parameters of water and soil of these water bodies were also recorded to assess the environmental health of the habitats of different bioresources and also to understand the seasonal dynamics of those parameters and their relationships with the biological organisms. From the people perceptions, it was noted through **RBQ** analysis that the pollution of water by pesticides and heavy metals appeared to cause depletion and also loss of aquatic biodiversity, but it was not possible in this research venture to estimate the concentration of pesticides and heavy metals of water, soil, flora, and fauna of the studied aquatic ecosystems because such analysis would require more financial involvement.

A methodology has been devised based on participatory rural appraisal (PRA) method for the determination of the conservation categories of different commercially important finfishes. Out of such **27** finfishes, **24** species were found to belong under threatened category, of which **2** species were ranked as critically endangered (**CE**), **3** species were categorized as endangered (**EN**), **9** species were given the status as vulnerable (**VU**), and **10** species were determined as near threatened (**NT**).

For the propagation and simultaneous conservation of these threatened fishes, proper hypophyzation technique was applied (Mishra et al. 2001). Through the involvement of fisherman community, the main objectives of this research venture would be achieved if proper protection of fish habitats along with their genetic resources be done given due importance through different fisheries act and laws formulated by the Government of India.

9.9 Methods for Environmental Assessment of Study Areas

9.9.1 Application of Geographic Information System (GIS) Software for Mapping Study Sites

A **Geographical Information System (GIS)** as a repository of relational database acts as foundation for mapping and also for spatially distributed modeling.

All the data layers containing information of the topography, water features, forests, built structures, etc. can be stored in two forms: (**1**) Linear features, such as roads or rivers, are stored in vector form as a series of azimuths and distances tracing the path of the landscape feature. (**2**) Other attributes, such as topography, soil type, land use, or vegetation type, may be represented with vectors enclosing a polygon(s) or as matrices of position and attribute data in primary layers.

For example, topography is mathematically represented with a **digital elevation model (DEM)** with **x** and **y** as longitude and latitude, easting and northing, or **UTM** grid coordinates and **z** as elevation above the mean sea level. For other layers, identification numbers or attribute (integer) codes to differentiate soil, vegetation, or land-use types are the **z** value at a given (**x**, **y**) location.

Secondary layers are formed with the attribute data (as real numbers) pertaining to a primary layer (soil, thickness, infiltration capacity, and permeability or vegetation density, biomass, and condition). **GIS** layers also may be comprised of point data, such as building, wells, small water bodies, or other features of limited or discrete size (Wetzel and Likens 2004).

Point line and area (polygon) data can be combined to map and model interrelationships, calculate areas, or create new layers. For example, the **DEM** is routinely used to generate a slope layer (by calculating the change in elevation between adjacent grid cells). The slope layer can be used to estimate flow path (cell-to-cell linkages from the watershed divide to stream valleys) and contributing area (upslope of any given grid cell). These derivative layers are valuable for watershed modeling and management.

In sum, a **GIS** provides analytical and operational capabilities that were once limited to small experimental watersheds for a wide range of needs (Wetzel and Likens 2004):

(a) **In the initial stage** of **GIS** spatial database development, various analogue maps, which were in different scales obtained from different organizations, will be converted into digital format by using manual digitization method using GIS software.
(b) **In the second stage**, digital image processing of the satellite data will be carried out for extraction of pertinent information. The **IRS-P6** LISS-III and LISS-IV and **RADARSAT** data will be classified using supervised and unsupervised classification technique. The land-use maps of the **10**-year sequence will be prepared, and the original extent of the land-use change will be compared to compute an overall change patterns in each land-use class.
(c) **The third stage** focuses on bringing up all essential components of GIS platform for further processing and analysis.
(d) **The fourth stage** is with the objective of constructing composite information set to explain various queries in the spatial context through an integrated analysis of multidisciplinary data sets. **GIS** and land use are natural partners, as both of them deal with spatial data. The land-use change evaluation with respect to subsurface water changes will be provided.

GIS-based assessment for basic morphometric characteristics of lakes, streams, or rivers needs a reasonably accurate hydrographic survey facilitated with surveying equipment supplemented by obtaining aerial photographs in order to get the outline of the lake or streams. This is followed by the measurement of the shoreline sand formulated section by section. Most shoreline surveys use the traverse method, in which a series of points are connected by straight lines of known lengths and angles from each other.

Sophisticated methods of point location and survey are possible by the use of the Global Positioning System, where coordinates are determined from triangulation from satellites (Wetzel and Likens 2004). The salient features of the natural resources like rock outcrop patterns, lineaments, drainage patterns, vegetation patterns, soil phase and texture, and land-use patterns were interpreted and evaluated from **LANDSAT** products of different seasons and also the aerial photographs by using the interpretation elements like the shape, pattern, tone, and texture.

The courses of the prior stream channels were reconstructed and mapped from the aerial photographs, and a drainage map showing the present and prior stream channels was also prepared. The geomorphic characteristics of the meandering rivers, viz., amplitude, meander length, meander width, width of the existing channels, etc., were computed, and relationships between them were established.

The existing nadis and tanks were also interpreted and mapped. The changes in the land use, morphology of the landforms, and their changes due to degradation, flood, water pollution, etc. can also be detected and mapped from the temporal **LANDSAT** images of different seasons by additive color viewer (I2S), reflection projectors, and Zoom transfer stereoscope. The geomorphic characteristics of the catchments, meandering rivers, and sand dunes calculated in the laboratories were also checked in the field, and necessary corrections in case of any difference were made based on the ground truth of the land and vegetation resources.

The special characteristics of the landforms and vegetation were digitally analyzed and tabulated from two **computer compatible tapes (CCTs)** of **LANDSAT MSS** (bands **5** and **7**) – and with high-power computer with standard peripherals (image analyzer console, line printer, graphic display terminal, magnetic tape drivers, input scanner unit, solid-state refresh memory).

9.10 Selection of Study Sites: Design of Boring Activity at Onda, Bankura, District, West Bengal, India

9.10.1 Lithological Information: Prerequisite for Boring Activities

A survey based research study was conducted in the vier beds of fresh water riverine networks of south West Bengal Bengal, India in order to derive information of the lithological characteristics of the riverine beds and to develop understanding on the surface water-ground water interactions so that strategies for sustainable water resource management could be chalked out (Chakraborty et al. 2013). To understand the subsurface lithology and river morphology, **950** slim bores, **36** test wells, and **180** observatory wells were drilled in the selected study sites (Manbazar on Kansai River at Purulia District, and Onda, Joypur and Indus on Darakeswar River at Bankura District, West Bengal, India) on both the river beds (Kansai and Darakeswar) and on the river banks. At each site, **three test** wells were constructed. For each test well, **four** observatory wells were drilled, **2** were located at a distance of **185 m** away from each test well, and the rest **2** were drilled more than **30 m** away from the test wells. As far as yield is concerned, the starting point of the sampling site of the riverine stretch of Onda is being recommended as probable suitable for water withdrawal (Chakraborty et al, 2013).

Variations in the depth of slim bores: In Onda, out of **189** slim bores, the average depth of the layers varied from **2.5** to **8 mt**. In Indus, out of **186** slim bores, the average depth of the layers varied from **6** to **20 mt**. In Joypur, out of **191** slim bores, the average depth of the layers varied from **5** to **16 mt**. Yield test for Joypur block also has revealed the maximum possibility of water withdrawal from the starting point of the riverine bed, while at Indus, also the starting point appears to be the suitable site for water withdrawal. At Manbazar block, of Puroulia district of West Bengal, India on Kansai River, **5 km** downstream (site **3**) may be recommended for suitable water withdrawal. Drawdown test conducted also revealed maximum decline of water level is just a little more than 1 m after **72 h** of pump test with **100** mm pipe and **5** horsepower pump especially in the middle stream of Joypur and middle stream of Indus.

At Manbazar I, drawdown was found to be considerably low ranging from **11** cm at **5** km downstream to **18** cm at initial point. Sedimentological analysis has revealed almost similar sediment stratification in **three** sites of Dwarakeswar River of Bankura having a maximum percentage of coarse sand (**70%** at Onda, **72%** at Indus, **73%** at Joypur) and **65%** at Manbazar I on Kansai River followed by medium sand (**10%** at Onda, **11%** at Indus, **13%** at Joypur, and **15%** at Manbazar I). The silt, clay, fine sand, and gravels remained below 4% in all sites. However, at Manbazar I, higher occurrences of larger coarse sand blended with broken gravels have been noted in comparison to different sites of Dwarakeswar. Detailed textural analysis also showed higher percentage of sand (**97.6–99.75%**) in all sites except a few sampling sites at Manbazar I on Kansai River, Purulia District, where only big and small gravels were found.

The porosity of the sediment is a measure of how much water sediment contains, whereas permeability determines how fast water can flow through the soil. Effective porosity is the volume percentage of a sediment sample that consists of interconnected pores through which water can flow. In the present study, porosity ranged from **24%** to **46%** with the respective specific yield of **3%** to **19%**. The specific yield is controlled by grain size of different soil profiles. Specific retention decreases rapidly with increasing grain size. Specific yield is at its maximum in medium grained sands because porosity decreases with increasing grain size. Relationship between permeability and specific yield has shown that aquifers having a high specific yield tend to be more permeable.

This research study has also revealed the unconsolidated sediment profile of the rivers flowing through lateritic undulating landscape depicting higher permeability, porosities, and hydraulic conductivities (permeability in respect of water). Sediment, having higher sand percentage and gravels, especially at Manbazar I, shows higher hydraulic conductivities as in the present study areas. On the other hand, in order to understand groundwater flow rates and slopes of the water tables, the reciprocal of hydraulic conductivities in hydraulic resistance.

Good aquifers have a low resistance to flow and require only relatively shallow hydraulic gradients. The volume of water in an aquifer is calculated as the storage coefficient, termed as storativity, which is exactly the same as specific yield in water table aquifers. The storage coefficient is defined as the volume of water released from a unit volume of the aquifer for a unit decline in head.

The water quality parameters of both surface water and groundwater during different seasons and from different sites have been found to be well under permissible limits. Although negligible microbial load have been detected from the groundwater, water after normal treatment process can be served as drinking water. Analysis of pesticide residues is currently under way:

1. Fist (top) layer – medium sand, average **2 m** thickness, bright whitish color
2. Second layer – mud, average **2 m** thickness (within river course)

3. Third layer – courser sand, average thickness **2 m**
4. Fourth layer – very courser sand and gravel, average thickness **3 m**
5. Fifth layer – gravel and boulders or nodules size rock materials found in one cross-sectional part with **>0.5** m thickness

9.10.2 Sloping Pattern of River Bed

Average gradient of river bed within the selected river course is **10,500 m** length). Maximum elevation is **73.15200 m**, while minimum elevation is **57.6072 m**. So the gradient of this part = **(73.15200 m–57.6072 m)/10,500 m = 15.5448 m/10,500 m = 0.0014**. Maximum height of river bank (left) is **4.3** m; minimum height of river bank (left) **0.3 m** (almost flat with sand deposition); maximum height of river bank (right) **6.0** m; and minimum height of river bank (left) **0.5** m (almost flat with sand deposition).

9.10.3 Design of Boring Activities

Total number of cross section is **21**, total number of test bores **3**, total number of slim bores (in **30** m interval) **240**, average number of bores per cross section **11–12**, maximum boring depth **16.76** m, minimum boring depth **2.43** m, and average boring depth **6.7** m.

9.10.4 Pumping Cycles

Management of water resources in order to achieve sustainability takes into consideration the requirements of water both for ecosystem and for the human beings. Baseline information pertaining to interconnectivities between surface water and groundwater resources also help profusely to ensure successful water resource management as a prerequisite to achieve the goal, **i.e.**, sustainable water management of these resources. Management of groundwater and surface water systems in an integrated manner is impeded by the laws and policies of the countries concerned.

Most of the countries across the world have their separate rules and regulations for managing groundwater and surface water resources because of the significant seasonal variability of surface water supplies which contrasts to the fluctuation of groundwater use and supply on annual basis: groundwater budget and change in groundwater storage. The aquifers underlying the Central Valley receive water through deep percolation from the land surface, seepage from rivers and lakes, conveyance and delivery system recharge, and subsurface inflow from surrounding small watersheds. Outflows from the groundwater system to rivers and lakes, and to on-farm tile drains are primarily through groundwater pumping (Brush et al. 2013). The groundwater budget for the **C2VS**im model reports the beginning and ending of groundwater storages as well as inflows and outflows to/from the groundwater as summarized below (Dogrul 2012b):

1. **Deep Percolation**: Precipitation and excess irrigation water percolating through the unsaturated zone and entering the groundwater.
2. **Gain from Stream**: Water losses from streams that enter the aquifer system. Recharge from conveyance and delivery canal system and recharge to the aquifer from injection wells (artificial recharge).
3. **Boundary Flows**: Net inflow into the aquifer through the boundaries including flows from the small watersheds.
4. **Pumping**: Total pumping from the groundwater.
5. **Other Flow**: Water lost from lakes that enter the aquifer system, flow released out of groundwater storage due to subsidence, and flows from the groundwater into tile drains; these flows are generally not significant compared to the other flows, and they are grouped. When an aquifer is pumped, the water withdrawn is either taken out of storage, which means groundwater levels decline, or water is taken from other sources, including natural recharge, deep percolation, flows from boundaries of the groundwater basin, and seepage from stream.

9.10.5 Components of Pumping Test

Pump test is an important tool in the realm of hydro-geological study which mainly estimates the capacity and performance of the wells in order to highlight the potential and hydro-geological characteristics of both confined and non-confined aquifers. It also helps to understand the influence of well and aquifer's abilities to store and transmit water and also to ensure possible hydraulic connection to surface water.

A pumping test includes two major objectives: firstly, pumping of groundwater from a well maintaining a constant rate and, secondly, an estimation of the change in water level (drawdown) in the pumping well and any nearby wells (observation wells) or surface water bodies during and after pumping. The entire duration of traditional pumping test generally ranges from **24** to **72 h** depending on the extent of aquifers and other geohydrological features especially the interconnectivities among surface and subsurface water and groundwater (**Figs.** 8.1 **to** 8.4).

9.10.6 The Criteria for the Selection of Pumping Rates and Other Operational Components

The well should be pumped in accordance with the desired pumping rate which should not be rated above the pumping rate used during the test. Wells should not be

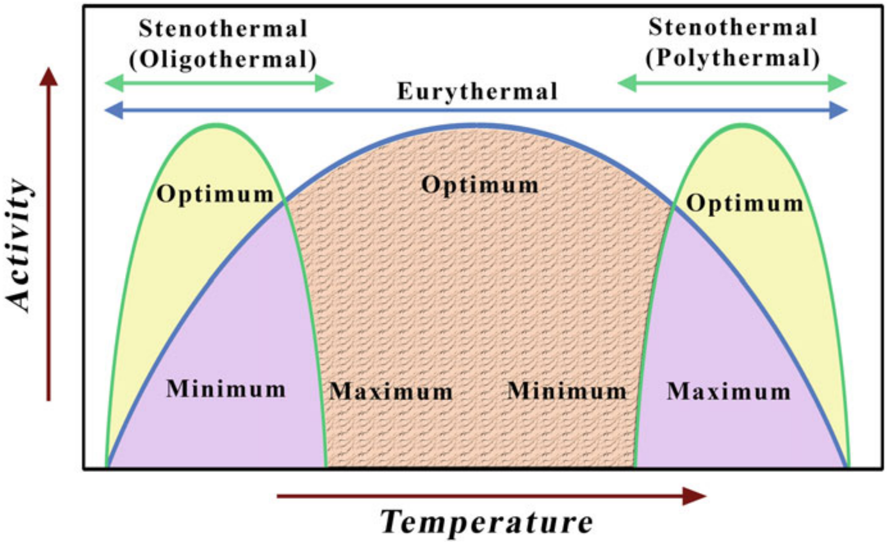

Fig. 9.1 Graphical representation depicting different levels of tolerability of living organisms

pumping of the well should be geared as per the recommendations of the manufacturers of the pump. This precaution can resist the prospective damage to the well or a sand/gravel pack developed around the well. For those wells which are constructed in unconsolidated sediments, having more sands and gravels than silts and clays with an open bottom (no well screen) should not be pumped at a rate which could cause the dislodging of aquifer materials and subsequent blocking up of the pump. In contrast, over pumping in the bedrock wells may result in exceeding the drawn down of water level over the uppermost level of water bearing fracture, because of the possibility of damaging the aquifer formation at the borehole and also in well interface due to the combined actions of water turbulence and turbidity of the available and extracted water also rendered hindrance, and inhibition to the pumping capacity (Fig. 9.1).

9.10.7 Boring Process: Sustainability of Water Resources

Extensive boring operations have been undertaken in the riverine beds of **four** selected study sites, viz., Onda, Indus, and Joypur on Dwarkeswar River in the Bankura District and Manbazar in the Kansai River in the Purulia District in the state of West Bengal, India. The term environmentally sustainable level of extraction is called sustainable yield of water (Figs. 9.2, 9.3, 9.4 and 9.5).

The exceeded level of water extraction from particular aquatic system inputs stress to the different ecosystem processes and the productive base of the resources. The groundwater extraction regime is estimated over a preplanned and

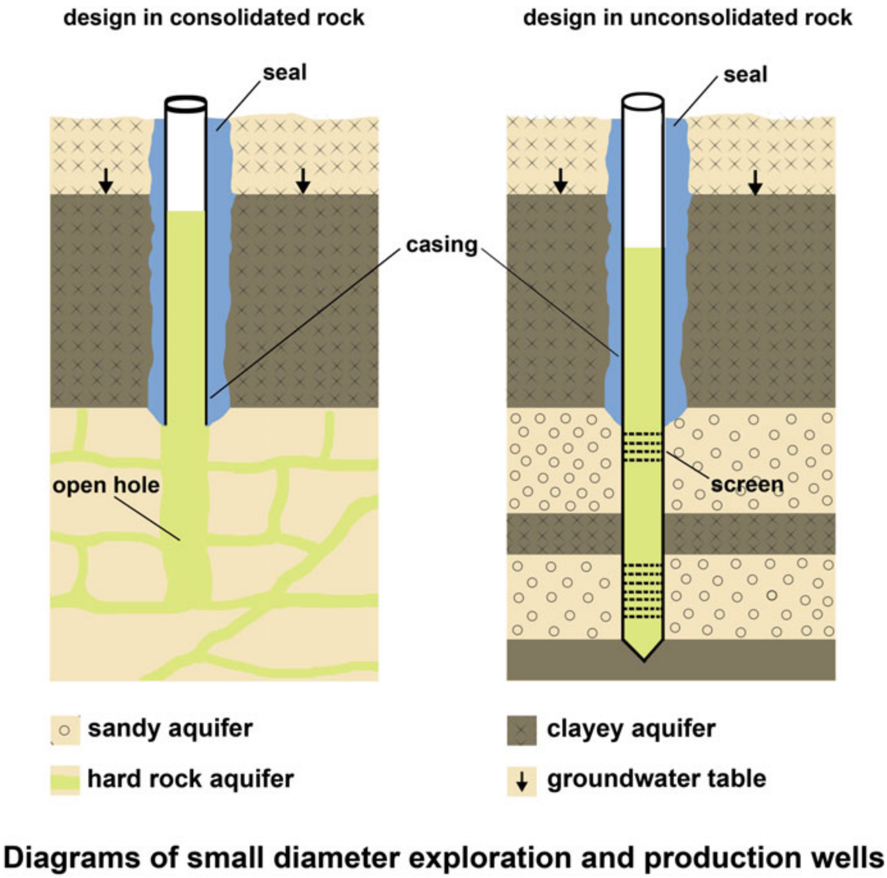

Fig. 9.2 Boring pipe insertion for studying cycle

predetermined time frame which tends to impose stress within the desired level and thereby save economic, social, and environmental values. The approach to the implementation of sustainable groundwater yield may include extraction regime of groundwater, acceptable level of stress on the groundwater, storage depletion trend to assess the lowering of water levels, and protecting dependent economic, social, and environmental values of estimated groundwater yield (Chakraborty et al. 2013).

9.10.8 Extraction Regime

The extraction regime concept is a regime of groundwater extraction under a set of management practices that are defined within a specified time and space. It is the maximum volume that is being withdrawn in any single year. Care should be taken to keep a balance between the rate of withdrawal and rate of recharging to compensate the loss.

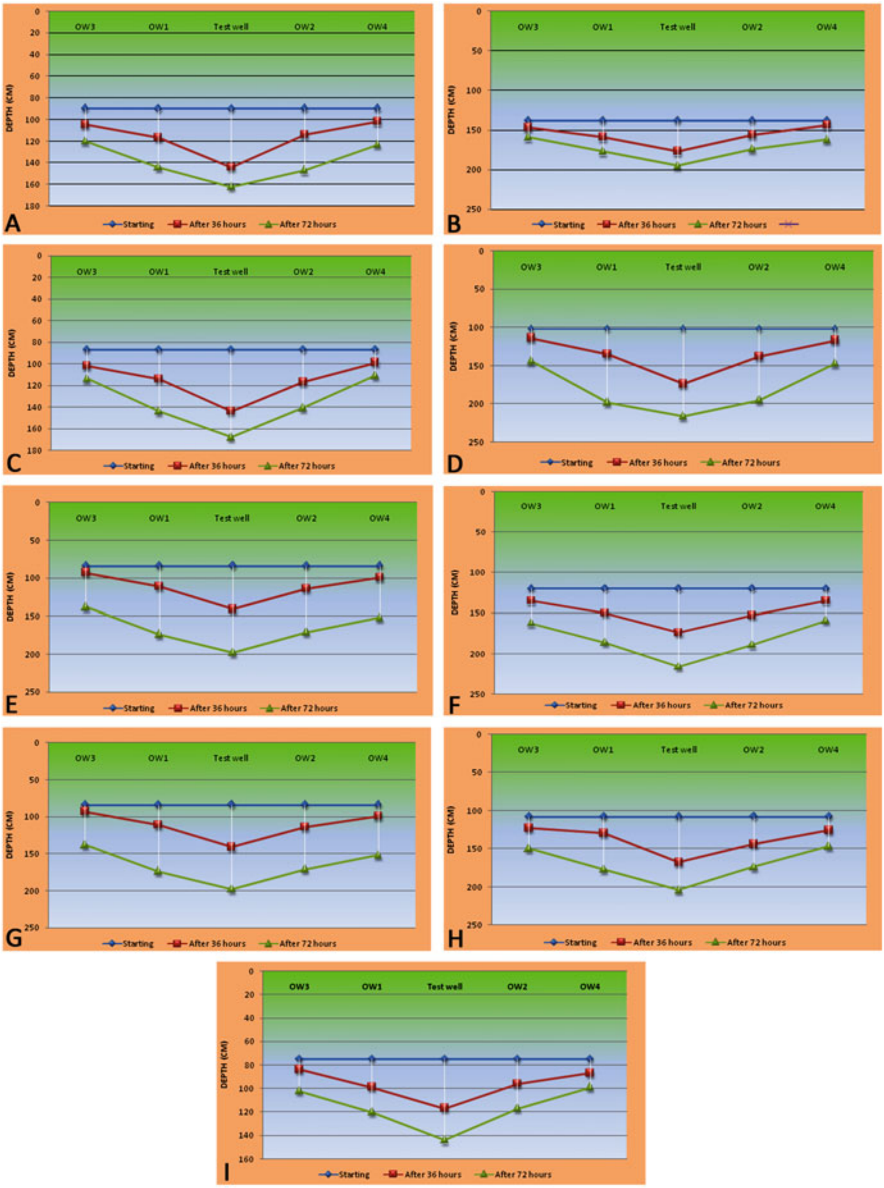

Fig. 9.3 Results of drawdown in the pumping cycle in 72-h duration

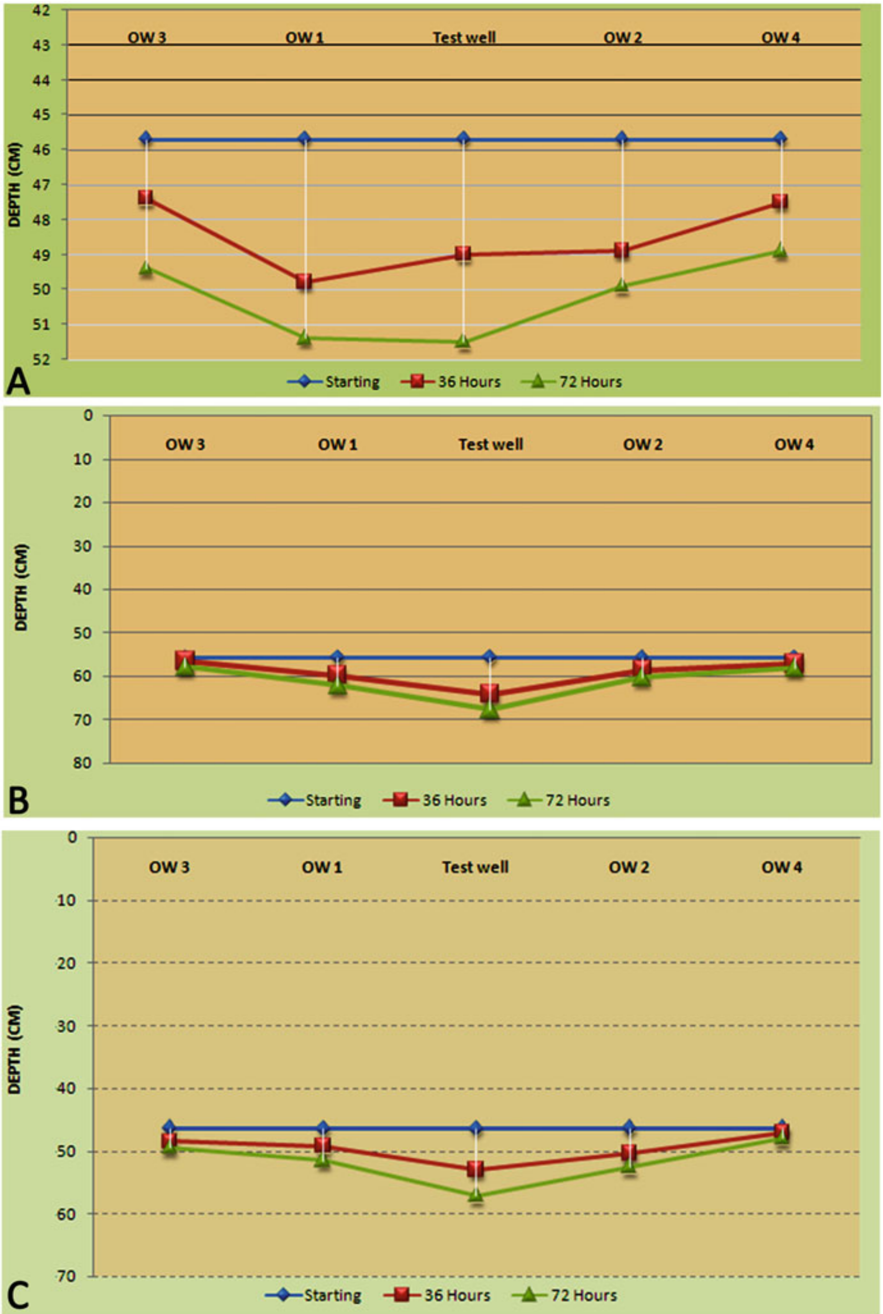

Fig. 9.4 Results of drawdown in the pumping cycle at specific site test well

Fig. 9.5 Photographs depicting different field activities relating to insertion of bore-well for studying pumping cycle (**A**–**D**): Geological, geomorphological and lithological assessment of different fresh water riverine beds of Bankura and Purulia , Districts of West Bengal; (**E** to **G**) Extraction and quantification of subsurface and ground water with the help of bore wells and test wells to generate data for the evaluation of draw-downs; (**H** to **L**) Field activities pertaining to the installation of bore wells and test wells at specified site mainataining requite distances based on the lithological assessment

9.10.9 Acceptable Levels of Stress

This approach recognizes that any extraction of groundwater of even any amount generally put different sorts of stresses on the total system of the water resources especially on the groundwater-dependent ecosystems. This concept being a controlling factor towards sustainable yield incorporates the necessity for trade-offs which in turn ensures balances among environmental, social, and economic requirements. In some cases, the stress may be temporary as the system adjusts to a new equilibrium. This holistic approach recognizes the interactions between aquifers and between surface and groundwater systems (Chakraborty et al. 2013).

9.10.10 Storage Depletion as a Parameter to Be Considered

The extraction of groundwater over any time frame results in an unacceptable depletion of storage which requires an assessment of that acceptability of that continuation and whether an intervening action is required to reduce the extraction. Major consideration in determining the acceptability of any specific level of storage depletion should be "**intergenerational equity**" and a balance between environmental matters identified in the National Principles for Provision of Water for Ecosystems and social and economic values. In this context, the sustainable yields of surface water can be estimated from the difference of the total available water resource and water used for the cological and anthopogenic purposes.

9.10.11 Sources and Values of Groundwater and Surface Water in the Studied River Basin

Potential and trend of water use: The combined estimated potential for the water supply of all the rivers in India is around **1900 Km^3** (billion cubic meters (**BCM**)), of which about **700 Km^3** is considered as the ultimate utilizable flow. Development of this scenario in respect of the water resources and its distribution in India is explained and correlated with the intensity and totality of rainfall of this country. Almost one-third of the potential rainfall of India is shared by the northeastern region; Cherrapunji in northeast of India, known as the wettest place in the world, remains underutilized. Out of so many rivers in India, the longest is the Ganga followed by the Brahmaputra, both of which are perennial rivers and cause massive damage to the plain river basin areas with floods every year (Environment Report, W. B. P.C.B. 2009).

9.10.12 Trends of Water Use

The total volume of water abstracted from all sources in and around the riverine networks of the Southwest Bengal, India, has increased substantially over the past 100 years. Total freshwater abstractions for agriculture ranked first followed by the utilization of water for public water supply. Household use is another important component of public water supply.

Industrial and commercial uses of water, both from the public water supply and by direct abstraction, have also been increasing during the couple of centuries because of the lack of awareness for environment. Besides, the total water resource and annual water budget of the districts understudy in the state of West Bengal, India can be assessed from the decadal data of in the forms of rainfall, runoff from neighboring regions, and replenishable groundwater (Chakraborty et al. 2013).

9.11 Values of Groundwater and Surface Water

The groundwater resources have multiple values, some of which are extractive while others are in situ. In considering trade-offs in resource values, due recognition should be given to environmental dependencies, and the risk of irreversible impacts and any decisions shall be made in accordance with the principles of ecological sustainable development. All surface water and groundwater originate from precipitation. Except during rainfall events, most surface water in streams and rivers is furnished by the slow release of groundwater as in the form of "**base flow**" which forms the primary source of water at the time of low river flow (Cartwright et al. 2005).

Groundwater serves as the prime supplier of water in most of the river basins including the present studied ones. A steady increase in the demand for the surface and groundwater resources during last couple of centuries has resulted in the river flow depletion and groundwater overdraft. Such steady increase in water use has threatened the sustainability of the water resources which has caused adverse effects of storage depletion, salinity intrusion, undesirable inter-aquifer flows, land subsidence, and groundwater contamination (Hanson et al.2002). Groundwater is also extracted for human uses in the river catchment areas and is now being considered as a possible alternative to direct stream extraction.

In the river basins having strong hydraulic connection between aquifers and river, groundwater extraction can lead to lowering of groundwater levels and a reduction of base flow from groundwater. In extreme cases, base flows can be reduced to an extent that the flow regime of the river catchment is fundamentally changed and rivers can shift from a perennial flow to an ephemeral flow regime (Glennon 2002).

9.11.1 Water Received as Runoff from Upstream Region

The quantum of runoff into geographical region lying in a particular basin is the runoff from the geographical region that lies upstream in the same basin. Treating the entire upstream region of the basin as a single entity and assuming that there is no flow of water from one basin to another, the runoff from the upstream region into the region at hand in a particular season can be evaluated following the undermentioned guideline (Environment Report, WB Pollution Control Board 2009):

Runoff from upstream region in current season = total water resources in upstream region in current season + quantity of previously intercepted water released in current season – evapotranspiration from upstream region in current season – infiltration in upstream region in current season – water intercepted in upstream region in current season, where total water resources in the upstream region in this season = rainfall in upstream region in current season + groundwater draft and discharge in upstream region in current season. Thus, runoff received from upstream region in current season = rainfall in upstream region in current season + groundwater discharge/

draft in upstream region in current season + quantity of water released from storage in current season – water intercepted in the region in current season – infiltration in the region in current season – evapotranspiration from the region in current season.

Precipitations tend to accumulate on the surface of the land and subsequently overflow the land surface as runoff, when the soil is saturated with the infiltration processes and capacity. The timing of runoff depends on the rate of precipitation over time as well as the infiltration capacity curve for a particular setting. In the study undertaken in the Southwest Bengal, India, it has been observed that the initial runoff was in the form of sheet flow over unchanneled ground, much of which ultimately on reaching the gullies and river channels drain large volumes of runoff loaded with eroded sediments to estuaries and then to ocean through the riverine networks (Chakraborty et al. 2013).

9.11.2 Groundwater–Surface Water Relationship

Groundwater flows through the subsurface and discharges to springs, lakes, rivers, and oceans. Groundwater flows on reaching to river beds, into the ground mostly by percolation and infiltration. These types of rivers may be hydraulically either connected to or disconnected from groundwater. Hydraulic connection implies surface water moves into the groundwater domain and vice versa, without encountering barriers to flow or unsaturated zones.

Effluent rivers occur mostly in the tropical humid regions of the world having the saturated water table very close to the land surface. These effluent rivers may become influent during the period of flooding, when the water levels within the rivers swell up and flow over the normal level with more currents and much faster flows than groundwater. Elevated river levels force some amount of water to seep into the channel banks.

Rivers may be effluent along some stretches and influent along others. A river flowing down a mountain may start out effluent but become influent near production wells that pump groundwater and induce infiltration of river water. Groundwater levels can be used for assessing the gaining or losing status of a surface water body. Higher groundwater levels (compared to the surface water elevation) usually indicate the surface water body is gaining groundwater. Conversely, lower groundwater levels often coincide with losing surface water conditions. Surface water that seeps into the ground can be an important source of groundwater recharge.

The present study has unearthed both subsurface and groundwater distributions of different study sites of Dwarkeswar and Kansai river beds. Conclusion: The research project has investigated the geomorphological, lithological, hydrobiological, microbiological, socioeconomic, and biological characteristics of the proposed study areas in order to evaluate the existing surface and subsurface flow characteristics so as to formulate and implement effective water recharge strategies incorporating government and public involvement.

Water is a "**common property resource**"; hence, for its effective distribution among people and proper utilization by people, people's participation is essential. For formulating policies that shall encompass people's participation, scientific investigation into the present status of the said resource is vital. Such studies not only generated awareness about current trends of the resource and the conditions pertaining to it but also shed light on the potential remediation and restoration strategies that can be adopted. The proposed study endeavors to do so with expert guidance from competent personnel and advanced infrastructural facilities of the proposing institution to find a solution to the growing problem of scarcity of freshwater resources in the arid tracts of the districts of Bankura and Purulia, West Bengal.

9.12 Sacred Grooves: Novel Approach for Biodiversity Conservation

The onward journey of human civilization on this planet from the primitive hunter-gatherers to the present high technology-based human society experienced a series of phases and the intervals in between different phases had encountered varied forms of anthropogenic activities and intervention on the natural set ups of the environment such as clearing of forests to give way to agriculture, industrial development with the help of new and newer scientific and technological innovations and inventions, and the experiences derived from such incidents ultimately paved the way for developing realization of the importance of natural gifts of nature, both living and nonliving ones. This has necessitated the initiation of pro-environmental thinking for the protection and conservation of biodiversity alongside several natural surrounds for their own survival and well-being (Ehrlich 2002). Human civilization now faces a number environmental crisis such as global warming, eutrophication, acidification, etc., out of which depletion or loss of biodiversity has appeared to be an important one because the very existence of humans is directly connected with it.

Virgin forests along with their biodiversity protected by the local people through generation after generation triggered by their cultural and religious beliefs manifested by different taboos and deities within tract of forest are designated as sacred groves These worships of natural patches of vegetation, valued and protected by the ancient societies, mainly based on their religious practices and cultural traditions known as sacred groves develop an interlinkages between man and his natural environment as well as his ecological prudence (Chandran and Hughes 1997).

Owing to the existence of vast diversity of ethnic culture in different parts of India, the nomenclatures of sacred groves also display variations of different local names (Gadgil et al. 2000). The Indian culture and traditions are closely intricate with the concern for the environmental conservation. Hence, there is a much scope to adopt this strategy for the conservation of biodiversity on religious ground in India.

In such context, the need of the hour is to develop a well-integrated and holistic approach involving existing status of the respective sacred grove to undertake ecological assessment of their roles for the conservation of biodiversity and also for formulating appropriate planning and strategies for their protection. Sacred groves being the reliable indicators of the ecological health of an area especially based on the potential of natural vegetation (Schaaf 1998) contribute profusely towards the well-being of the human society.

Sacred groves with assemblages of sacred trees act as the secured residences to so many birds and mammals and thereby facilitate conservation process of living organisms (Islam et al. 1998). Besides, a number of ecosystem services are provided by the sacred groves and maintain the desirable health such as conservation of soils, maintenance of hydrological cycle, restoration of soil erosion, availability of water of desired quality, natural dispersal of seeds of useful species, hindrance to habitat destruction, conservation of the viable population of pollinators and predators, etc.

The sacred groves also act as the source of propagules which enable the indigenous flora and fauna to flourish alongside preserving the cultural and ethical especially through indigenous knowledge of generations (Ramakrishnan and Ram 1988; Godbole et al. 1998; Godbole and Sarnaik 2004) (Figs. 9.6 and 9.7).

In such context, the following significant points can be highlighted with regard to developing proper awareness so that viable options can be developed for sustaining the economic condition of the peoples involved in the conservation of sacred grooves:

1. The traditional beliefs and knowledge should be provided with more attention in the process of protection and conservation of sacred forest patches including relict vegetation along with other biodiversity components of the concerned area.
2. The ongoing conflicts and contradictions between the traditional, local, or regional beliefs and the uprising of a number of the so-called economic and social issues to render the sacred grooves less effective should be amicably settled taking the local people into confidence in order to ensure sustainable eco-management of sacred groves and sacred sites.
3. Sacred groves having more unique in respect of their sizes, extent, and operational policies should be brought under the "**protected area network**" in order to strengthen the existing conservation strategies.
4. Attempts should be made to create mass awareness programs in order to make the peoples acquainted with and realized about the different ecological services rendered by sacred grove needs so that they should be convinced that the conservation of groves is of utmost essential for their sustenance.

9.13 Ethnozoological Potential of Animal Diversity

Since ancient times, different body parts and organs of animal bodies have been in use as medicinal substances by different groups of peoples having different cultures residing in different parts of the Earth. The twenty-first century is an era in which a

Fig. 9.6 Different sites of sacred grooves: (**A**) Chilkigarh Kanak-Durga Temple in the Jhargram District of West Bengal, India; (**B**) within Kuldiha Forest Sanctuary in the State of Odisha, India; (**C**) at Lodhasuli Forest of Jhargram District, West Bengal, India; (**D**) Idols of Bonbibi at Sundarbans, West Bengal, India; (**E**) near Galudih Subarnarekha Dam in the State of Jharkhand, India; (**F**) a typical tree sacred groove near Jharkhand and West Bengal border, India; (**G**) an artistic manifestation of the shelter built by local indigenous people depicting their traditional culture in tune with their natural settings; (**H**)–(**I**) local indigenous people by the side of Subarnarekha River, soldiers of sacred grooves, the custodian of nature and natural resources

great deal of effort and resources are being invested in the research of medicinal plants around the world. These studies are based mainly on historical, ethnic, and traditional sources of information (Costa-Neto 1999). The usage of animal extracts, products, and even secretions as medicines is thought to have coevolved with the evolutionary pathways of human beings and reached its highest acceptability during medieval period, which enjoys its existence in the present-day folk medicine across the globe (O'Hara-May 1971). India, with its diverse cultures and ethnicities, accommodates several isolated aboriginal human populations who have been practicing age-old healthcare systems (Modak et al. 2015).

One estimate made by the **World Health Organization (WHO)** has revealed that 80% of the world's population depend on traditional medicine for primary healthcare (Ekor 2013). The significance of recording the faunal biodiversity does not restrict only on the roles of wild fauna, both chordates and nonchordates in the food chain–food web dynamic of the riverine ecosystem, but also their contribution

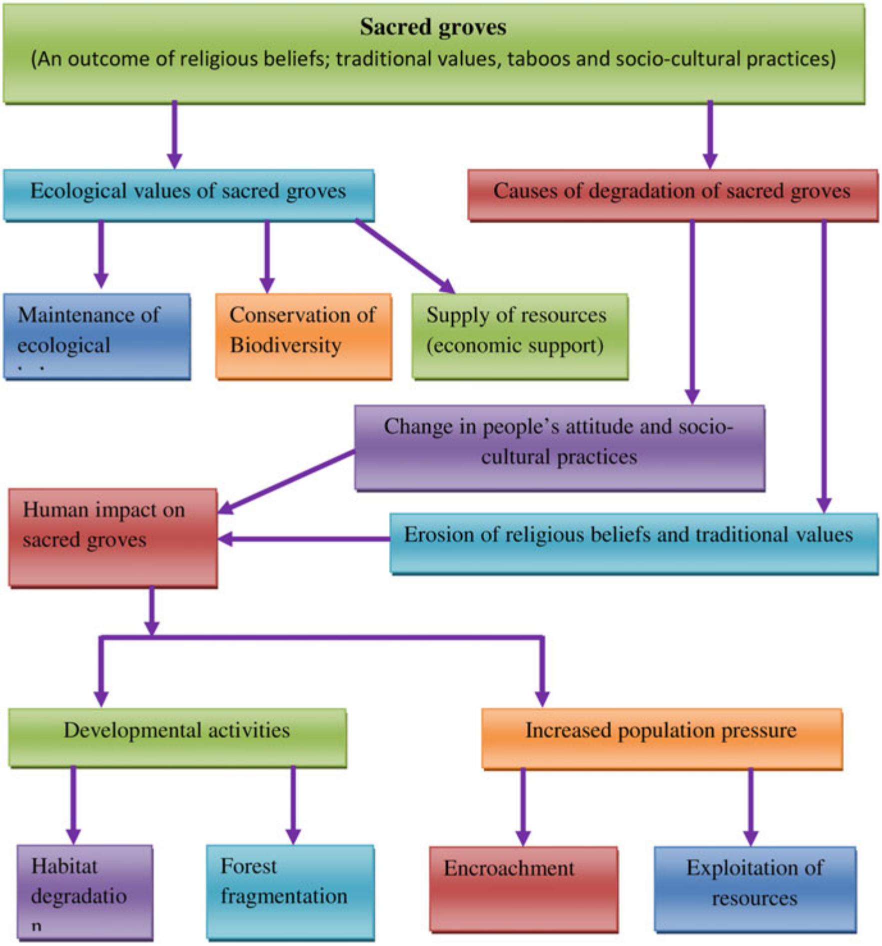

Fig. 9.7 A flow chart depicting different interconnected components for conservation of nature by scared grooves

in providing a lot of ingredients and commodities to the local peoples for the human healthcare purposes.

A new subject has emerged, known as ethnozoology, which mainly focuses on identifying natural products as ethnomedico-biologicals of the human healthcare system (Farnsworth 1990). These modes of medical treatment practices are preferred by local community over conventional treatments because ethnomedicines are cheaper, readily available, and efficacious and have fewer side effects (Modak et al. 2015). Many wildlife products are also used for ceremonial and religious practices as well as fetishes. Knowledge about animals that were used for remedial purposes in the past and are still used as such to the present day is part of traditional and ethnic medicine. Its importance lies in its fostering for better understanding of this phenomenon from historical, economic, sociological, anthropological, and environmental viewpoints throughout bygone centuries.

Several biomaterials from different faunal components have been in use for the biotherapy of human beings since the inception of human civilization such as the usage of blood of the black caiman (*Melanosuchus niger*, Spix 1825) for the treatment of epilepsy and cardiac problems and smashed products of the bodies of the ant species belonging to genus *Pseudomyrmex* for the treatment of toothache. The more potentiality of poisons as antipoison becomes more in the more poisonous animals (Werner 1970). El-Kamali (2000) has recorded **23** animals that are used as sources of remedies in the Sudanese traditional medicine. For example, external application of the fresh manure of a dromedary (*Camelus dromedarius* [Linnaeus 1758]) to the affected parts relieve and alleviate arthritis; use of honey can heal to some extent hepatic and gastrointestinal disorders, gastric ulcers, and wounds; the fats of the lion (*Panthera leo* [Linnaeus 1758]) and hyena (*Crocuta crocuta* [Erxleben 1777]) have been in use topically to alleviate abdominal pains; and the tusks of hippo (*Hippopotamus amphibious* [Linnaeus 1758]) are used for aphrodisiacs and ornamentals.

The drug development from a component of snake venom can be made successfully (Wied 1824). Administration of the aqueous extracts of shredded skins of *Naja naja* on pregnant female rats cause a decrease of urinary volume in a dose-dependent manner, increase urinary calcium output, reduce urinary magnesium, and increase urinary creatinine output (Mukherjee et al. 2013, 2019).

The choice of animal species in trado-medicinal preparations is guided by several factors, some of which include (**i**) the recognized bioactive ingredient(s) in the animal part, (**ii**) some behavioral ecological tendencies naturally associated with the animal or the concerned part, (**iii**) some mythological conceptions surrounding the animal, and (**iv**) the array of complimentary ingredients, faunistic or floristic, that oftentimes possess some behavioral ecological tendencies complimentary to that of the main fauna species as far as the condition to be treated is concerned.

The potentials of nonchordate metazoans for therapeutic use of leeches, one interesting annelids mostly prefer to live in the humid moist places in association with hydrophytes and also with the sediments, have been in use for treating some health problems of human beings such as abnormal swellings, piles, inflammatory abscess, skin diseases, rheumatoid arthritis, eye diseases, poisonous bites, erysipelas, etc. Insect-derived drugs are used in the treatments of immunological, analgesic, antibacterial, diuretic, anesthetic, and antirheumatic properties (Ratcliffe et al. 2011). However, the efficacy and safety of these animal-derived medicines are required for proper eco-toxicological testing prior to their application in order to encourage a broader acceptance and application of alternative treatment strategies. Another primary constrains for the conservation efforts is the nonjudicious utilization of selected flora or fauna for the purpose of medicines of food and this is designated as is the threatening effects on wildlife diversity because of overharvesting of animals and animal-derived products (Schmeda-Hirschmann et al. 2014). Illegal hunting and poaching have led to the rapid decline of many animals in their natural habitat, and measures are needed for their conservation and sustainable utilization.

9.14 Peoples Participation: An Emerging Issue on Biodiversity Conservation

The introduction of Peoples Participation (**PP**) in water management is a long and challenging process aimed at solving complex environmental, economic, and societal problems and increasing the sustainability of decisions. The global biodiversity has been under intensive threats because of a multitude of reasons such as habitat destruction, several pollutants coming out from the activities of modern industrial society, human population explosion, unplanned urbanization, excessive combustion of fossil fuels, introduction of exotic species, overexploitation of some targeted species, and so on and so forth. The reasons of enunciation of such detrimental causes leading to the loss of biodiversity have found to have direct connections with the culture, the structure of the economies, and the sociopolitical status of the actors.

In such context, conserving of biodiversity is in need of the participation of those people who are required to interact and change their perceptions towards biosphere in a great number of ways in order not only to enrich their knowledge base but also to address the plurality of reasons before taking up actions for conservation. Besides, independent efforts must be replaced by a collective ones so that prime objective of conserving biodiversity as maximum as possible can be fulfilled. Negotiating and developing collective agreement among the peoples with negative and destructive approaches to biosphere have appeared to be difficult mainly for two reasons: **First**, differences among different actors endowed with inherent or acquired destructive attitudes and activities accelerating the pace of biodiversity loss make the target inherently difficult to find common ground for reducing the destructive modes of interactions. **Second**, peoples are required to simplify the complex problems of biodiversity loss and also to find out suitable avenues in order to facilitate the formation of collective venture because politics associated with combating and arrest of biodiversity loss has mostly carried out those groups of people who seek particular combinations of simple strategies to meet the self-interest of all ends with renewed directions. As the development of common community consensus for the biodiversity management decisions forms the main structure of conservation planning, peoples attach more importance on their self-interest to gain short-term return as their livelihoods are entirely dependent on biodiversity. All these have necessitated to undertake more holistic, sustainable, and long-term conservation strategies for the conservation of biodiversity.

Public participation (**PP**) from the different strata of human society for the effective management of environmental resources has emerged as an important environmental issue and was identified by the United Nations in the year 1993 as one of the seven key elements for the long-term environmental program. The potential benefits of **PP**, associated with water resource management, are the better-informed decision-making and more creative solutions, more acceptance of water management and water prices, fewer implementation problems, and also social learning of all involved (Mostert 2003).

The second important issue is the greater involvement of nongovernmental organizations (**NGOs**) involving local peoples to strengthen the intersectoral cooperation for the sustainable water management, environmentally and economically. In order to introduce and fully implement **PP**, one should start with training and education of all the interested parties involved in (a) changing the decision-making culture, (b) empowering citizens and their initiatives, (c) making water and environmental management transparent and responsible, and (d) creating a framework to find a common solution (Chakraborty and Majumber 1995; Ramkrishna et al. 2014; Gadgil et al. 1993; Devi 2000).

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