INTER-RELATIONSHIPS OF WADERS AND MACROBENTHIC ASSEMBLAGES WITH REFERENCE TO ABIOTIC VARIABLES IN RESERVOIRS OF CENTRAL GUJARAT, INDIA

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सत्यं शिवं सुन्दरम्

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2013

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CERTIFICATE

This is to certify that the thesis entitled "**Inter-relationships of Waders and Macrobenthic assemblages with reference to Abiotic variables in reservoirs of Central Gujarat, India**" submitted by **Ms. Chandni Patel** for the degree of Doctor of Philosophy has been carried out under my guidance in the Department of Zoology, Faculty of Science, The Maharaja Sayajirao University of Baroda, Vadodara. The matter presented in this thesis incorporates the results of investigations of the independent researcher carried out by the researcher herself. The matter contained in this thesis has not been submitted elsewhere for the award of any other degree.

Dr. Geeta Padate
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13th September 2013

DECLARATION

I hereby declare that the entire work embodied in this thesis has been carried out by me under the supervision and guidance of Dr. Geeta Padate and to the best of my knowledge no part of the thesis has been submitted for any degree or diploma to this university or any other university or institutes in India or abroad.

Chandni A. Patel
Department of Zoology
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A THESIS SUBMITTED

TO

THE MAHARAJA SAYAJIRAO UNIVERSITY
OF BARODA

FOR THE DEGREE OF

DOCTOR OF PHILOSOPHY

IN ZOOLOGY

Dedicated to my

Grandfather, Grandmother

And in loving memory of my

Papa.....!

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CHANDNI A. PATEL

CONTENTS

INTRODUCTION

The inland freshwaters portray a diverse array of ecosystems such as lakes and river, ponds and streams, temporary puddles, etc. Although a small fraction of the world's water resource, these freshwater habitats show variety in their physical and chemical characteristics in comparison to the marine habitats. They may be lentic or lotic and perennial or transient (Subramanian and Jaiswal, 2012). Of these, wetlands are among the most important and productive ecosystems of the world, occupying about 6% of the earth's surface (Maltby and Turner, 1983). Wetlands provide key resources for different groups of organisms, including humans. Most of their functions can be classified into three major categories, namely hydrologic, biogeochemical and biological (Lewis, 1995). For example, some of their functions are improvement of water quality by retention and export of nutrients (Howard-Williams, 1985), supply of water for aquifer charge and recharge, and flood mitigation (De Laney, 1995). Wetlands also provide food for a wide range of aquatic organisms (van der Valk, 1989). Sustainable management of wetlands, however, requires detailed understanding of the factors controlling their community (Burroni *et al.*, 2011).

According to the Ramsar convention (1971), 'Wetlands are area of marsh, fen, peatland, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres.' One of the first widely used classifications systems, devised by Cowardin *et al.*, (1979), was associated to its hydrological, ecological and geological aspects, such as: marine (coastal wetlands including rock shores and coral reefs), estuarine (including deltas, tidal marshes, and mangrove swamps), lacustarine (lakes), riverine (along rivers and streams) and palustarine ('marshy'- marshes, swamps and bogs). Given these characteristics, wetlands support a large variety of plant and animal species adapted to fluctuating water levels, making the wetlands ecologically and critically significant. Utility wise, wetlands directly and indirectly support millions of people in providing services such as food, fibre and raw materials, storm and flood control, clean water supply, scenic beauty and educational and recreational benefits.

Freshwater habitats also provide a home to many species including phytoplankton, zooplankton, aquatic plants, insects, molluscs, fish and birds. They are organized at many levels from smallest building blocks of life to complete ecosystems, encompassing communities, populations, species and genetic levels (Pir *et al.*, 2010). These organisms are directly or indirectly dependent on the hydrological changes taking place in the freshwater systems they inhabit. Their hydrologic conditions can directly modify or change chemical and physical properties such as nutrient availability, degree of substrate anoxia, soil salinity, sediment properties and pH. These modifications of the physicochemical environment, in turn, have a direct impact on the biotic response in the wetland (Gosselink and Turner, 1978).

Wetlands of India

India, with its varied topography and climatic regimes support and sustain diverse and unique wetland habitats. Natural wetlands in India consists of the Himalayan lakes at high altitude, wetlands situated in the flood plains of the major rivers, saline and freshwater wetlands of the arid and semi-arid regions, coastal wetlands such as lagoons, backwaters and estuaries; mangrove swamps; coral reefs and marine wetlands, *etc*. In addition to various types of natural wetlands, a large number of man-made wetlands also contribute to the diversity of wetlands. These man-made wetlands, which have resulted from the needs of irrigation, water supply, electricity, fisheries and flood control, are substantial in number especially in arid and semi-arid zone. The various reservoirs, shallow ponds and numerous tanks support wetland biodiversity and add to the countries wetland wealth. It is estimated that freshwater wetlands alone support 20% of the known range of biodiversity in India (Deepa and Ramachandra, 1999).

Indian wetlands cover an area of about 58.2 million hectares (Prasad *et al.*, 2002). Wetlands in India account for 18.4% of the country's geographic area, of which 70% is under paddy cultivation (Garg *et al.*, 1998). There are about 14,657 natural inland wetlands covering about 14,32,628 hectare area and 23,444 man-made Inland wetlands covering about 35,58,916 hectare area. Majority of the inland wetlands are directly or indirectly dependent on the major rivers like, Ganga, Brahmaputra, Narmada, Godavari, Krishna, Kaveri, Tapti. They occur in the hot arid regions of Gujarat and Rajasthan, the deltaic regions of the east and west coasts, highlands of central India, wet humid zones of south peninsular India and the Andaman and Nicobar as well as Lakshwadeep islands (Prasad, *et al.*, 2002). A recent study has shown about 38% loss of inland wetland in India during 1971 to 2001 (Prasad *et al.*, 2004). Despite their key role, many wetlands have been lost or degraded because of the anthropogenic activities over the past century (Williams, 1997; Brown, 1998; Wood *et al.*, 2003). Wetland loss or degradation not only alter the community of aquatic invertebrates, but also affect other organisms linked to them. Many wetlands, have been drained, modified or created to produce or enhance agricultural crops and also treated as waste disposal areas around the world (Guptha *et al.*, 2011). Recent losses for wetlands worldwide have been among the fastest of any ecosystem type (Balmford *et al.*, 2002) with inevitable impacts on their characteristic species. Losses and changes are unlikely to diminish in the future as economic activity, agriculture intensification, global water scarcity and climate-change pressurise remaining wetland areas (Ramsar Convention, 2002). Loss or deterioration of wetlands, which represent highly valuable environments, is a worldwide phenomenon.

Wetlands of Gujarat

The state of Gujarat is bounded by Arabian Sea in the west, shares an international border with Pakistan on its north-western fringe and with Rajasthan in north and Madhya Pradesh in east. Its total geographical area is 1,96,024 sq.kms. which comprises of 6% of the total land area of the Indian sub-continent. Gujarat has the longest coastline of 1600 kms. Total wetland area of Gujarat is estimated to be 34,74,950 ha, which accounts for about 17.56 % of geographical area of the state. The major wetland types include Intertidal mud flats (22,60,365 ha), River/Stream (2,75,877 ha), Reservoirs/Barrages (2,48,979 ha), Creeks (1,49,898 ha) and Salt Marsh (1,44,268 ha).

The hydrological regime of the state is governed by the complex geo climatic condition. Most of the ground water resource is concentrated in the unconsolidated formation, covering about 40% of the area of the state. The surface water is dominantly concentrated in the southern and central parts of the state.

Wetlands in Gujarat are important habitats for wintering waterbirds. This region is also a key area for wintering water birds and migratory shorebirds (Deshkar, 2008). The only breeding sites for the greater and lesser flamingos in Asia are confined to the

Rann of Kachchh (Stanley, 2004). Information on total inland wetlands of Gujarat state and Vadodara district which are rain fed is given below (See table).

Area estimates of inland wetlands in Gujarat

Sr. No.	Wetland Category	Number of Wetlands	Total Wetland Area (ha)	% of wetland area
	Inland Wetlands – Natural			
1	Lakes/Ponds	40	23550	0.68
2	Ox-bow lakes/ Cut-off meanders	1	6	0.00
3	Waterlogged	278	20660	0.59
4	River/Stream	1039	275877	7.94
	Inland Wetlands – Man-made			
5	Reservoirs/Barrages	1214	248979	7.16
6	Tanks/Ponds	8818	73873	2.13
7	Waterlogged	34	13951	0.40
8	Salt pans	9	1295	0.04
	Total – Inland	**11433**	**658191**	**18.94**
	Vadodara District	**-**	**35553**	**1.02**

* National Wetland Atlas: Gujarat

Birds in Gujarat are well documented with the pioneering work by Salim Ali and Dharmakumarsinhji. In continuation of these studies late Prof. R. M. Naik and Prof. V. C. Soni (Saurashtra University, Rajkot) contributed to studies on avifauna of Saurashtra, Prof. B. M. Parasharya of Anand Agricultural University, Anand on agricultural ornithology, Dr. G. S. Padate of M. S. University of Baroda, Vadodara on birds of central Gujarat, Dr. I. R. Gadhvi of Bhavnagar University on birds of Kachchh and Bhavnagar and Dr. Nishith Dharaiya of North Gujarat University, Patan on birds of North Gujarat. However, naturalists and bird watchers like Shri Shivrajkumar Khachar and Shri Luvkumar Khachar, Shri Himmatkumarsinhji, Shri Lalsinh Raol, Dr. Bakul Trivedi and large number of amateurs and photographers have contributed to documentation of more than 500 species of birds of Gujarat. Gujarat having 17.56% of its geographical area under wetland and also being in part of Central Asian Migratory Pathway supports huge density of birds especially migratory during winter.

Waterbird communities are influenced by food accessibility, which often is limited by water depth within wetlands (Bolduc and Afton, 2004) and the abiotic factors in the wetlands (Jaksic, 2004; Lagos, *et al.,* 2008). Among these, the migratory shorebirds generally utilise very different habitats, great distances apart, during breeding and non-breeding (wintering) seasons (Hale, 1980; Lane, 1987; Piersma, 1997). On the wintering grounds their primary concern is fuelling up in recovery from, and preparation for, long distance migration (Battley *et al.*, 2003; Kvist and Lindstrom, 2003). Migratory shorebirds have a relatively high metabolic rate and the largest daily food requirements relative to body weight of any marine predator (Schneider, 1983). Further, they have characteristic bill-lengths and shapes, neck length, leg length and body sizes that allow them to feed at specific water depths (Zwarts and Wanink, 1984).

Many wintering waterbirds on their non-breeding grounds feed on macrobenthic fauna which become available at various freshwater wetlands. It is widely suggested that these birds choose to feed in places where they can get the most food in shortest time (Goss-custard, 1970; Hale, 1980; Quammen, 1982; Dann, 1987; Colwell and Landrum, 1993; Barbosa, 1996; Rippe and Dierschke, 1997). India is the core country of the Central Asian Flyway that supports 257 migratory species of waterbirds. Of these, 81 species are of conservation concern, including three critically endangered, six endangered and 13 near threatened species (Davidson, 2003).

A number of studies have reported that the distribution of feeding shorebirds is directly correlated with the density of their main prey and this relationship occurs spatially at both large scales and fine scales. Hence, prey density is an important factor in shorebird habitat selection along with the properties of the substratum (Grant, 1984). Though the importance of abiotic factors has long been recognized in the habitat preference of birds (Patterson, 1976; Murphy *et al.*, 1984) only recently investigators have concentrated on finding out how particular abiotic factor affects water-birds (Nagarajan and Thiyagesan, 1996; Takekawa *et al.*, 2006). Thus, quality of water is also important in water bird habitat assessment because a host of interacting physical and chemical factors can influence the levels of primary productivity in aquatic ecosystems and influence total biomass throughout the aquatic food web (Wetzel, 1975). It has been inferred that the physico-chemical characteristics of the water largely determine the water bird community of wetland habitats, primarily by their direct and indirect impact on the availability and abundance of the birds' prey (Nagarajan and Thiyagesan, 1996).

Further, in the wetland ecosystem, sediment is the physical foundation on which plants and animals depend for their vital needs (Brinson, 1993; Mitsch and Goselink, 1993; Brinson and Rheinhardt, 1996). Properties of sediment such as degree of stratification and organic matter distribution reflect the wetland environment (Fanning and Fanning, 1989). As said earlier the prey base (mainly invertebrates) of the shore birds is affected by the water quality which in turn is influenced by the physico-chemical variables of sediments. These invertebrates have also been found to strongly influence the distribution and feeding behaviour of water birds (Bolduc and Afton, 2008).

The community of organisms that live on, or in, the bottom of a water body is known as "benthos". The term "benthos" (from ancient Greek meaning "depth, depth of the sea, bottom") was introduced by the eminent German naturalist and artist Ernst Haeckel (1834–1919), who also introduced the term "ecology" (Tagliapietra and Sigovini, 2010). The functional role of macrobenthic communities in the trophic dynamics of reservoir ecosystems is well acknowledged. Macrobenthos consists of the organisms that live at the bottom of a water column (Link *et al.*, 2006) and are visible to the naked eye. In one of the classification schemes, these organisms are larger than 1 mm; in another, the smallest dimension is considered at least 0.5 mm. The composition, abundance and distribution of benthic organisms over a period of time provide an index of the ecosystem. In recent years, there is a greater emphasis world over for better understanding of benthic environment, its communities and productivity and this has led to increased exploration of many inland water bodies (Garg *et al.*, 2009). Ecologically, benthic macroinvertebrates are primary consumers of plant material (live and detrital) and predators in aquatic food webs and hence many researchers have studied their importance in an ecosystem (Cummins and Klug, 1979; Duran, 2006; Cui *et al.*, 2008).

Knowledge of special habitat requirements can also guide positive management (Sutherland and Hill, 1995) and, in some aquatic ecosystems, such positive management for conservation can be effective (Heathwaite, 1995; Thompson and Finlayson, 2001). However, conservation strategies for wetland invertebrates are still poorly developed, and, in general, there are few case studies on the conservation of this large, diverse and important group (Watson and Ormerod, 2004). It is a shortcoming of the fresh-water invertebrate literature that information bearing on the fundamental mechanisms for colonization and ecesis in the rigorous fresh-water environment is generally fragmentary, scattered, ignored, or mentioned incidentally (Pennak, 1978; Macan, 1961).

Further, in a wetland ecosystem, macrophytes are the primary producers having an important role in maintaining the stability of dynamic equilibrium, nutrient cycling, sedimentation processes, and biofiltration (Wetzel, 1983). They are also valuable as indicators of water quality. Although their presence is regulated by water quality, water depth, and substrate characteristics and, morphometric characteristics on the whole, they show better correlations with vegetation structure than any measured chemical parameters (Heegaard *et al.,* 2001; Makela *et al.,* 2004). Favourable morphometrical conditions make quick colonization possible in still water (Neiff, 2000). However, a high level of macrophyte development and especially overgrowth of emerged plants due to excess nutrients cause eutrophication of reservoirs (Moss, 1990). Plants are also known to be extremely important for composition and abundance of bottom fauna providing food source and protection against predators and excessive water movements (Poznanska *et al.*, 2009). De Szalay and Resh, (2000) have demonstrated that invertebrate communities may differ within plant stands with heterogeneous amounts of emergent cover. Management practices that alter the structure of wetland vegetation can influence macroinvertebrate communities colonizing seasonal marshes.

On the basis of this background, the present study aims to find out influence of macroinvertebrates on wader populations as well as its dependence on abiotic factors and vegetation density and diversity of small and large waders depending on benthos (infauna- in sediments and epifauna- on sediments) at three irrigation reservoirs, WIR

(Wadhwana irrigation reservoir), TIR (Timbi irrigation reservoir) and JIR (Jawla irrigation reservoir) situated in the semi-arid zone of Central Gujarat. The first two of these are regularly inundated with Narmada water since the turn of century. The seasonal occurrence of waders is also considered. Good density and diversity of water birds has been reported in the area (Deshkar, 2008).

The thesis begins with density, diversity, and seasonal variation in the small and large waders at the three reservoirs. To find out the availability of food in the form of macrobenthic fauna the next chapter *i. e.* chapter II deals with the diversity of benthic fauna, the main prey base of the waders. Its density and seasonal occurrence is also considered within the three reservoirs. Chapter 3 includes a unique group of benthos separated out as birds depend on this source for their calcium needs, *i.e.* Molluscs. Their good density is reported by Deshkar, (2008) subsequent to beginning of Narmada inundation.

As these prey base depend on physico-chemical characteristics of water and soil, Chapter IV deals with the same. The reservoirs, being located in semi-arid zone of central Gujarat, do face annual environmental changes. Hence, an attempt is made to find out the influence of the same physico-chemical properties of water and soil. Lastly in Chapter V vegetation characteristics *i.e.* the characteristics of primary producers in wetland studied is also considered.

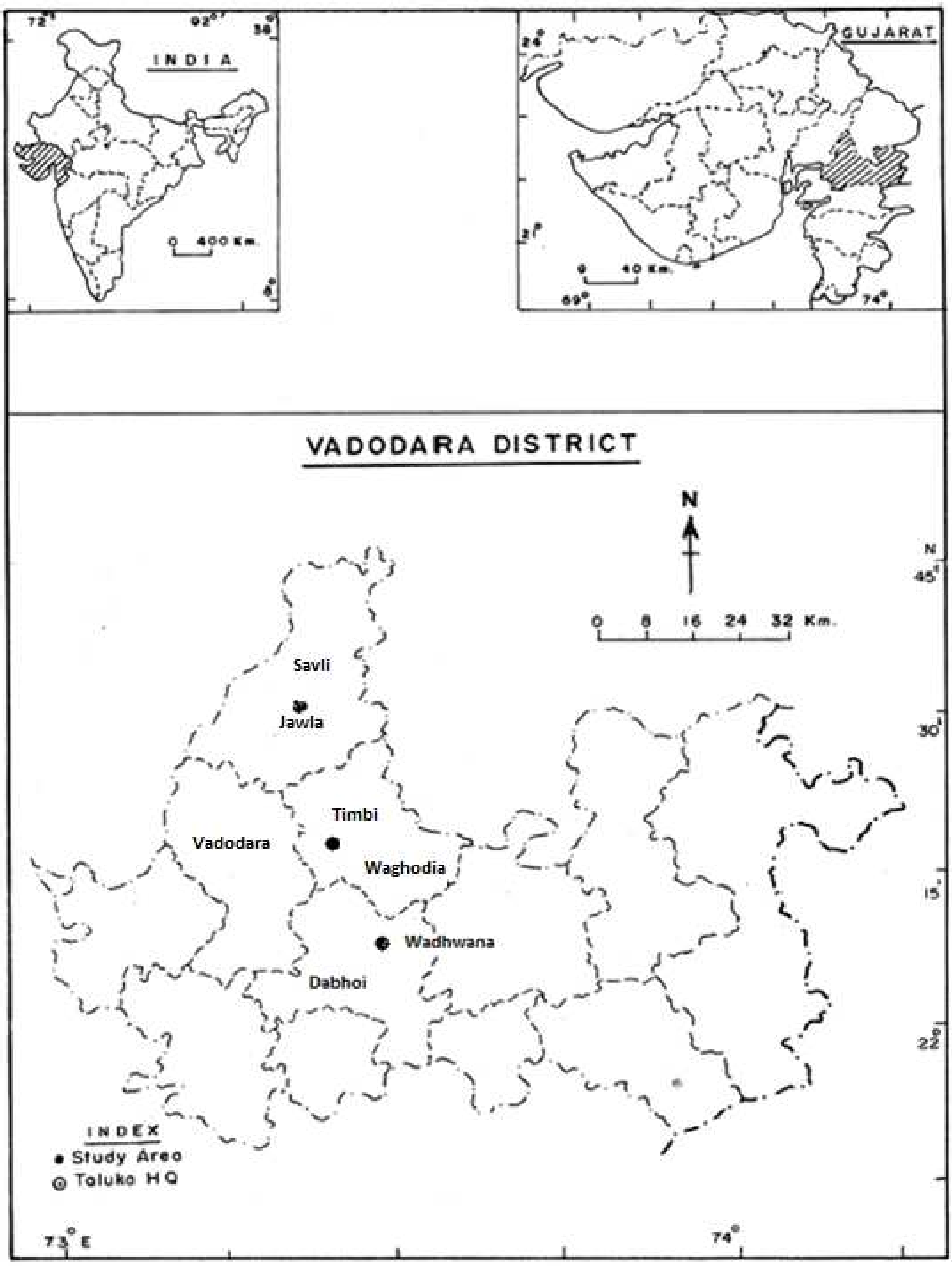
Further, as two reservoirs selected are regularly inundated with Narmada water while third receives it indirectly, impact of Narmada water on birds, benthic fauna including Mollusc, physicochemical properties of water and soil of the reservoir and vegetation in also considered in respective chapters.

STUDY AREA

Gujarat state located in the western region of the Indian subcontinent lies between 20° 6' N to 24° 42' N north latitude and 68° 10'E to 74° 28'E east longitude and spread across an area of 196077 sq.kms. Vadodara District (73° 11' E - 73° 19' E and Lat. 22° 18' N- 22° 30' N) is located in the semi arid central-eastern part of the state of Gujarat in western India with Vadodara city as its administrative headquarters. Vadodara District covers an area of 7,794 km². In 2011, Vadodara had population of 4,165,626 of which 2,099,855 was the rural population constituting 50.41% of the total population while 2,065,771 was urban population constituting 49.59%.

Located between the Doab of Mahi in North and Narmada in South, prior to independence, Baroda was the capital of one of the most powerful Princely State of India. The character of this city closely reflects the legacy of His Highness Shrimant Maharaja Sir Sayaji Rao Gaekwad III. Being a great city planner and a progressive ruler he had built many reservoirs during his rule for the storage of water for the welfare of people. The present study has been conducted around three such irrigation reservoirs (Wadhwana Irrigation Reservoir, Timbi Irrigation Reservoir and Jawla Irrigation Reservoir) in the Vadodara District. All the three reservoirs are situated in different directions of the Vadodara city within 50 kilometer radius (**PLATE I**). All the three reservoirs have different land matrix composition and face different types of human pressures.

PLATE I. Map showing the three study sites situated in the semi-arid region of Gujarat



***Wadhwana Irrigation Reservoir (WIR)* (PLATE III)**

Located 50 kms in the south-east direction of Vadodara city (22^{o} 10′ 20" N to 22^{o} 10′ 22" N and 73^{o} 29' 2" E to 73^{o} 29' 13" E) this irrigation reservoir was constructed during 1909-1910 by His Highness Shrimant Maharaja Sir Sayajirao Gaekwad III of erstwhile State of Baroda at the Wadhwana village, Taluka Dabhoi of Vadodara District to make the farmers independent of rain water dependency. It is an earthen dam of 8.2 kms. with the periphery of approx. 11.2 kms. The reservoir covers an area of about 1430 acres. The full capacity of the reservoir is 5 billion cubic feet. It irrigates about 8815 ha agricultural land of the nearby villages surrounding the dam. On the basis of the waterfowls supported by this wetland it was declared as wetland of National Importance in 2005. It mainly receives water from Jojwa dam on Orsang river. However, in recent years, it has been receiving water from the famous Sardar Sarovar on Narmada River. Due to marked increase in environmental awareness, this reservoir has now become a tourist spot and tourists throng the area during winter for bird watching.

Climatic parameters

The average minimum temperature recorded during the study period at WIR was 20.13°C while the average maximum temperature was 34.5°C. The temperature at the Wadhwana Irrigation reservoir varied between minimum of 6.2°C in January 2011 to a maximum of 42.3°C in May 2010 (Table A). However, differences were noted in the temperature during different seasons of the year. In summer the average temperature varied between minimum 22°C to maximum 39.7°C, in monsoon it ranged between 25°C to 34°C, in post-monsoon from 21.6°C to 33.5°C while in winter it dropped and was noted between minimum 11°C and maximum of 30°C. The mean annual average rainfall was nearly 77mm (Table B). The annual rainfall at WIR during the study period was 923 mm. 508 mm rainfall was noted in 5 months *i.e* . June to October during the first year with 39 rainy days while in the second year 1338 mm rainfall was noted with 57 rainy days during 6 months *i.e.* June to November. The average relative humidity recorded was 62% while it was maximum 75% in monsoon and minimum 45% in summer.

Timbi Irrigation Reservoir (TIR) **(PLATE IV)**

This reservoir is located about 15 kms east of Vadodara city (22°18' 49" N to 22°18' 53 " N longitude and 73°17' 11" E to 73°17' 22" E latitude). This reservoir was also constructed by His Highness Shrimant Maharaja Sir Sayajirao Gaekwad III of erstwhile State of Baroda in 1947-48 near village Shripor Timbi of Waghodia Taluka, District Vadodara. With an area of about 100.5 acres, the water from this reservoir is supplied to agricultural fields of eight villages surrounding Shripor Timbi village. It is an earthen dam which has a periphery of approximately 3 kms. Due to human disturbances, usage of water for irrigation purposes and other activities like washing clothes, etc. the reservoir is now under threat. As the city is enlarging and people moving out of the city limits, many residential areas and college campuses are coming up in the area which may produce an undesirable impact in the serene area surrounding the reservoir.

Climatic Parameters (Table A)

The climatic parameters for this reservoir are obtained from the Waghodia weather station located 4 kms. from the reservoir. Though WIR and TIR are only about 25 kms away from each other, variations were noted in the climatic conditions at the two reserviors. The mean annual minimum temperature recorded for TIR was 21.1°C and maximum 33.5°C which is approximately 1° higher than the minimum and 1° lower than the maximum temperature at WIR. However, here the lowest temperature recorded was 11.6°C in January 2011 and highest 40.8°C in May 2010. The average minimum and maximum temperatures in summer varied between 22.7°C to 39°C, while in monsoon 25.3° C to 32.6°C, post-monsoon 22.3°C to 32.6°C and in winter 14°C to 29°C respectively. The annual mean rainfall during the two years of study was 630.25 mm (Table B). Rainfall was from June to November in the first year of the study while from June to September in the second year of the study. The rainfall noted in the first year was comparatively low with 35 rain days compared to the 62 rain days in second year of study. The average annual rainfall recorded during study period was 52 mm with maximum rainfall in monsoon and light showers in post-monsoon. The relative humidity was comparatively high at TIR with average relative humidity of 72% which was highest in monsoon with 83% while lowest in summer with 59%.

***Jawla irrigation reservoir (JIR)* (PLATE V)**

This irrigation reservoir is located in the South -West of Savli pond about a kilometer away (22^o 33' 21" N to 22^o 33’ 25" N and 73^o 14' 22" E to 73^o 14' 28" E) on East side of Jawla village. It is a monsoon dependent reservoir. In recent years anthropogenic disturbances have increased around JIR due to development of a rural residential area for translocated villages due to Narmada Dam. JIR is totally surrounded by the agricultural fields. It has a temple on earthen dam of 2 kms. which marks the Western boundary and the reservoir spreads in 0.78 km^2 area.

Climatic Parameters (Table A)

Due to absence of a weather station in the nearby areas weather information of this reservoir regarding its temperature and humidity is taken as the one recorded at the Waghodia weather station as is recorded for TIR. The annual rainfall at JIR was 639.5 mm during the study period (Table B). During the study period rainfall was noted only for 4 months *i.e.* June to September. Here also as in TIR the rainfall was more during the second year of study with more rain days *i.e.* 925 mm rainfall in 43 rain days in comparison to 554 mm rainfall in 28 days of the first year.

Table A. Minimum Temperature, Maximum Temperature and Relative Humidity noted at the Bhilapur Weather station of the Dabhoi Taluka of Vadodara District (Considered for Wadhwana Irrigation Reservoir) and Waghodia Weather Station of the Vadodara District (Considered for Timbi Irrigation Reservoir and Jawla Irrigation Reservoir)

Months	Minimum Temperature ºC		Maximum Temperature ºC		Relative Humidity %	
	WIR	TIR/JIR	WIR	TIR/JIR	WIR	TIR/JIR
2009						
March	18.0		37.2		41.1	
April	21.0		40		36.3	
May	26.7		39.3		55.9	
June	27.7		37.7		59.1	
July	25.2		32.1		83.8	
August	25.7	24.3	32.7	27.6	77.9	93
September	25.9	25.5	34.5	33.8	73.4	78.4
October	22.9	21.9	34.3	34.3	66.2	68.4
November	16.9	18	31.0	30.4	64.5	70.1
December	14.8	16.2	30.5	29.6	65.4	74.5
2010						
January	13.1	14.4	29.6	29	56.8	68.8
February	14.9		32.3	30.8	54.3	62
March	18.9		38.3	36.2	45.7	60.4
April	22.4		40.8	39.7	43.4	60
May	25.4		42.3	40.8	45.9	60.3
June	24.9		37.8	36.1	65.7	71.7
July	23.7		32.6	31.2	83	87.3
August	24.0		32	30.8	85.1	89
September	23.7	25.2	32.4	31.4	82.1	85.9
October	21.7	23.7	35.6	34.6	64	73.6
November	18.5	20.4	32.9	31.1	70	80.9
December	10.9	13.2	29.7	28.5	63.7	75.3
2011						
January	6.2	11.6	30	28.8	50.5	68.3
February	10	13.9	32.5	31.6	53.1	68.2
March	12.9	16.6	37	36.1	41	72.5

Source: R.G. Subdivision, Kuber Bhavan Vadodara.

Table B. Rainfall and Rainy Days at Wadhwana Irrigation Reservoir (WIR)Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

	Wadhwana Irrigation Reservoir		Timbi Irrigation Reservoir		Jawla Irrigation Reservoir	
	Rainfall (mm)	Rainy days	Rainfall (mm)	Rainy days	Rainfall (mm)	Rainy days
2009						
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	22	3	24	1	0	0
July	299	23	177	20	188	19
August	131	9	67.5	7	123	6
September	41	4	28	3	9	1
October	15	2	9	2	34	2
November	0	0	22.5	2	0	0
December	0	0	0	0	0	0
2010						
January	0	0	0	0	0	0
February	0	0	0	0	0	0
March	0	0	0	0	0	0
April	0	0	0	0	0	0
May	0	0	0	0	0	0
June	90	4	78	4	33	2
July	380	17	199	22	155	13
August	560	18	377.5	21	468	17
September	253	14	278	15	269	11
October	22	2	0	0	0	0
November	33	2	0	0	0	0
December	0	0	0	0	0	0
2011						
January	0	0	0	0	0	0
February	0	0	0	0	0	0

Source: R.G. Subdivision, Kuber Bhavan Vadodara

PLATE II. Google Earth images of the Study Area

a. Wadhwana Irrigation Reservoir

b. Timbi Irrigation Reservoir (TIR)

c. Jawla Irrigation Reservoir (JIR)

PLATE III. Habitats available during various seasons at WIR

Large waders at WIR during summer

High water levels during monsoon at WIR

PLATE III (Contd.) Habitats available during various seasons at WIR

WIR in post-monsoon alongwith vegetation on earthen dam

Huge migratory wader populations at WIR during winter

PLATE IV. Habitats available during various seasons at TIR

Low water level during summer favoring large waders

High water level during monsoon alongwith dense macrophytes

PLATE IV. (Contd.) Habitats available during various seasons at TIR

Post-monsoon at TIR

Domestic input at TIR

PLATE V. Habitats available during various seasons at JIR

Low water level at JIR during summer

Dense vegetation covering the earthen dam during monsoon

Scrub vegetation at JIR during post-monsoon

Winter with surrounding agricultural matrix at JIR

Ongoing Construction of a concrete dam at WIR

WADING BIRDS AT THE RESERVOIRS OF CENTRAL GUJARAT

Introduction

India has 67,429 wetlands covering an area of about 4.1 million hectares (MoEF, 1990). Out of these wetlands, 2,175 (1.5 million hectares) are natural and 65,254 (2.6 million hectares) are man-made. Gujarat has 36% of the total wetland area of the country with 2,092 km² area under inland wetlands. Central Gujarat, being part of Semi arid zone large numbers of irrigation reservoirs are constructed in the area over past century. These reservoirs depend on monsoon rains for water. However, since last decade several of these are inundated with Narmada water. As Gujarat falls in the central Asian migratory route of birds, migratory birds from Europe and Asia pass through this part of the country and enjoy the varied habitats that provide a huge prey base. Many of these wetlands are promising habitat for migratory birds during winter which congregate in large number amounting to several thousands. Gujarat supports 257 species of waterbirds (Parasharya *et al*., 2004). Of these, 81 species are "Central Asian Flyway conservation concern", including three critically endangered, six endangered and 13 near threatened species (Davidson, 2003).

Research on waterbird communities in India has mainly involved habitat diversity, population structure and the importance of migratory species visiting from other continents, essentially in the western, eastern and southern areas of the country. Various groups of water birds that are found in and around wetlands are waders, divers, swimmers, *etc.* In a wetland ecosystem which comprises of shallow waters, waders are considered to be the health indicators (Custer and Osborne, 1977; Kushlan, 1993; Hoffman *et al.*, 1994). Waders are the long legged birds with long neck and/or beak preferring shallow marshy lands and wade on soft marshy base. These wading birds respond behaviourally by moving to local concentrations of food availability and move away from unsuitable areas. Hence their presence and absence is also used to assess the transient conditions of wetlands (Erwin, 1985; Dugan *et al.*, 1988). The overall trend of majority of population of waders is known to be declining all around the world - a matter of international conservation concern (Boere *et al.,* 2006).

Waders, having high foraging intake to compensate energy demands, are known to be present in large congregations at wintering sites (Wilson, 1991; Maestro and Perez-Hurtado, 2001; Kvist and Lindström, 2003). In a habitat that attracts predatory species availability of food base is an important component. For waders, benthic fauna forms the major prey base (Martin and Hamilton, 1985; Skagen and Oman, 1996). This prey base with various physical factors is important in developing community structure (Murkin *et al.*, 1982). Even newly constructed wetlands have been reported to rapidly provide sufficient food supply for waders (Sanders, 2000).

Further, the avian use of a wetland is also influenced by hydroperiod and fluctuations in depth of water (Brinson, 1993). Depending on change in depth of water the use of wetland by different species of wader is expected. Inundation of the reservoirs with Narmada water in Central Gujarat has influenced the hydroperiod and water levels of several reservoirs. A positive influence of this on duck population has been reported by Padate *et al.*, (2008). However, as waders are also positioned at the higher trophic level in wetland ecosystem, and occur in large numbers in the area in the area, this study is conducted to find out population of waders in and around three irrigation reservoirs in semi arid zone of Central Gujarat, India. By feeding on benthic fauna this group of birds play a cardinal role in structuring benthic invertebrate communities too (Thrush, 1999) Hence, an attempt is also made in present study to correlate density of waders with benthic fauna (Chapter II). Further, as benthic fauna depend on quality of soil as well as water in a wetland, an attempt is also made to find out if there exists any association between wader communities and physico-chemical components of water and sediment (Chapter IV).

Materials and methods

The study sites selected are irrigation reservoirs Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation reservoir (JIR), each under varied agricultural matrix and anthropogenic pressures. All the reservoirs were visited twice a month from March 2009 to February 2011. The census of birds was conducted while walking on the earthen dam for identified transect during morning hours; half an hour after sunrise; which is known to be the best time for the observation of birds (Dawson, 1981). The birds present on both the sides of transect, in water as well as on the land were counted while walking on the edge of the wetland. Direct counts were carried out with the help of binoculars having the magnification of 10x50. The birds were identified on the basis of field guides by Ali and Ripley, (1983); Grimmett *et al*., (1998) and Kazmierczak, (2000).

To make the analysis simpler the birds observed were categorised into two groups according to their size. These are: Large waders (Threskiornithidae and Ardeidae) and Small waders (Scolopacidae, Recurvirostridae, Charadriidae, Rostratulidae and Glareolidae).

The data collected was analysed for diversity indices like Species richness, Species diversity: Shannon-Weiner index (H') and Equitability (E) (Krebs, 1985) as well as Density using formula D = n/2wl (Rodgers, 1991) for each visit for small waders while for large waders only species richness and density were calculated as their low numbers would affect the calculation of diversity indices. The birds observed in the reservoirs as well as those present in the agricultural fields and observed to move in and out of the reservoirs within transect width were also counted carefully by avoiding double counts. The density was calculated as per km^2 (Rodgers, 1991). The length of the transects were 3.2 kms. for WIR, 1.33 kms. for TIR and 0.89 kms. for JIR while width was considered as 0.5 km (on the basis of Google earth images). Total number of species observed per visit is considered as species richness for the visit. Shannon-Weiner diversity index was calculated as $H' = -\sum pi \ln pi$ (for maximum number of birds) where pi is total sample belonging to the i^{th} proportion of species, calculated as proportion of the total number of individuals of all the species and ln is the natural log. Evenness/equitability is calculated as $E = H^{'} / H$ max where H is information content of sample (bits/individuals) = index of species diversity (Krebs, 1985; Javed and Kaul, 2002) using PAST software. For the statistical analysis the data for 3 months is pooled according to the seasons as Summer: March, April, May; Monsoon: June, July, August; Post-monsoon: September, October, November and Winter: December, January, February. Further the Mean and standard error of mean (SEM) were calculated on annual basis as well as seasonal basis and applied to One-way ANOVA as described by Fowler and Cohen (1995) with No post test for various parameters for four seasons using GraphPad Prism version 3.00 for Windows, (GraphPad Software, San Diego California USA). The correlation of bird density with various abiotic parameters (Details in Chapter IV), benthic fauna (Details in Chapter II) and molluscs (Details in Chapter III) is carried out using SPSS 7.5 software. The p value for ANOVA is non- significant if $P > 0.05$ (ns), significant if $P < 0.05$ (*), significantly significant (**) if P is < 0.001 and highly significant (***) if $p < 0.0001$.

Results

A total of 25 species of Waders of seven families were observed at WIR, 18 species of seven families at TIR and 13 species of six families at JIR from March 2009 to February 2011 (Annexure 1). Small waders include Charadriidae (plovers and lapwings), Scolopacidae (sandpipers, stints, godwits, etc.), Recurvirostridae (Black-winged Stilt), Rostratulidae (Painted snipe) and Glareolidae (coursers and pratincoles). The families of large waders include Threskiornithidae (three species of Ibises) and Ardeidae (two species of herons and three species of egrets). However, family Glareolidae was not recorded at JIR. All together 11 resident, one resident-migratory and 13 migratory species were noted.

Annual Mean Density, Species Richness, Shannon Weiner Diversity Index (H') and Evenness (E) at the three reservoirs

<u>Small waders (Table 1.1)</u>

Mean density (Fig. 1.1) of small waders was highest at WIR (335.4±80.78 birds/km^2) followed by TIR (138.3±30.87 birds/km^2) and JIR (25.56±7.4 birds/km^2). Highly significant differences were noted at the three reservoirs ($P<0.0001$, $F_{(2,112)}$ 7.73). When species richness (Fig. 1.1) was considered, highest mean richness was also noted at WIR with 4.58±0.42 species followed by TIR with 3.59±0.28 species and JIR with 1.48±0.13 species ($P<0.0001$, $F_{(2,112)}$ 21.33). However, the mean Shannon-Wiener diversity index (Fig. 1.1) was highest at TIR (0.79±0.05) followed by JIR (0.63±0.06) and lowest at WIR (0.59±0.06) with a significant differences ($P<0.05$, $F_{(2,81)}$ 3.14), while mean evenness (Fig. 1.1) was highest at JIR (0.77±0.07), followed by TIR (0.65±0.04) and lowest at WIR (0.46±0.06) without any significant differences ($P>0.05$, $F_{(2,124)}$ 2.12).

Annual Mean Density and Species Richness of Large waders (Table 1.2, Fig.1.2)

Annual mean density of large waders was highest at JIR (67.07±17.66 birds/km^2) followed by WIR (63.65±16.59 birds/km^2) and lowest at TIR (50.31±7.53 birds/km^2). No significant differences were noted among the three reservoirs (P>0.05, $F_{(2,119)}$ 0.37). When mean species richness was considered highest richness was noted at WIR (5.05±0.3 species), followed by TIR (4.24±0.23 species) and lowest at JIR (2.79±0.24 species) with highly significant differences (P<0.0001, $F_{(2,119)}$ 18.75). Due to the presence of few species of large waders its Shannon-Wiener diversity index and Evenness could not be calculated.

Seasonal Density, Species Richness, Shannon-Weiner diversity index (H') and Evenness (E) of small waders at the three reservoirs (Table 1.3; Fig.1.3)

At WIR the seasonal density of small waders was found to be highest during winter (978.9±178.1 birds/km^2) followed by summer (163.0±60.3 birds/km^2). It declined significantly in monsoon (6.7±1.76 birds/km^2) and started increasing from post-monsoon (66.1±32.2 birds/km^2). Highly significant seasonal variations were noted (P<0.0001, $F_{(3,39)}$19.17). At TIR also a similar trend in density was noted with maximum 307.70±18.88 birds/km^2 during winter. In summer and monsoon the small wader density was 96.61±43.84 and 6.47±2.13 birds/km^2 respectively. While the density was second highest during post-monsoon (116.60±95.20 birds/km^2) but with higher fluctuations. Significantly significant seasonal variations were found (P<0.001, $F_{(3,37)}$ 5.74). In comparison to WIR and TIR, JIR had the overall low density of small waders with 60.26±18.89 birds/km^2 in winter; 11.54±2.17 birds/km^2 in summer; 5.13±1.40 birds/km^2 in monsoon and 8.12±2.24 birds/km^2 in post-monsoon with significantly significant seasonal variations (P<0.001, $F_{(3,27)}$ 4.89).

The seasonal mean species richness at WIR was also found to be highest during winter (7.5±0.73), followed by summer (4.92±0.42) which was almost low in monsoon (2.11±0.39) and post-monsoon (2.9±0.5) with highly significant seasonal variations ($P<0.0001$, $F_{(3,39)}$ 19.01). When the seasonal species richness was taken into consideration for TIR, it was also found to be highest during winter (5.56±0.31), followed by summer (4.00±0.4) and minimum in monsoon (1.56±0.18) and post-monsoon (2.80±0.36) with highly significant seasonal variations ($P<0.0001$, $F_{(3,37)}$25.33). However, at JIR mean species richness was low across the seasons with 1.83±0.31 in post-monsoon; 1.8±0.29 in winter; 1.2±0.13 in summer and 1.0±0.0 in monsoon with no significant differences ($P>0.05$ $F_{(3,27)}$ 2.79).

When mean Shannon-Weiner diversity index (H') is considered, at WIR it was highest during monsoon (0.96±0.09), it declined in post-monsoon (0.58±0.15), winter (0.28±0.05) and increased in summer (0.77±0.1). Highly significant seasonal variations were noted ($P<0.0001$, $F_{(3,33)}$ 8.03).

However, the mean Shannon-Weiner Diversity index (H') was highest at TIR during summer (0.95±0.11) and lowest during monsoon (0.59±0.05) while moderate during post-monsoon (0.73±0.09) and winter (0.77±0.011). No significant seasonal variations were noted ($P>0.05$, $F_{(3,32)}$ 1.63). At JIR H' was highest during winter (0.56±0.09), followed by summer (0.52±0.17) and post-monsoon (0.78±0.1). As only one species, Black-winged Stilt (*Himantopus himantopus*) was recorded during monsoon, no H' could be calculated. No significant seasonal differences were recorded ($P>0.05$, $F_{(2,8)}$1.57). Birds were most evenly distributed at WIR during monsoon (0.9±0.04) then, post-monsoon (0.55±0.14), summer (0.53± 0.08) and least even during winter (0.14±0.02). Highly significant variations ($P<0.0001$, $F_{(3,33)}$

13.44) were found across the seasons. At TIR also, the population of small waders was most evenly distributed in monsoon (0.86±0.07), post-monsoon (0.68±0.07) and summer (0.73±0.06) but low in winter (0.44±0.05). The seasonal variations were highly significant (P<0.0001, $F_{(3,32)}$ 6.98). At JIR, the population was most evenly distributed during post-monsoon (0.98±0.02) and summer (0.75±0.25) and least in winter (0.61±0.08). As said earlier the evenness also could not be calculated because of the presence of single species. Significant seasonal variations were noted (P<0.05, $F_{(2,8)}$4.5).

<u>Comparisons among the reservoirs</u>

When mean densities were compared among the reservoirs, no significant differences were found during summer (P>0.05, $F_{(2,30)}$ 2.71), monsoon (P>0.05, $F_{(2,20)}$ 0.15) and post-monsoon (P>0.05, $F_{(2,23)}$ 0.57) while highly significant differences were noted during winter with P<0.0001, $F_{(2,30)}$ 17.87. However, for mean species richness highly significant differences with P<0.0001, $F_{(2,30)}$ 28.13 and P<0.0001, $F_{(2,30)}$ 30.26 were noted only during summer and winter respectively. Monsoon (P>0.05, $F_{(2,30)}$ 3.13) and post-monsoon (P>0.05, $F_{(2,23)}$ 1.49) did not show any significant differences for species richness. The Shannon-Weiner diversity index (H') could not be calculated for monsoon, while highly significant seasonal differences were noted for it during winter only (P<0.0001, $F_{(2,25)}$ 10.15). Summer (P>0.05, $F_{(2,22)}$ 1.61) and post-monsoon (P>0.05, $F_{(2,18)}$ 0.6) did not show any significant differences while the diversity index could not be calculated for monsoon. Evenness followed a similar trend to H'. It could not be calculated for monsoon and showed highly significant seasonal variations for winter only with P<0.0001, $F_{(2,25)}$ 25.39. Summer (P>0.05, $F_{(2,22)}$ 2.03) and post-monsoon (P>0.05, $F_{(2,18)}$ 3.07) did not show any significant differences for mean evenness.

Seasonal Density and Species Richness of Large waders at the three reservoirs (Table 1.4; Fig.1.4)

Large waders included the three species of ibis *i.e.* Black-headed Ibis (*Threskiornis melanocephalus*), Black Ibis (*Pseudibis papillosa*) and Glossy Ibis (*Plegadis falcinellu*), two species of herons *i.e.* Grey Heron (*Ardea cinerea*) and Indian Pond Heron (*Ardeola grayii*) and three species of Egrets *i.e.* Little Egret (*Egretta garzetta*), Intermediate Egret (*Mesophoyx intermedia*) and Large Egret (*Casmerodius albus*). When seasonal comparisons were made in the mean density of large waders at WIR, the density was maximum during winter (128.2±50.05 birds/km^2). During summer mean density was 63.96±22.53 birds/km^2 with further decline in monsoon (21.32±12.7 birds/km^2) while in post-monsoon it was 23.88±8.02 birds/km^2. No significant seasonal variations were obtained over the three seasons ($P>0.05$, $F_{(3,39)}$ 2.57). At TIR also, large waders were maximum during winter with 97.96±15.64 birds/km^2 mean density. While during summer an average population of 39.93±8.76 birds/km^2 was noted which further declined to a minimum in monsoon (18.74±8.95 birds/km^2) and increased to 37.48±13.64 birds/km^2 in post-monsoon. Highly significant seasonal variations were obtained over the three seasons ($P<0.0001$, $F_{(3,37)}$8.06). At JIR also the mean density of large waders was highest during winter with 133.3±54.8 birds/km^2 which declined to 34.83±9.08 birds/km^2 during summer, increased to 59.94±19.21 birds/km^2 in monsoon and decreased during post-monsoon to minimum with 26.37±9.69 birds/km^2. No significant seasonal variations were observed ($P>0.05$, $F_{(3,34)}$ 2.25).

The mean species richness of large waders was highest at WIR during winter (6.67±0.28 species). Summer supported the second highest species richness with 5.5±0.4 species; it declined in monsoon (2.67±0.55 species) while in post-monsoon it was 4.7±0.56 species ($P<0.0001$, $F_{(3,39)}$ 13.7). At TIR, it was 4.58±0.38, 3.22±0.43, 4.0±0.5 and 4.91±0.41 species during summer, monsoon, post-monsoon and winter respectively. Significant seasonal variations were observed ($P<0.05$, $F_{(3,37)}$ 2.88). At JIR, the mean species richness were high during post-monsoon and winter with 3.29± 0.64 and 3.64± 0.45 species and low during summer and monsoon with 2.08± 0.29 and 2.25± 0.41 species respectively. However, significant variations were observed across the seasons ($P<0.05$, $F_{(3,34)}$ 3.36).

Comparisons among the reservoirs

The density of large waders among the three reservoirs showed no significant differences in any of the seasons. However, differences in species richness were highly significant during summer ($P<0.0001$, $F_{(2,33)}$ 24.36) and winter ($P<0.0001$, $F_{(2,31)}$ 15.88) only. Monsoon and post-monsoon did not observe any significant differences. The number of species being low H and E were not calculated.

Annual and Seasonal variations in mean densities of Families of Small and Large waders at the three reservoirs (Table 1.5; Fig.1.5,1.6,1.7,1.8,1.9, 1.10,1.11)

When the families of small waders were compared, Scolopacids dominated with the maximum mean density (479.5±107.7 birds/km^2) at WIR. They were maximum during winter (923.0±177.7 birds/km^2) while there were 174.0±66.33 and 101.8±46.72 scolopacids /km^2 during summer and post-monsoon respectively but they were not observed during any visit of monsoon. The seasonal variations were highly significant ($P<0.0001$, $F_{(2,25)}$11.21). Family- Recurvirostridae was the 2^{nd} highest family in mean annual density with a single dominating species *i.e.* Black-winged Stilt (13.4±2.4 birds/km^2). The density of this species was maximum during winter (19.32±4.3 birds/km^2), followed by summer (14.38±3.81 birds/km^2) and minimum during monsoon (2.26±0.75 birds/km^2). During post-monsoon its density was

4.38±2.53 birds/km^2 and showed no significant seasonal variations (P>0.05, $F_{(3,28)}$ 2.75). Glareolidae (10.71±5.14 birds/km^2) and Charadriidae (8.74±1.75 birds/km^2) showed low density in comparison to the earlier two families. Glareolids were highest during winter (10.75±7.55 birds/km^2), declined in summer (3.44±2.81 birds/km^2), increased in monsoon (8.13±3.75 birds/km^2) and were not observed in post monsoon. No seasonal variations were noted in their mean densities (P>0.05, $F_{(2,6)}$ 0.19). Similarly, Charadriids were most dense during winter (23.07±3.86 birds/km^2) but least dense during summer (3.07±0.65 birds/km^2), monsoon (3.4±0.5 birds/km^2) and post-monsoon (3.13±0.65 birds/km^2). While both tended to follow the same trend; Charadriidae showed highly significant seasonal variations over the seasons (P<0.001, $F_{(3,39)}$21.39). Family Rostratulidae had a mean annual density of 2.81±1.36 birds/km^2. During monsoon 2.5±0.0 rostratulids/km^2 were observed while during post-monsoon 5.31±0.31 birds/km^2 and winter 5.31±0.31 birds/km^2 were noted. The annual mean density of large waders at WIR was 50.27±19.01 birds/km^2. Its seasonal density was highest during winter 128.2±50.05 birds/km^2 which decreased noticeably in summer 63.96±22.53 birds/km^2 as well as monsoon 21.32±12.7 birds/km^2 and was maintained low in post-monsoon 23.88±8.02 birds/km^2 with no significant differences (P>0.05; $F_{(3,39)}$ 2.57). The mean annual density of Family Ardeidae at WIR was 22.73±6.57 birds/km^2. It was highest with 48.18±20.35 birds/km^2 during summer, 17.29±11.76 birds/km^2 in monsoon, 10.5±3.32 birds/km^2 in post-monsoon and 11.56±3.13 birds/km^2 in winter. No significant differences (P>0.05; $F_{(3,37)}$ 0.88) were noted at WIR.

At TIR the densities of the five families followed a similar trend as was noted for WIR. The scolopacids dominated the wetland with a total density of 150.3±35.57

birds/km^2. They dominated in all seasons with 267.8±20.84 birds/km^2 in winter, 106.8±98.92 birds/km^2 in post-monsoon; 83.08±46.68 birds/km^2 in summer and 1.49±0.0 birds/km^2 in monsoon but with no significant seasonal variation ($P>0.05$, $F_{(3,27)}$ 2.51). Recurvirostridae was the second most dense family found at TIR with mean annual density of 22.39±3.35 birds/km^2. Their mean density was maximum during winter 28.96±4.21 birds/km^2, followed by 20.22±5.78 birds/km^2 during summer, it declined during monsoon 8.21±6.12 birds/km^2 and again increased during post-monsoon 20.15±9.76 birds/km^2 with no significance ($F_{(3,25)}$ 0.93).

Annual mean density of Charadriids was 8.63±0.98 birds/km^2. Its maximum density was noted during winter (13.16±2.22 birds/km^2); which declined in summer (8.41±1.93 birds/km^2), monsoon (4.15±0.78 birds/km^2) and increased again in post-monsoon (7.91±1.37 birds/km^2). Significant seasonal variations were found ($P<0.05$, $F_{(3,37)}$3.56) for Charadriidae. Representaives of Family Glareolidae (*i.e.* Indian courser) were found only during monsoon and winter respectively with 1.5±0.0 and 4.5±0.0 birds/km^2 respectively. Family Rostratulidae was noted only during post-monsoon (4.5 ± 0.0 birds/km^2). Annual mean density of Threskiornithids at TIR was 37.93±7.99 birds/km^2. Density was 97.96±15.64 birds/km^2 during winter, 39.93±8.76 birds/km^2 during summer, 18.74±8.95 birds/km^2 during monsoon and 37.48±13.64 birds/km^2 during post-monsoon with highly significant differences ($P<0.0001$; $F_{(3,37)}$ 8.06). During summer, 25.5±6.19 Ardeids/km^2 were noted at TIR followed by 15.42±8.65 birds/km^2 during monsoon, 13.43±2.99 birds/km^2 in post-monsoon and 18.86±3.95 birds/km^2 in winter with no significant differences ($P>0.05$; $F_{(3,37)}$ 0.88). The annual mean density was 18.86±2.89 birds/km^2.

All families except glareolidae were noted at JIR. Here the densities were found to be very low with Charadriidae the most common family with 35.43±8.81 birds/km^{2}during winter followed by 11.03±2.68 birds/km^2 in summer, 5.13±1.81 birds/km^2 in monsoon and 4.7±1.22 birds/km^2 in post-monsoon with significantly significant seasonal variations ($F_{(3,27)}$5.39). Families-Scolopacidae and Recurvirostridae were not observed during monsoon and summer respectively. Density of Scolopacids was maximum during winter (26.15±16.98 birds/km^2); declined in summer (2.56±0.0 birds/km^2) and it was 5.13±2.56 birds/km^{2}during post-monsoon. No significant seasonal variations were observed ($P>0.05$, F(2,6) 0.58). Mean density of Recurvirostrids was 5.13±0.0 birds/km^2 during winter and 5.13±0.0 birds/km^2 in monsoon while 3.42±0.85 birds/km^2 during post-monsoon. Family Rostratulidae was absent at JIR. The annual mean density of Threskiornithids at JIR was 43.14±20.25 birds/km^2. It was 133.3±54.8 birds/km^2 during winter, 34.83±9.08 birds/km^2 during summer, 59.94±19.21 birds/km^2 during monsoon and least with 26.37±9.69 birds/km^2 during post-monsoon with non-significant differences ($P>0.05$; $F_{(3,34)}$ 2.25). Highest density for family Ardeidae was noted at JIR during winter with 75.38±25.55 birds/km^2, 21.91±5.58 birds/km^2 during summer, 58.61±22.85 birds/km^2 during monsoon and 21.61±7.61 birds/km^2 during post-monsoon ($P>0.05$; $F_{(3,31)}$ 2.41). Its annual mean density was 44.47±9.47 birds/km^2.

Percentage distribution of migratory, resident and resident-migratory populations (Table 1.6, Figure 1.12)

Among the three reservoirs, maximum percentage of population of migratory birds was noted at WIR with 86% in winter, 64% in summer, 8% in monsoon and 68% in post-monsoon while the minimum migratory bird populations were noted at JIR with 6 % in winter, 0.96% in summer, nil in monsoon and 4.55% in post-monsoon. At TIR, these were 66% in winter, 50% in summer, 1% in monsoon while 64% in post-monsoon. Similarly, maximum population of resident species of birds was noted at TIR with 99% in monsoon, 25% in post-monsoon, 16% in winter and 42% in summer. At WIR, they were 30% in summer, 92% in monsoon, 20% in post-monsoon and 4% in winter while at JIR population of resident birds was highest during post-monsoon with 95%, 62% in winter, 73% in summer and 94% in monsoon. When the resident- migratory populations were compared, maximum populations were noted at JIR with 32% in winter, 26% in summer, 6% in monsoon and nil in post-monsoon. At WIR, it was 6% in summer, nil in monsoon, 12% during post-monsoon and 10% during winter while at TIR it was 8% in summer, nil in monsoon, 11% in post-monsoon and 18% in winter.

Jaccard's similarity index (Annual and Seasonal) at the three reservoirs (Table 1.6 & 1.7; Fig. 1.13 & 1.14)

When Jaccard's similarity index was calculated for small waders, the annual similarity index was found to be 69% between WIR and TIR, 45% between TIR and JIR and 31% between JIR and WIR. The seasonal similarity index for summer between WIR and TIR was 70%, between TIR and JIR 43% and between WIR and JIR 30%. During monsoon, it was 25%, 50% and 33% respectively while during post-monsoon it was 50%, 63% and 50%. During winter, 44% species were common between WIR and TIR, 71% between TIR and JIR and only 31% between WIR and JIR.

For the large waders group, annual Jaccard's index between the three reservoirs was found to be 100%. However, this was mainly between WIR and TIR for three seasons except monsoon (when it was 85%), all three reservoirs during winter, 75% for both larger reservoir with JIR only in summer, 88% only in post-monsoon and 71% and 85% for JIR with WIR and TIR respectively during monsoon.

Correlations between physico-chemical properties of water soil (details in Chapter IV) and food base i.e. benthic fauna (details in Chapter II) (Table 1.9 & table 1.10)

As seen in table 1.8, majority of abiotic factors studied in relation to water showed variable correlations at the three reservoirs. Only pH and sulphates were correlated positively at the level of 0.01 at WIR. While, bicarbonate alkalinity was positively correlated at the same at TIR and Kjeldahl Nitrogen at JIR, while free CO_2 and water temperature showed negative correlation at the level of 0.05 with wader density at the same reservoir.

With various abiotic factors of soil also the wader density showed variable correlations at the three reservoirs as noted for water. A positive correlation of magnesium at the level of 0.01 was noted only at WIR and with total phosphates at the level of 0.05 only at TIR. Further with benthic fauna also the wader density correlated variedly and non-significantly.

Table 1.1. Annual Mean Density, Species Richness, Shannon Weiner Diversity Index (H') and Evenness (E) of the small waders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Sites	**Density (***) $F_{(2,112)}$ 7.73**	**Species Richness (***) $F_{(2,112)}$ 21.33**	**Shannon-Weiner index (*) $F_{(2,81)}$ 3.14**	**Evenness (ns) $F_{(2,124)}$ 2.12**
WIR	335.4±80.78	4.58±0.42	0.59±0.06	0.46±0.06
TIR	138.3±30.87	3.59±0.28	0.79±0.05	0.65±0.04
JIR	25.56±7.4	1.48±0.13	0.63±0.06	0.77±0.07

Table 1.2. Annual Mean Species Richness and Density of large waders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

	Density (ns) $F_{(2,119)}$ 0.37	Species Richness (***) $F_{(2,119)}$ 18.75
WIR	63.65±16.59	5.05±0.3
TIR	50.31±7.53	4.24±0.23
JIR	67.07±17.66	2.79±0.24

Table 1.3. Seasonal differences in the Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of small waders of Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	Seasons	WIR	TIR	JIR	Comparison of significance between 3 sites
Density individuals/ km²	**Summer**	163.0±60.3	96.61±43.84	11.54±2.71	ns; $F_{(2,30)}$ 2.71
	Monsoon	6.7±1.76	6.47±2.1	5.13±1.4	ns; $F_{(2,20)}$ 0.15
	Post-mon	66.1±32.2	116.6±95.2	8.12±2.2	ns; $F_{(2,23)}$ 0.57
	Winter	978.9±178.1	307.7±18.88	60.26±18.89	***; $F_{(2,30)}$ 17.87
		***; $F_{(3,39)}$ 19.17	**; $F_{(3,37)}$ 5.74	**; $F_{(3,27)}$ 4.89	
Species Richness	**Summer**	4.92±0.42	4.0±0.43	1.2±0.13	***; $F_{(2,30)}$ 28.13
	Monsoon	2.11±0.39	1.56±0.18	1.0±0.0	ns; $F_{(2,20)}$ 3.13
	Post-mon	2.9±0.52	2.8±0.36	1.83±0.31	ns; $F_{(2,23)}$ 1.49
	Winter	7.5±0.73	5.56±0.31	1.8±0.29	***; $F_{(2,30)}$ 30.26
		***; $F_{(3,39)}$ 19.01	**; $F_{(3,37)}$ 25.33	ns; $F_{(3,27)}$ 2.77	
Shannon-Weiner index(H')	**Summer**	0.77±0.1	0.95±0.11	0.52±0.17	ns; $F_{(2,22)}$ 1.61
	Monsoon	0.96±0.09	0.59±0.05	0.0±0.0	-
	Post-mon	0.58±0.15	0.73±0.09	0.78±0.1	ns; $F_{(2,18)}$ 0.6
	Winter	0.28±0.05	0.77±0.11	0.56±0.09	***; $F_{(2,25)}$ 10.15
		***; $F_{(3,33)}$ 8.03	ns; $F_{(3,32)}$ 1.63	ns; $F_{(2,8)}$ 1.57	
Evenness (E)	**Summer**	0.53±0.08	0.73±0.06	0.75±0.25	ns; $F_{(2,22)}$ 2.03
	Monsoon	0.9±0.04	0.86±0.07	0.0±0.0	-
	Post-mon	0.55±0.14	0.68±0.07	0.98±0.02	ns; $F_{(2,18)}$ 3.07
	Winter	0.14±0.02	0.44±0.05	0.61±0.08	***; $F_{(2,25)}$ 25.39
		***; $F_{(3,33)}$ 13.44	***; $F_{(3,32)}$ 6.98	*; $F_{(2,8)}$ 4.5	

1- Charadriidae, 2- Scolopacidae, 3- Recurvirostridae, 4- Glareolidae and 5- Rostratulidae

Table 1.4. Seasonal differences in the Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of large waders of Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	Seasons	WIR	TIR	JIR	Comparison of significance between 3 sites
Density individuals/ km^2	Summer	63.96±22.53	39.93±8.76	34.83±9.08	ns; $F_{(2,33)}$ 1.09
	Monsoon	21.32±12.7	18.74±8.95	59.94±19.21	ns; $F_{(2,23)}$ 2.67
	Post-mon	23.88±8.02	37.48±13.64	26.37±9.69	ns; $F_{(2,23)}$ 0.48
	Winter	128.2±50.05	97.96±15.64	133.3±54.8	ns; $F_{(2,31)}$ 0.18
		ns; $F_{(3,39)}$ 2.57	***; $F_{(3,37)}$ 8.06	ns; $F_{(3,34)}$ 2.25	
Species Richness	Summer	5.5±0.4	4.58±0.38	2.08±0.29	***; $F_{(2,33)}$ 24.36
	Monsoon	2.67±0.55	3.22±0.43	2.25±0.41	ns; $F_{(2,23)}$ 1.04
	Post-mon	4.7±0.56	4.0±0.5	3.29±0.64	ns; $F_{(2,23)}$ 1.51
	Winter	6.67±0.28	4.91±0.41	3.64±0.45	***; $F_{(2,31)}$ 15.88
		***; $F_{(3,39)}$ 13.7	*; $F_{(3,37)}$ 2.88	*; $F_{(3,34)}$ 3.36	

Table 1.5. Seasonal variations in the mean Densities of Families of large and small waders of Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

	Family	Seasons	WIR	TIR	JIR
SMALL WADERS	Scolopacidae	Annual	479.5±107.7	150.3±35.57	16.24±9.78
		Summer	174.0±66.33	83.08±46.68	2.56±0.0
		Monsoon	0.0±0.0	1.49±0.0	0.0±0.0
		Post-mon	101.8±46.72	106.8±98.92	5.13±2.56
		Winter	923.0±177.7	267.8±20.84	26.15±16.98
			***; $F_{(2,25)}$ 11.21	ns; $F_{(3,27)}$ 2.51	ns; $F_{(2,6)}$ 0.58
	Recurvirostridae	Annual	13.4±2.4	22.39±3.35	4.27±0.54
		Summer	14.38±3.81	20.22±5.78	0.0±0.0
		Monsoon	2.26±0.75	8.21±6.72	5.13±0.0
		Post-mon	4.38±2.53	20.15±9.76	3.42±0.85
		Winter	19.32±4.3	28.96±4.21	5.13±5.13
			ns; $F_{(3,28)}$ 2.75	ns; $F_{(3,25)}$ 0.93	-
	Charadriidae	Annual	8.74±1.75	8.63±0.98	17.7±3.99
		Summer	3.07±0.65	8.41±1.93	11.03±2.68
		Monsoon	3.4±0.5	4.15±0.78	5.13±1.81
		Post-mon	3.13±0.65	7.91±1.37	4.7±1.22
		Winter	23.07±3.86	13.16±2.22	35.43±8.81
			***; $F_{(3,39)}$ 21.39	**; $F_{(3,37)}$ 4.36	**; $F_{(3,27)}$ 5.39
	Glareolidae	Annual	8.54±4.18	2.99±1.5	-
		Summer	3.44±2.81	0.0±0.0	0.0±0.0
		Monsoon	8.13±3.75	1.5±0.0	0.0±0.0
		Post-mon	0.0±0.0	0.0±0.0	0.0±0.0
		Winter	10.75±7.55	4.5±0.0	0.0±0.0
			ns; $F_{(2,6)}$ 0.19	-	-
	Rostratulidae	Annual	2.81±1.36	4.5±0.0	-
		Summer	0.0±0.0	0.0±0.0	0.0±0.0
		Monsoon	2.5±0.0	0.0±0.0	0.0±0.0
		Post-mon	5.31±0.31	4.5±0.0	0.0±0.0
		Winter	0.63±0.0	0.0±0.0	0.0±0.0
			-	-	-
LARGE WADERS	Threskiornithidae	Annual	50.27±19.01	37.93±7.99	43.14±20.25
		Summer	63.96±22.53	39.93±8.76	34.83±9.08
		Monsoon	21.32±12.7	18.74±8.95	59.94±19.21
		Post-mon	23.88±8.02	37.48±13.64	26.37±9.69
		Winter	128.2±50.05	97.96±15.64	133.3±54.8
			ns; F(3,39) 2.57	***; F(3,37) 8.06	ns; F(3,34) 2.25
	Ardeidae	Annual	22.73±6.57	18.86±2.89	44.47±9.47
		Summer	48.18±20.35	25.5±6.19	21.91±5.58
		Monsoon	17.29±11.76	15.42±8.65	58.61±22.85
		Post-mon	10.5±3.32	13.43±2.99	21.61±7.61
		Winter	11.56±3.13	18.86±3.95	75.38±25.55
			ns; F(3,39) 2.14	ns; F(3,37) 0.88	ns; F(3,31) 2.41

Table 1.6. Seasonal percentage distribution of Migratory, Resident and Resident migratory waders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR)and Jawla Irrigation Reservoir (JIR)

Seasons	Summer			Monsoon			Post-monsoon			Winter		
Distribution \ Sites	WIR	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR	WIR	TIR	JIR
Migratory	64.23	49.76	0.96	8.42	1.32	0.00	68.24	63.95	4.55	86.19	66.25	6.68
Resident	30.08	42.33	72.60	91.58	98.68	93.91	20.08	24.73	95.45	3.80	15.89	61.62
Resident-migratory	5.69	7.92	26.44	0.00	0.00	6.09	11.67	11.32	0.00	10.01	17.86	31.71

Table 1.7. Annual and Seasonal Jaccard's Similarity Index of small waders between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Sites	Annual		Seasons							
			Summer		Monsoon		Post-monsoon		Winter	
	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR
WIR	69%	31%	70%	30%	25%	33%	50%	50%	44%	31%
JIR	45%	-	43%	-	50%	-	63%	-	71%	-

Table 1.8. Annual and Seasonal Jaccard's Similarity Index of large waders between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Sites	Annual		Seasons							
			Summer		Monsoon		Post-monsoon		Winter	
	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR	TIR	JIR
WIR	100%	100%	100%	75%	85%	71%	100%	88%	100%	100%
JIR	100%	-	75%	-	85%	-	88%	-	100%	-

Table 1.9. Correlation of wader density with various physico-chemical properties of water at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	**WIR**	**TIR**	**JIR**
Acidity	0.161	0.058	-0.182
Chlorides	0.073	0.176	0.055
Dissolved oxygen	-0.164	-0.031	0.020
Free carbon dioxide	0.115	0.017	-0.244*
Benthic fauna	0.310	0.025	-0.208
Bicarbonate Alkalinity	0.190	0.381**	-0.239
Inorganic phosphates	0.042	0.218	-0.061
Kjeldahl nitrogen	0.080	0.122	0.310**
Mollusc	0.051	-0.078	0.377
Nitrate	-0.081	-0.205	-0.134
Nitrite	0.0003	0.053	-0.144
Hydroxyl Alkalinity	0.223	-0.024	-0.118
pH	0.319**	-0.001	-0.037
Salinity	-0.015	0.176	0.055
Sulphate	0.440**	0.162	-0.014
Water temperature	-0.345	-0.209	-0.476*
Total phosphorus	-0.075	0.203	-0.175
Water cover	0.262	0.256	0.148

Table 1.10. Correlation of waders with various physico-chemical properties of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	WIR	TIR	JIR
Calcium	0.021	-0.077	0.112
%Coarse sand	-0.282	0.376	-0.049
%Fine sand	0.322	-0.289	-0.346
Magnesium	0.714**	0.053	0.014
pH	-0.081	0.116	-0.116
%Silt +clay	-0.257	-0.054	-0.168
Total N	0.279	-0.152	-0.034
Organic matter	-0.453	-0.243	0.130
Total P	-0.191	0.268*	-0.127
%Very fine sand	0.309	-0.192	0.576

Fig. 1.1. Annual mean Density, Mean species richness, Shannon-Weiner diversity index (H') and Evenness (E) of small waders at the three irrigation reservoirs

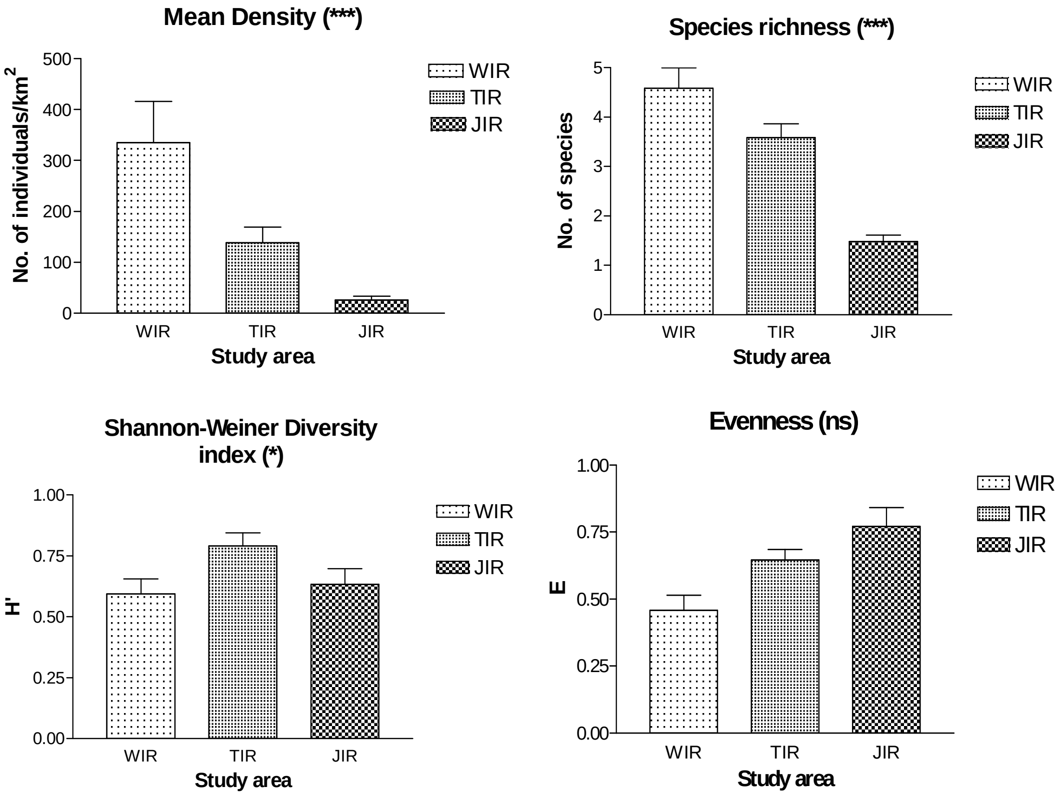


Fig. 1.2. Annual Density and mean species richness of large waders at the three irrigation reservoirs

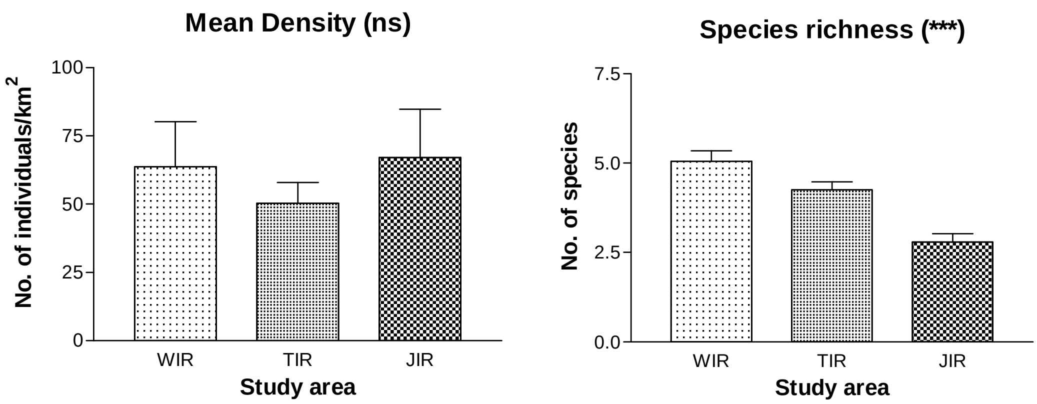


Fig. 1.3. Mean Seasonal Density, mean species richness, Shannon-Weiner diversity index (H') and Evenness (E) of small waders at the three irrigation reservoirs

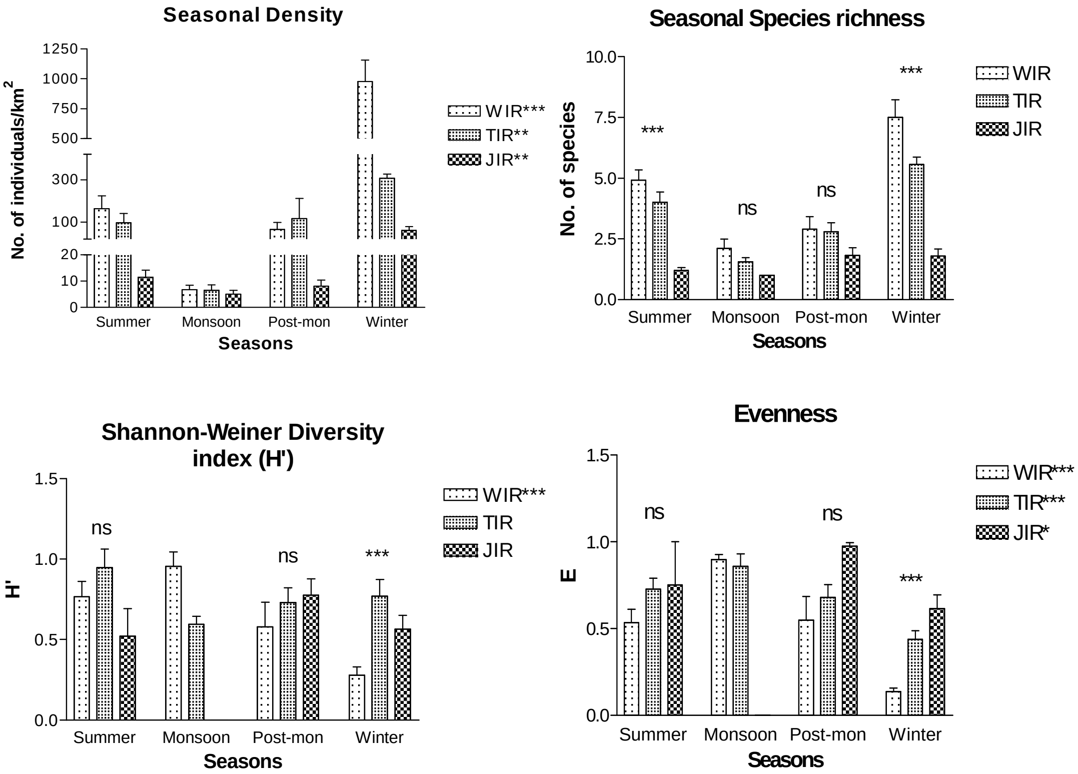


Fig. 1.4. Mean seasonal Density and mean species richness of large waders at the three irrigation reservoirs

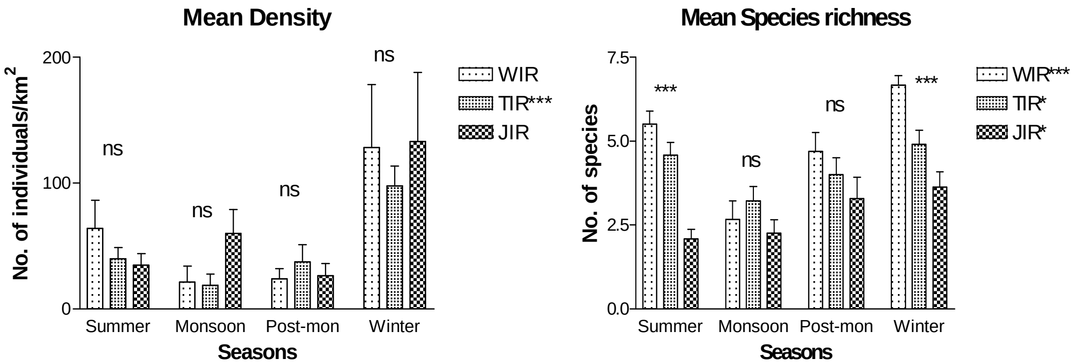


Fig. 1.5. Annual distribution in families of small and large waders at the three Irrigation Reservoir

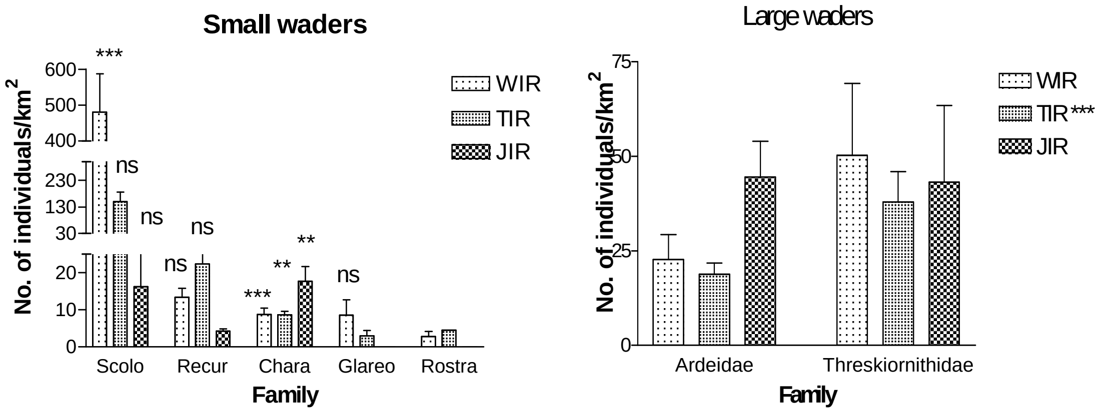
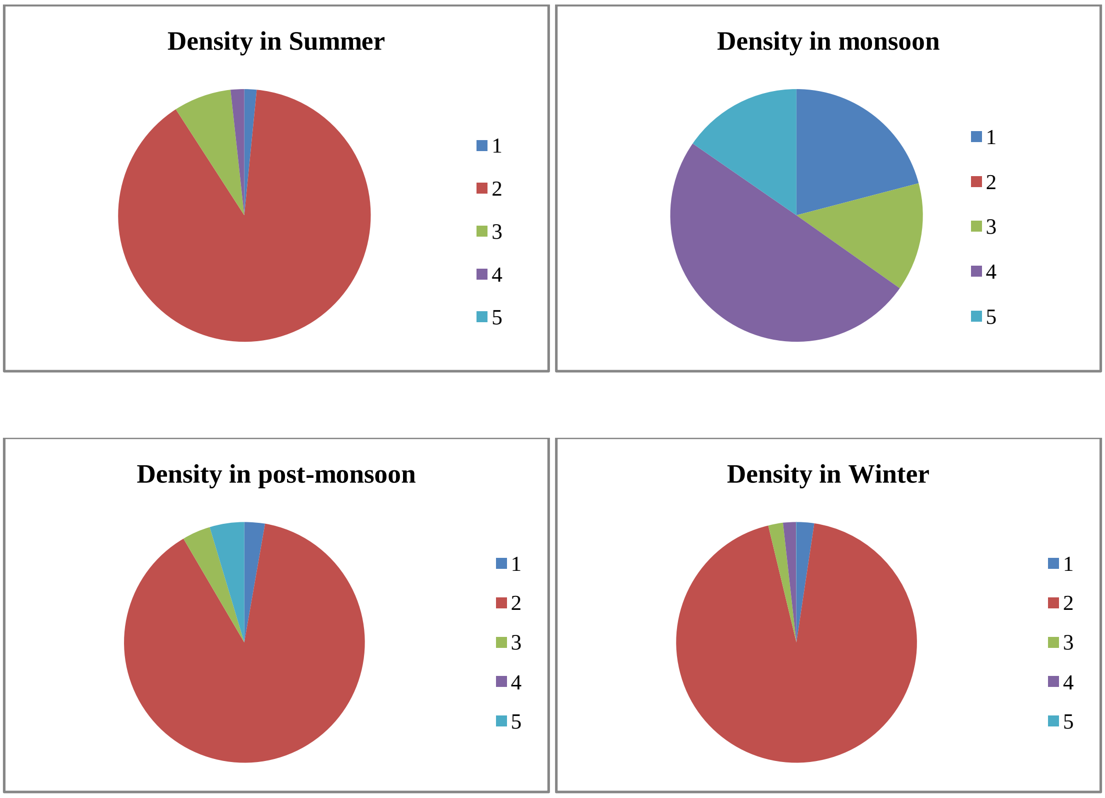
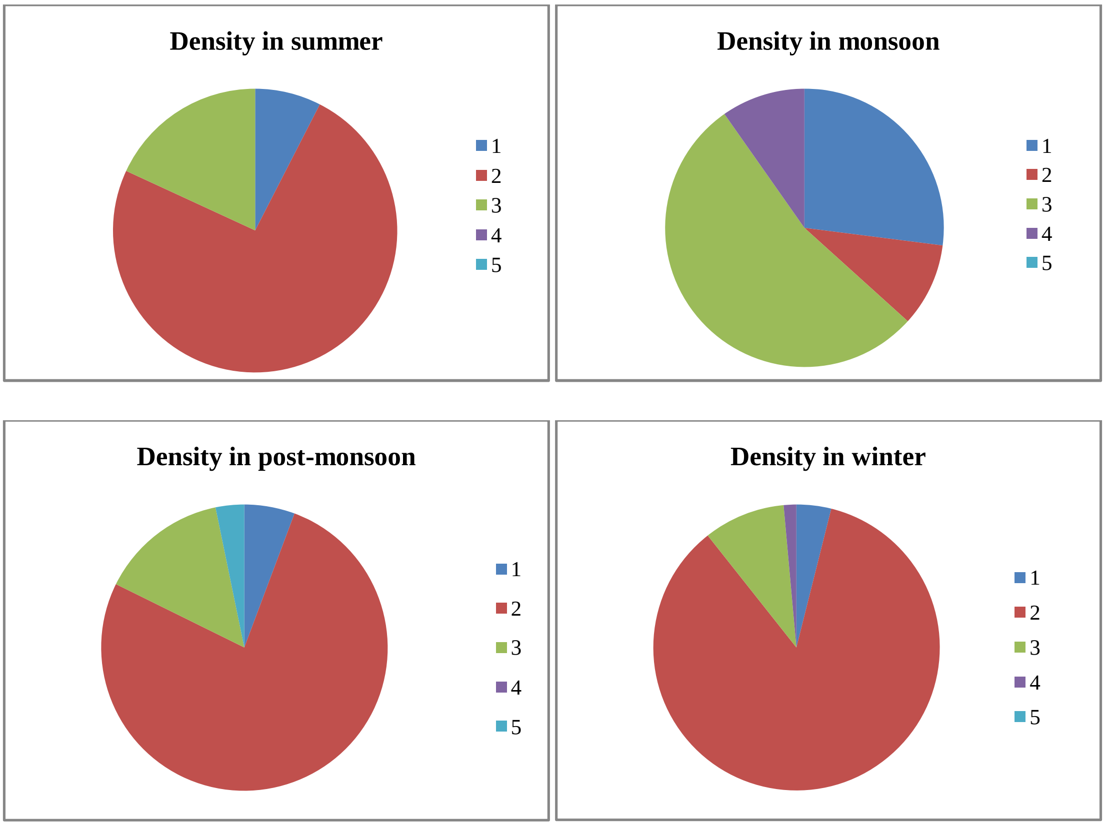


Fig. 1.6. Seasonal distribution in families of small waders at Wadhwana Irrigation Reservoir



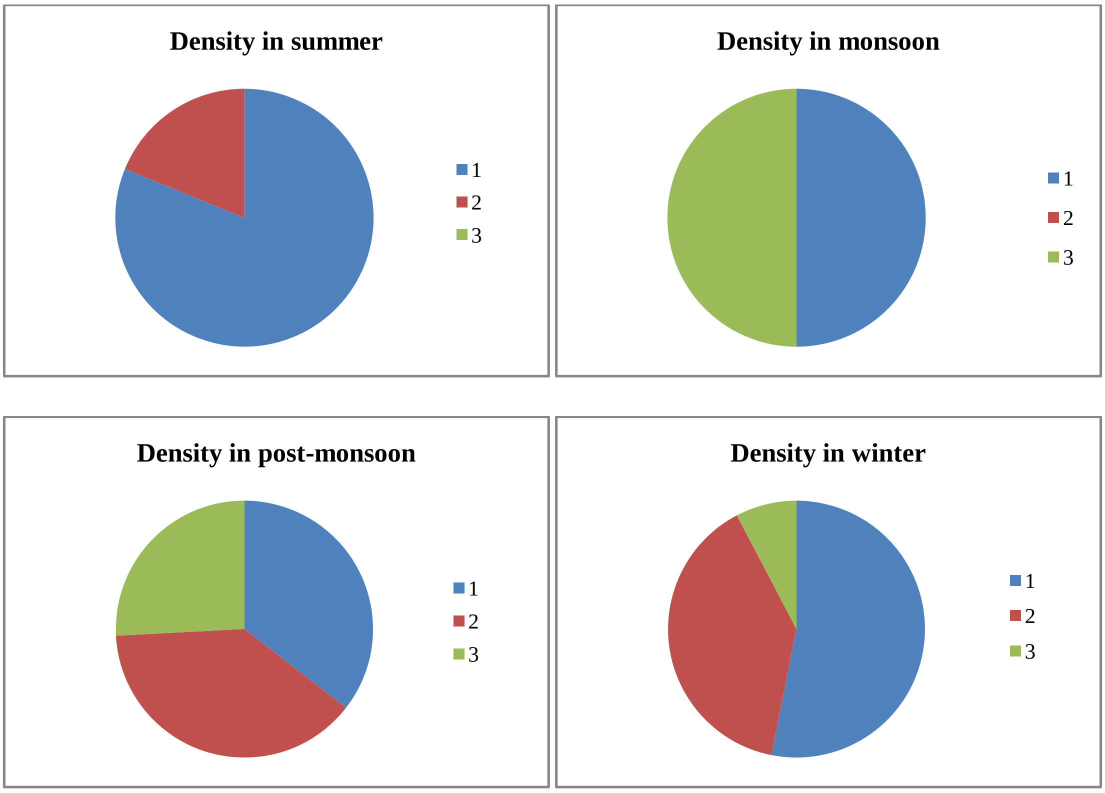
1- **Charadriidae, 2- Scolopacidae, 3- Recurvirostridae, 4- Glareolidae and 5- Rostratulidae**

Fig.1.7. Seasonal distribution in families of small waders at Timbi Irrigation Reservoir



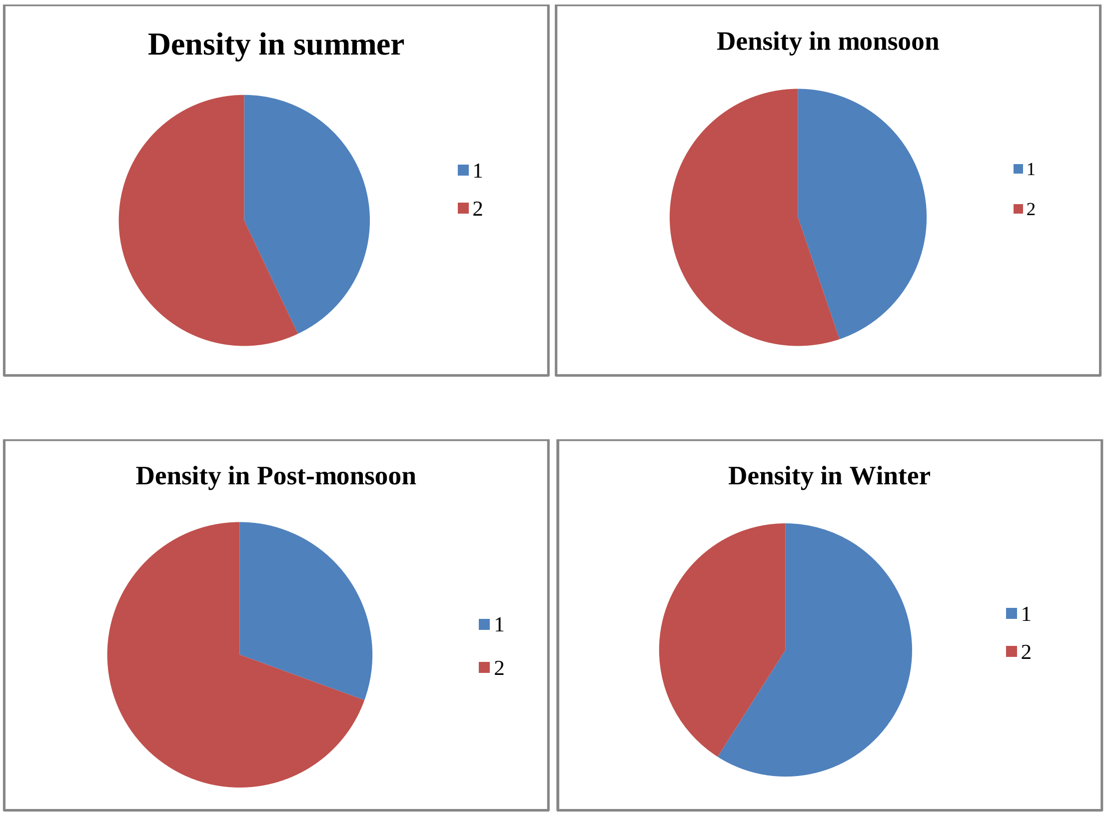
1-Charadriidae, 2- Scolopacidae, 3- Recurvirostridae, 4- Glareolidae and 5-Rostratulidae

Fig. 1.8. Seasonal distribution in families of small waders at Jawla Irrigation Reservoir



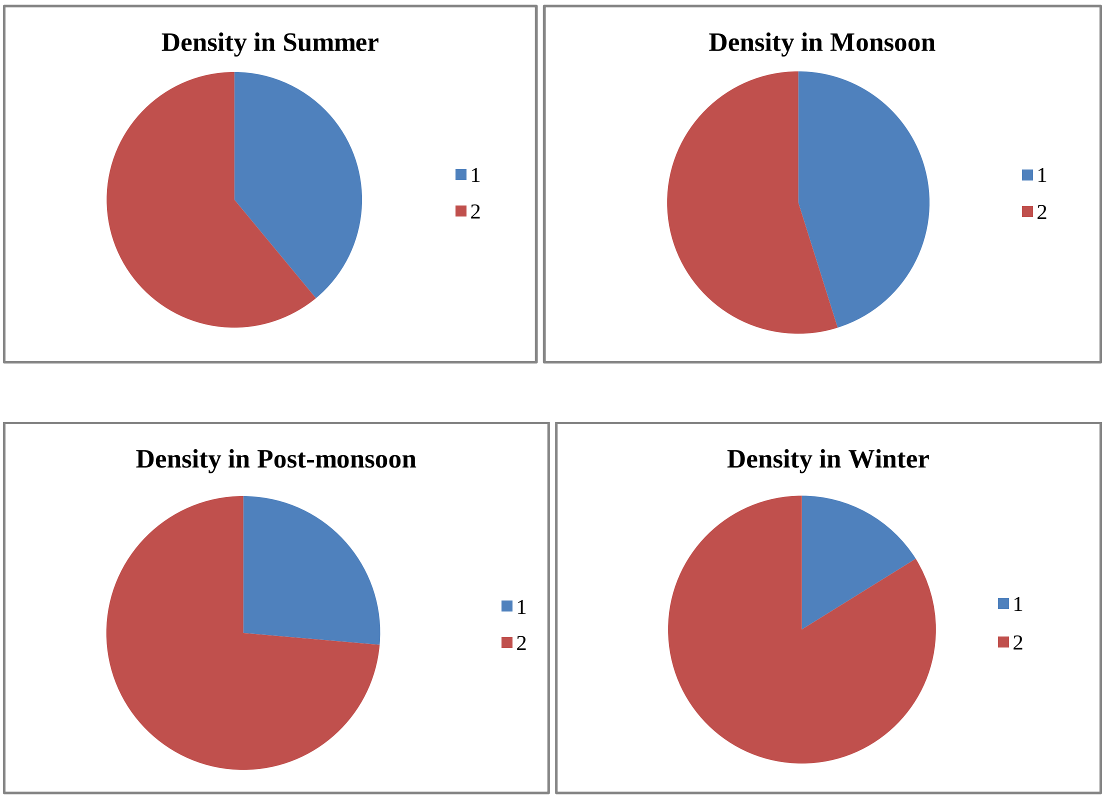
1- Charadriidae, 2- Scolopacidae, 3- Recurvirostridae

Fig. 1.9. Seasonal distribution in families of Large waders at Wadhwana Irrigation Reservoir



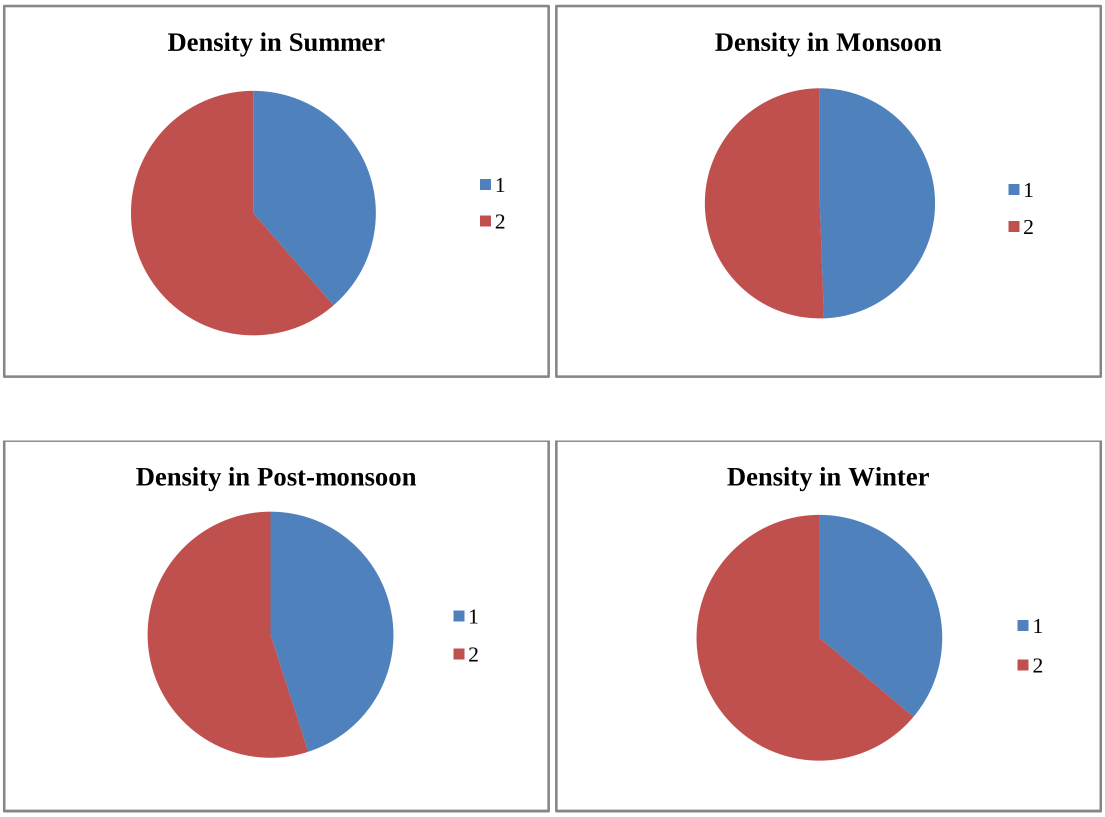
1-Ardeidae, 2- Threskiornithidae

Fig. 1.10. Seasonal distribution in families of Large waders at Timbi Irrigation reservoir



1-Ardeidae, 2- Threskiornithidae

Fig. 1.11. Seasonal distribution in families of Large waders at Jawla Irrigation Reservoir



1-**Ardeidae, 2- Threskiornithidae**

Fig. 1.12. Percentage distribution of migratory, resident and resident-migratory waders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

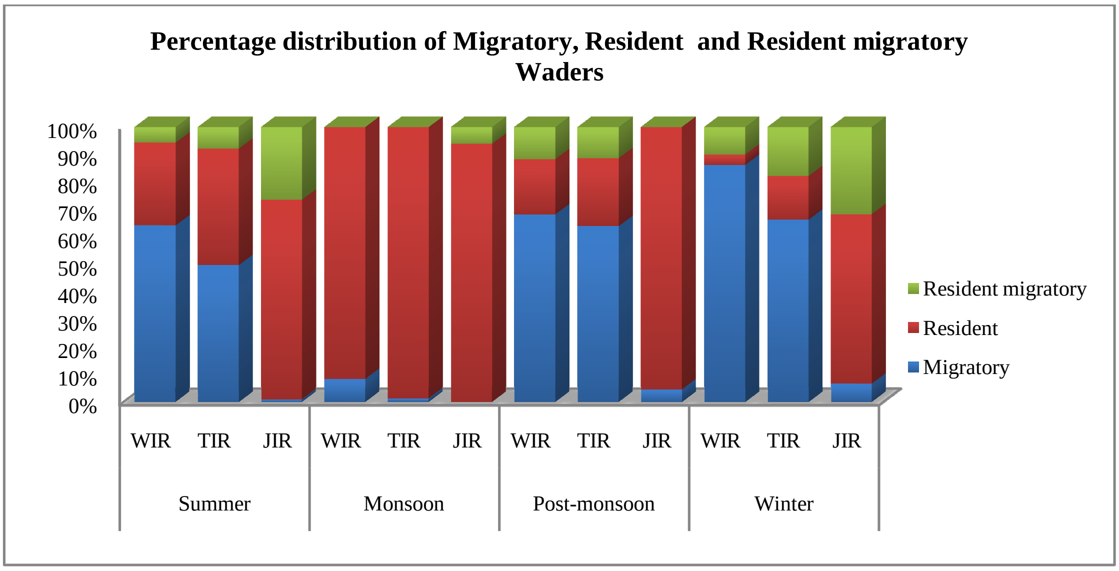


Fig. 1.13. Annual Jaccard's similarity index between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

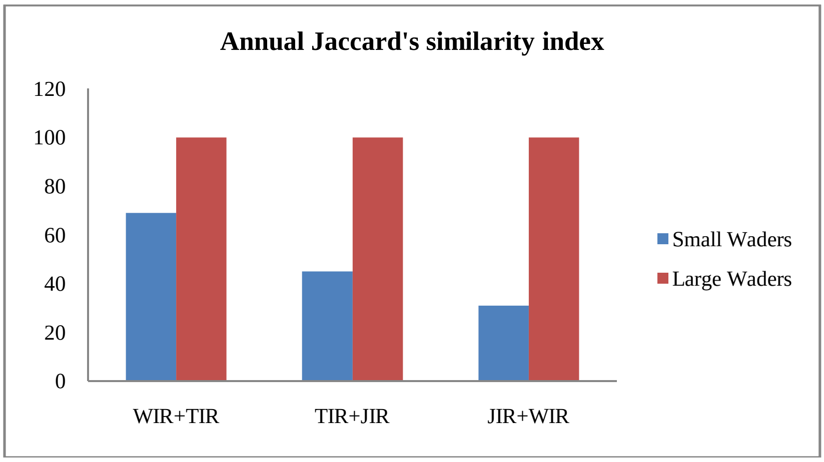
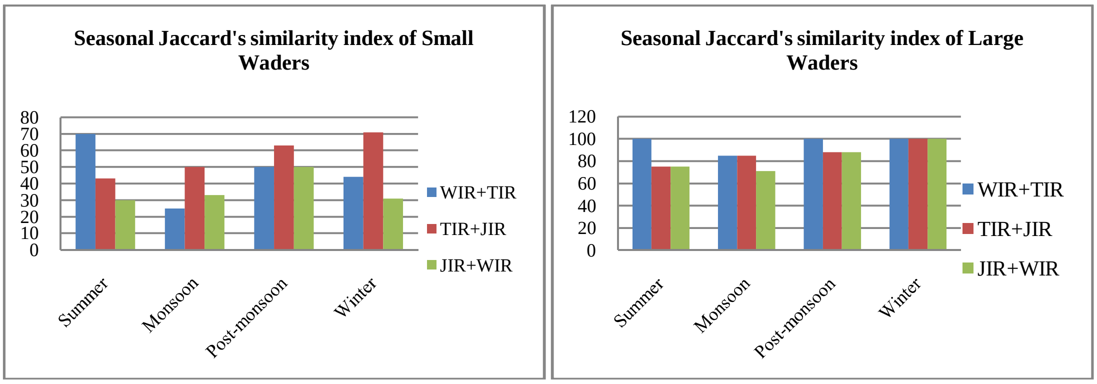


Fig. 1.14. Seasonal Jaccard's similarity index of small waders and Large waders between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



Discussion

The occurrence of 25 species of waders found during the study indicates the presence of their good diversity in the region. Large number of species was recorded at WIR and TIR which are open larger wetlands with submerged vegetation indicating the preference given by the birds to open habitat. Further the hypothesis that larger area supports higher diversity of species (Oertli *et al*., 2002) also stands true for the present study. It is very well elucidated from the earlier arrival of migratory species at the two reservoirs with open area which in turn is reflected as higher percentage of migratory populations in post-monsoon and presence of late migrants till early summer (Table 1.3 Fig. 1.12). Common Sandpiper (*Actitis hypoleucos*) and Ruff (*Philomachus pugnax*) are the early arriving and late departing species of the area.

Migration back to breeding ground is one of the energy demanding events in the bird's life cycle. These long-distance migrants rely virtually entirely on stored energy and nutrients (McWilliams *et al*., 2004). Hence, to fuel migrations, shorebirds must deposit large quantities of fat. This fattening during a limited feeding period (migratory season) requires that these warm-blooded vertebrates feed at prodigious rates. The need to feed rapidly is exacerbated by the high metabolic rates of shorebirds; higher than predicted on standard scaling curves of avian metabolic rates on body size (Kersten and Piersma, 1987). Thus the larger open wetlands providing both effortless and additional food as well as visibility of an approaching predator are preferred by the migrating birds.

Annual Density (D), Species richness (SR), Shannon-Weiner diversity index (H') and Evenness (E)

The differences in the habitat is also reflected as the differences in the density of small waders which was maximum at WIR and minimum at JIR. However, almost same density of large waders at the two may be attributed to two different reasons; effect of size to the former and vegetation at the later wetland. At WIR both resident as well as migratory populations are observed while at JIR mainly resident species are observed. TIR shared many of these species indicating pronounce influence of Narmada water. However, at JIR more resident species are recorded in comparison to the other two reservoirs. The vegetation composition, that depends on seasonal changes, is known to play a major role in determining the distribution and abundance of species (Lee and Rotenberry, 2005; Aynalem and Bekele, 2008). The highest density at WIR was mainly because of migratory species like Ruffs and Black-tailed Godwits arriving in large numbers during winter. Further, the shallow waters at the backside of the reservoir (low water level) seemed to attract the migratory birds coming in search of food at the reservoirs. Water depth is also an important factor that can be used to predict waterbird use patterns (Nagarajan and Thiyagesan, 1996) as the way birds respond to vegetation is affected by the hydrology (Hoffman *et al*., 1994). However, the large wader population at JIR were mainly due to the presence of Glossy Ibis and three species of Egret populations. The height of these species allow them to keep a better watch on approaching predators and the large wadding legs facilitated the access in the vegetation. The study reservoirs are the irrigation reservoirs with surrounding agriculture fields having paddy/wheat as the major crops. These fields when irrigated also serve as a habitat for large waders and hence the species that prefer such habitat were noted during the present study. Further, these vegetation in wetlands and surrounding area also supports good diversity and density of epifaunal and infaunal prey base. At the three reservoirs studied huge insect populations are also reported (Gandhi, 2012) that are accessible for many species.

The results of the study conducted by Deshkar (2008) on water birds showed that the smaller wetlands with low species richness showed higher diversity index compared to the larger wetland with higher species richness. The higher diversity index at TIR supported the above observation. Because of the availability of food at the reservoirs throughout the year, the resident species of small waders like Red-wattled Lapwing increases the usage of this wetland. Higher the number of species of birds uneven is the distribution leading to lower E (evenness). The evenness was highest at JIR where minimum number of species were observed and the population seeming to be more evenly distributed.

Seasonal Density (D) and Species richness (SR)

Waterbird communities are important components of wetland environments having direct and indirect effects on the ecosystems (Comin *et al.*, 2000). Generally, being at or near the top of most wetland food chains, they are highly susceptible to habitat disturbances and are therefore good indicators of general conditions of aquatic habitats (Kushlan, 1992; Jayson and Mathew, 2002; Kler, 2002). During winter the maximum density and species richness of small waders at WIR was due to the presence of Ruffs, Black-tailed Godwits, Black-winged stilts and the two species of Plovers *i.e.* Little ringed Plover and Kentish Plovers. On theoretical grounds more productive ecosystems are expected to allow the coexistence of more diverse species than less productive systems (MacArthur, 1970). Further, it has been reported that wintering plovers are highly mobile and use a diversity of habitats that include cultivated fields too (Knopf and Rupert, 1995). WIR being larger in size and surrounded by vast agricultural matrix, a variety of food resources for waders are available. This is likely to contribute to the highest wader species diversity and density at WIR. Further, open water habitats also possess significantly higher availability of benthic fauna than all the other habitats (Nagarajan and Thiyagesan, 2008). WIR and TIR have open shallow marsh lands (suitable for foraging) along with good aquatic vegetation which JIR lacks. At JIR more emergent vegetation, free-floating (*Nelumbo nucifera*) as well as rooted emergent (*Ipomoea aquatica*) are present. Thus water levels and vegetation both played important roles in the distribution of bird communities in the present study.

The turnover between migrants and resident species over the year resulted in significant seasonal variations in the number of species. During monsoon the migrants are away, while resident species are engaged in the nesting activities, decreasing the overall density and species richness of waders. This is also the season when water level is high, water is available all over the area, the productivity is high and nesting birds get food nearer to their nests. In salt water lagoon of south-west Atlantic in Argentina the extended period during dry seasons contributed by rains produce insignificant effect of seasons on bird species abundance (Canepuccia *et al.,* 2007). However, in present study of fresh water wetlands in semi and subtropical region of India, the effect of inundation is significantly positive. Here, as the wetlands inundated with Narmada have extended hydroperiod and the early arrival and late departure of migratory species resulted into higher population of migratory birds in postmonsoon as well as early summer. In the monsoon dependent irrigation reservoirs of semiarid zone rainfall positively correlates with water surface, and negatively with habitat diversity (declined the heterogeneity), leading to dispersal of birds to wider area decreasing species richness as well as density.

Waterbird communities also are influenced by types, sizes, and quantities of food available within wetlands. Sandpipers and Ruffs were also found foraging in the surrounding agricultural fields at WIR. Among the large waders, Glossy Ibis dominated the area during winters with more than 1000 individuals observed during December. The egrets and herons utilised the wetland for the whole year. During summer a good population of both were noted. The percentile distribution being number dependent, when the number of species was also low at JIR, Glossy Ibis dominated the population whereas at other two waterbodies other species of waders shared the percentile distribution. The resident populations of egrets and herons were evenly distributed throughout the year. According to Aboushiba, *et. al.*, (2013) most egrets prefer to forage along the ponds' edges, at shallow water area which was also observed at the present study sites. These are most gregarious birds and often forage on variety of food items that occur in shallow wetland habitat (Frederick, 2002).

Food is frequently the most important density determining factor for birds (Lack, 1966). Monsoon rains lead to emergence and propagation of a diverse fauna with maximum vegetation growth, most favourable condition for survival. Birds do not need to move for longer distances in search of food. As said earlier this results in their low density at a particular habitat. However, higher small wader density noted during post-monsoon at TIR in comparison to WIR and JIR can be attributed to the high population of Ruffs at the reservoir during this period. However, at WIR almost same species that were present at TIR in post-monsoon were observed in winter indicating that these species arrive first at the smaller wetland with open area *i.e.* TIR, shifting to the larger one later.

JIR supports mainly resident species compared to the other two reservoirs. Even in monsoon density of large waders at JIR was higher due to the presence of Intermediate egret. Rainfall leads to the emergence of large insect fauna around these vegetated areas which may have attracted more individuals of this specie in and around the reservoir. The presence of resident species like Large Egret, Intermediate Egret and Little Egret; Grey Heron, Indian Pond Heron, Black-headed Ibis, Black Ibis and Glossy Ibis during postmonsoon and winter indicates the availability of food. With prey base available these species also get food amongst the scrub vegetation around the reservoir. 106 species belonging to 44 insect families of 9 orders have been reported around JIR (Gandhi, 2012).

Seasonal Shannon-Weiner Diversity Index (H') and Evenness (E)

Among bird communities, variations in the components of diversity are known to differ between habitats and seasons (Rotenberry, 1978; Smith and MacMahon, 1981; Nudds, 1983; Powell, 1987; Bethke *et al*., 1993, Kannan and Pandiyan, 2012). Differences in feeding habits and habitats can increase diversity, evenness and species richness (Smith, 1992). Highest diversity index during monsoon at WIR, in summer at TIR and in post-monsoon at JIR indicates shifting of populations as the conditions change in the semi-arid zones mainly due to change in seasons accompanied with Narmada inundation. His Highness Shrimant Maharaja of the erstwhile state of Baroda had constructed the dam to collect rainwater and distribute it on the basis of gravitational force and slope. Narmada water added to this collection extends not only the hydroperiod but also maintains depth of water for longer duration influencing the habitat continuously at the local level. The populations of resident and migratory species found in the region change due to the availability of food in various seasons at particular depth. WIR is providing an important habitat for migratory waders which prefer shallow water for feeding and open agricultural fields for roosting. Largest congregation of Ruff (*Philomachus pugnax*) in the region amounting to a lac (Forest Department Report) occurs during winters. As said earlier even in summer and monsoon late migrants and early arrivals add up to the diversity of area.

Annual and seasonal Jaccard's similarity index (J)

Highest annual Jaccard's similarity index between WIR and TIR may be due to similarity in microhabitat resulted due to Narmada Inundation. At JIR, where more emergent vegetation and scrub in the catchment area occur (Chapter V), the habitat is not favoured by small waders. When seasonal similarity indices are compared the similarity was most pronounced during summer and winter at all the three reservoirs.

The three reservoirs are located under similar climatic regime influencing the arrival and departure of both resident and migratory species in the area. However, minimum similarity during monsoon observed is due to dispersal of resident species in wider area when vegetation starts flourishing. In addition, as the vegetation grows visibility decreases hence birds avoid the area. This is the season when they are more alert because of nesting activities. During other seasons the similarity is variable depending on local habitat differences. WIR and JIR had least similarity in the composition of species annually as well as seasonally which, as said earlier may depend on the difference in vegetation and microhabitat found at the two reservoirs. WIR supports more migratory bird populations whereas JIR resident bird populations.

As expected, the species of large waders were found to be 100% similar at all the three reservoirs as this group consisted mainly of resident common species in the area. Also the reservoirs are not very far away from each other (within 50 kms. range) for large flying species hence a high difference in the composition of flying species cannot be expected. Highest similarities were noted in summer, post-monsoon and winter, although monsoon also observed good similarity index among the three reservoirs. All the species at WIR and TIR were similar during all the seasons.

Correlation of wader density with physico-chemical properties of water

Studies on the effects of bird communities on the physico-chemical conditions of water and vice versa have been made by several authors (Sanders, 2000; Finlayson *et al.*, 2006; Nagarajan and Thiyagesan, 2008; Deshkar *et al.*, 2010, Patra *et al.*, 2010). The bird distributions are affected by various factors like the food availability, the size of wetland (Paracuellos, 2006) and the abiotic factors in the wetlands (Jaksic, 2004; Lagos *et al.*, 2008). Nagarajan and Thiyagesan (1996) and Pandiyan (2002) have reported that the physico-chemical parameters of water largely determine the wader communities of wetland habitats primarily by their direct and indirect impacts on the food availability and abundance. In semi arid zone of Gujarat, India, water precipitation takes place only during a restricted period of the year. As the monsoon is over, the evaporation starts. This is expected to change the water quality too. However, in recent times Narmada inundation is changing the habitats. The seasonal waterbodies are becoming almost perennial, and the water chemistry has started depending on time and amount of Narmada inundation. Hence at all the reservoirs no one common physico-chemical parameter could be correlated with density of birds.

The water nutrients are associated with plant production, and as plant abundance increases so does bird use (Guadagnin *et al.*, 2005). The migratory waterbirds are known to feed on a high protein diet on their wintering grounds (Halse *et al.*, 1996). The reservoirs with rich biota serve as important foraging grounds to waders as they provide adequate food supply. Hence the life of aquatic birds probably depends directly on physical and chemical properties of aquatic environment. Aquatic invertebrate communities are affected by hydrologic and sediment variables that determine the presence of specific taxa, their abundance, and size which inturn affect the bird communities (Bolduc and Afton, 2004). As said earlier, Narmada inundation probably keeps on changing the nutrient levels hence no single common physico-chemical or biotic parameter plays a significant role in structuring bird communities of the area. Waders having affinity for water move between the waterbodies locally and feed on available prey base. Deshkar (2008) has reported positive correlation of bird density with acidity, bicarbonate alkalinity, chlorides, CO_2, phosphates, temperature, water cover and TSS at WIR while with CO_2, mollusc, hydroxyl alkalinity, temperature, water cover and TSS at TIR. Her study was conducted during early days of Narmada inundation when the changes in the ecosystem had started while during the present study inundation was regular and probably carrying capacity of the newly modified ecosystem nearing to its complex.

Further, shorebirds are also dependent upon depths of water for foraging which also affect their habitat preferences (Wrona *et al.*, 2006) this affects their populations in the reservoirs which have fluctuating depths. These non-diving waterbirds have characteristic bill lengths and shapes, neck lengths, leg lengths, and body sizes that allow them to feed at specific water depths (Baker, 1979; Pöysä, 1983; Zwarts and Wanink, 1984).

Birds are also reported to prefer alkaline waters in their habitats. The three study areas have moderate alkaline water all throughout the year (Deshkar, 2008; Chapter IV) supporting good density and diversity of water birds including waders. The increase in alkalinity and decline in waterbird (wader) population during summer is merely the absence of migratory populations. pH of water from wetlands is also reported to have a profound influence on the avian population characteristics (Manikannan *et al.*, 2012). Levels of pH too high (> 9) or too low (< 5) can kill aquatic life (Younos, 2007) and influence the whole ecosystem. A significantly positive correlation of pH at WIR with the density of waders supports this observation. Correlations have also been reported between wetland pH and waterbird distribution and abundance for the Dipper *Cinclus cinclus* in the streams of southwest Scotland (Vickery, 1991). However no such correlation could be established at the other two smaller reservoirs.

A negative correlation of water temperature and birds was found at all the three reservoirs which was significant at 0.05 level at the wetland with vegetation *i.e.* JIR.. Duran (2006), in his study on the effect of water temperature on the diversity of macroinvertebrates in a stream, reported that change in macroinvertebrates affects the density of waders. However, Bolduc and Afton (2004) have found no significant correlation of temperature on waders in a coastal marsh pond. Myers *et al.,* (1987) reported that migratory shorebirds exploit resources seasonally making them dependent on a specific sequence of sites essential for completing the annual cycles.

Carbon dioxide, another important parameter in water, comes from the decaying organic materials, from respiration by both plants and animals, and also dissolved in groundwater and rain water received by ponds. The amount of dissolved carbon dioxide is usually higher at the bottom of ponds where benthic fauna occur. It also showed a positive but non significant correlation with bird density at WIR and TIR and negative but significant (0.05) at JIR. JIR, mainly used by large waders for whom the prey base is probably epifaunal (on sediment) and not infaunal (in sediment).

In the present study, though the levels of nitrogen and its molecules were high during summer, low populations of waders at the WIR and TIR in comparison to winter can also be attributed to absence of migratory populations. As JIR mainly support resident species these influence is not prominent here. A positive correlation of Kjeldahl nitrogen was observed at all the three reservoirs but significant only at JIR which is used by the locals for sanitation purposes. The high levels of sulphates may be due to the high TDS brought with surface runoff levels in the reservoirs. Sulphates are constituents of TDS and known to form salts with sodium, potassium, magnesium and other cations (McDaniel, 2007). A positive effect of sulphates on wader density has been reported by Manikannan *et al.,* (2012) which stands true for the present study too.

Correlation of wader density with physico-chemical properties of soil

In a wetland, available habitat surface, the amount and type of food resources (which in turn are affected by water quality, salinity, hydrodynamic regime, sediment, soil texture and moisture), and the configuration of particular sites affect the number and species of waterbirds present (Hill *et al.,* 1993). Sediment represent essential element as it supports both autotrophic and heterotrophic organisms.

Among the nutrients, the nitrogen concentration in the sediments is controlled by the presence of organic matter as 90% (or even more) of the nitrogen exist in organic forms (Martinova, 1993). Lower levels of nitrogen and organic matter during winter at WIR and TIR indicate increase in productivity which seems to attract large populations of small waders to the reservoirs. Nitrogen, not considered to be the limiting nutrient in most cases for fresh water lakes is nonetheless an essential nutrient for algal and rooted plant growth (Wetzel, 2001).

The other nutrient, phosphate also maintained a low level in sediments during winter which seemed to positively influence the populations of waders. Nagarajan and Thiyagesan, (1996) also observed same results in their study but in coastal water. A positive and significant correlation of phosphates was found at TIR.

Magnesium is one of the major soluble ions in soil (Bohn *et al.,* 1979). Fine-textured soils tend to contain more magnesium than those with coarse particles because less leaching occurs in finer soils (Millar, 1955). Calcium and magnesium are essential nutrients in the life-cycle of molluscs which influence their presence in a water body. The existence of calcium deposits in the tissues of freshwater mollusc is well established (Kapur and Gibson, 1968). Molluscs being the component of wader diet their availability may affect the wader population. A positive correlation of calcium was noted at WIR and JIR and that of magnesium at all the three reservoirs but it was significant only at WIR.

In conclusion, it can be said that soil and water of WIR and TIR having minimum risk of organic pollution and threat of eutrophication support both migratory as well as resident populations of waders whereas JIR needs critical evaluation and monitoring to avoid organic pollution as well as eutrophication and attract not only resident but huge population of migratory waders too.

Conclusion

Birds have higher dispersal rate and are the first to abandon any of the unfavourable condition and thus are considered to be the important component of a habitat. This chapter deals with the wading birds. They respond by moving to local concentrations of food availability and move away from unsuitable areas. Hence their presence and absence is also used to assess the transient conditions of wetlands.

Among the three reservoirs studied, WIR is the most preferred site for resident as well as the as migratory species with late migrants utilizing the wetland till early summer. WIR and TIR also provided habitats for the early migrants and resident species during post-monsoon. However, at JIR, the low density all throughout the year may be attributed to the absence of shallow water in the reservoir along with the dense vegetation on the earthen dam as well as in catchment area. Thus, TIR and WIR support both migratory (mainly small waders) and resident (Large waders) species of birds while JIR due to its vegetation composition supports large resident species of birds.

MACROBENTHIC COMMUNITY STRUCTURE AT THE THREE RESERVOIRS

Introduction

Benthic macroinvertebrates have been intriguing targets of biological monitoring efforts because they are a diverse group of long-lived, sedentary species that react strongly and often, predictably to human influence on aquatic ecosystems (Rosenberg and Resh, 1993). As many species of this group play important role as indicators of aquatic pollution they have been the subject of intensive ecological research (Wilhm, 1975; James, 1979; Tudorancea *et al.*, 1979; Mason, 1981; Olivieri, 1982). Many of them are filter feeders, feeding on phytoplankton and are themselves food sources for larger organisms such as fish, linking primary production to the higher trophic levels. Further, many of them being detrivores, link detritus deposits to higher trophic levels (Brinkhurst, 1974; Hanson and Peters, 1984) by reworking sediments and breaking down organic material before bacterial remineralization (Tagliapietra and Sigovini, 2010). Hence, detritivores prevail in habitats rich in organic matter, *e.g.* in the vicinity of plants (Timm *et al.*, 2001; Kornijow *et al.*, 2003).

These aquatic invertebrate communities are affected by hydrologic and sediment variables that determine the presence of specific taxa, their abundance, and size. Further, sediment organic content also determines these invertebrate communities (Benke, 1984; Batzer and Wissinger, 1996; Robinson *et al.*, 2000). In addition the structural complexity of their habitats is also affected by the amount of undecomposed vegetation in sediments (Minshall, 1984).

Hence, it is assumed that the macrozoobenthic taxa composition is the result of complex interactions of diverse environmental variables. Many studies report the relationships between basic quantitative parameters such as number of species, their abundance and biomass, and environmental gradients or temporal variations (Castric-Fey, 1991; Balachandran *et al.,* 2012; Patra *et al.,* 2010; Shah *et al.,* 2011). Further, the factors that influence the distribution of macrozoobenthic organisms within each sampling site can also be the type of substrate and its granulometry (Elexova and Nemethova, 2003). Consequently, the benthic infaunal activities also affect the physical and chemical processes within sediments. These aspects have received considerable attention during recent years (Mucha and Costa, 1999; Bially and Macisaac, 2000; Heilskov and Holmer, 2003) indicating that composition and abundance of zoobenthos depend on multiple environmental factors and substratum type (Heino, 2000; Tolonen *et al.,* 2001).

The benthic macroinvertebrates, being rich in proteins, form an important dietary component that influence habitat selection by waterbirds especially waders (Zwarts, 1997). Hence, in the study of waders, the density of benthic fauna has been used by many authors to explain differential habitat use by waterbirds at migratory stopover sites (Tsipoura and Burger, 1999; Gill *et al.,* 2001; Pandiyan, 2002; Pomeroy and Butler, 2005; Mendonca *et al.,* 2007). In recent years, substantial areas of feeding grounds of water birds have been lost in Europe and Asia due to habitat modifications. The non-diving waterbird species adapted for capturing prey of different sizes or minimal sized from the water column or sediments are the species whose ecology is closely affected due to distribution and abundance of such food resources (Nudds and Bowlby, 1984). Thus, the aquatic macro- invertebrates are important factors in determining avian use of a wetland (Mc Knight and Low, 1969; Schroeder, 1973; Swanson and Meyer, 1973; Kaminski and Prince, 1981).

Hence, the purpose of the present study is to make biologically based inferences on environmental conditions and to examine relationships between natural environmental factors (substrate) and the composition of benthic invertebrate communities at the three irrigation reservoirs-Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation reservoir (JIR) which support good density and diversity of birds.

Materials and Methods

The study area was sampled bimonthly for macro-invertebrates using quadrat sampling method from March 2009 to February 2011. A quadrat of 30 cms. X 30 cms. upto a depth of 5 cms. was selected randomly for collection of benthos. The macrobenthic samples were washed, sorted and preserved in 70% alcohol. Benthos forming a very large group were mainly identified upto family level and wherever possible up to genus as well as species level with the help of standard keys by Borror and DeLong, (1971); Needham and Needham, (1972); Pennak, (1989; 2004) and Johnson and Triplehorn, (2004).

The benthic fauna was analysed for diversity indices like Species richness (Krebs, 1985) as well as Density (Rodgers, 1991) for each visit. Density was measured on the basis of the number of individual of species found in each quadrat using formula: Number of individuals / area *i.e.* size of quadrat x depth. Total number of species observed per visit is considered as species richness. Percent Occurrence for each order was calculated taking all visits in consideration using formula: Number of times all species belonging to a particular order observed / Total number of all species of all Classes. Occurrence was calculated for each family observed as the number of times one particular family encountered in total visits during the study period. The rating was given as Abundant for families encountered >35 visits, Common for families encountered between 26-35 visits, Frequent for families encountered between 11-25 visits, Uncommon for families encountered between 6-11 visits and Rare for families encountered in <5 visits. For the statistical analysis the data for species richness and density is pooled for 3 months according to the seasons as Summer: March, April, May; Monsoon: June, July, August; Post-monsoon: September, October, November and Winter: December, January, February. Further the Mean and standard error of mean (SEM) were calculated for each season and applied to One-way ANOVA as described by Fowler and Cohen (1995) with No post test for various parameters for four seasons using GraphPad Prism version 3.00 for Windows, (GraphPad Software, San Diego California USA). The correlation is carried out using SPSS 7.5 software. The p value for ANOVA is non significant if $P > 0.05$ (ns), significant if $P < 0.05$ (*), significantly significant (**) if P is < 0.001 and highly significant (***) if $p < 0.0001$. Pearson correlation was carried out between benthic fauna and physico-chemical properties of water and soil along with waders using SPSS software 7.5.

Results

Species composition of benthic fauna at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir (Table 2.1, Fig. 2.1) (PLATE 6)

A total of three phyla were recorded during the whole study period. These include Phylum Annelida, Phylum Arthropoda (Annexure 2) and Phylum Mollusca. For the convenience of discussion, phylum Mollusca has been dealt with in separate chapter *i.e.* (Chapter III).

Altogether 79 species of benthos belonging to 38 families were observed at the three irrigation reservoirs. Phylum Annelida is represented by Sub-class: Oligochaeta and order Megadrilacea four families- Naididae, Megascolecidae and two unidentified families. Four genera were recorded for family Naididae and one under Megascolecidae.

The benthic fauna in the study areas mainly comprises of class Insecta. The largest orders noted were Coleoptera and Hemiptera (Annexure 2).

Order Coleoptera was represented by families Carabidae, Staphylinidae, Cleridae, Chrysomelidae, Coccinellidae, Hydrophilidae, Noteridae, Dysticidae Limnichidae and Curculionidae and one superfamily Hydrophiloidea. Out of these, six families were noted at all the three irrigation reservoirs, while family Curculionidae was absent at WIR, Cleridae and Coccinellidae at TIR and JIR while Dysticidae at WIR. Family Hydrophilidae was absent at JIR.

When family wise representation is considered, family Carabidae is represented by *Apotomus sp.*, *Tachys luxus*, *Bembidion sp.* and *Casnoidea indica* at TIR and all species except the last one at WIR while only *Apotomus sp*. and *Tachys luxus* was found at JIR. Family Staphylinidae was represented by *Paederus fucipes* and *Paederus sp.* at all the three study sites. *Bledius sp.* was noted only at WIR. Cleridae was represented by an unidentified genus observed only at WIR while family Chrysomelidae was illustrated by altogether six species with four representatives at TIR. Out of them, only three could be identified upto generic level. They were *Cryptocephalus sp.*, *Aphthona sp.* and *Chaetocnema basalis*. *Aphthona sp.* was also noted at WIR while at JIR, two additional unidentified chrysomelid species were recorded. Family Coccinellidae was noted only at WIR represented by an accidental genus, *Stethorus sp*. Further, four representatives of superfamily Hydrophiloidea were recorded at the three irrigation reservoirs. Of these *Hydrophilus sp.* belonging to family Hydrophilidae was noted at TIR while two more species could not be identified were noted at WIR and TIR. The family of one species recorded could not be identified and hence considered at superfamily level only. From family Noteridae, two representatives were recorded at WIR and TIR. Of these, the one not identified upto genus level occurred at all the three irrigation reservoirs while the one identified *Canthydrus sp.* occurred only at WIR and TIR. The next family, *i.e.* Dytiscidae was represented only at TIR and JIR with two identified genera *Hydaticus sp*. and *Laccophilus sp*. from TIR while only one unidentified species at JIR. The next coleopteran family noted only at TIR was Limnichidae with one identified genus *Byrrhinus sp.* while the other one remained unidentified. The next family of order Coleoptera, family Curculionidae was noted only at TIR and JIR represented by a single species *Lissorhptrus sp*.

Order Hemiptera was represented by altogether 11 families at the three irrigation reservoirs. Out of these, 11 were noted at WIR, 7 at TIR and 5 at JIR. Family Hebridae was the most frequent family at JIR but rare at WIR and TIR which was represented by

Hebrus sp. One unidentified genus of this family was noted only at JIR. Family Cercopidae was represented by nymph of frog hopper *Bofylus sp.* and an adult of family Mesovellidae (*Mesovelia sp*.) only at WIR. Family Pleidae (pygmy back-swimmers) was illustrated by *Paraplea sp.* only at WIR while nymph of one unidentified species at TIR and two unidentified genera at WIR and JIR. Representatives of family Gerridae were very common at the three study areas represented by *Gerris sp*. Nymph and adults of *Nerthra sp*. of family Gelastocoridae were observed at WIR and TIR while Family Ochteridae again represented by a single genus *Ochterus sp.* was found only at TIR and once during the whole study period at WIR. *Nepa sp*. (Family Nepidae) and *Micronecta sp*. (Family Corixidae) were observed at TIR and WIR. Family Notonectidae was also observed at these two reservoirs but with an unidentified genus while only one genus of family Aphidiidae was noted at TIR and of family Lygaeidae at JIR.

Diptera, Orthoptera, Odonata and Hymenoptera were illustrated by 2 families each, while Ephemeroptera and Trichoptera by a single family each at the three irrigation reservoirs. Two families of Order Diptera are Culicidae and Chironomidae while larvae of *Culex sp.* of former family were copious at all the three reservoirs; *Chironomous sp*. of the latter family were rarely observed at WIR and TIR. Family Gryllotalpidae of order Orthoptera was represented by *Gryllotalpa africana* and was noted at all the three irrigation reservoirs whereas genus *Xya* of the family Tridactylidae was observed at TIR and WIR only. Nymphs of Order Odonata were observed at all the three reservoirs. Although the families to which they belong could not be identified, sub-family Lestinae was noted at WIR and TIR. Six species of order Hymenoptera represented by genus *Camponotus sp.* of family Formicidae were found to move around on the moist soil at all the three irrigation reservoirs. In addition small ants *Oecophylla smaragdina, Monomorium minimum, Solenopsis invicta* were also observed at all the three irrigation reservoirs. Second family of order Hymenoptera noted only at TIR was Aphidiidae with genus *Aphis*. Naiad of may fly (Order: Ephemeroptera) were noted but only at WIR and JIR while those of Order Trichoptera represented by family Hydropsychidae only at TIR.

Class Arachnida on the other hand was represented by seven species under order Araneae. Of these, families noted were Araneidae (*Argiope sp.*) and Salticidae (*Plexippus sp.*) at all the three reservoirs, family Lycosidae (*Paradosa sp.*) at WIR and TIR while Tetragnathidae (*Tetragnatha sp.*) at JIR. Of the three unidentified genera, one each was noted at WIR, TIR and JIR. Of the two species belonging to order Trombidiformes, one *Hydrachna sp*. belonging to Hydrachnidae while the second one could not be identified upto the family level.

Mean species richness at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir

<u>Annual</u> (Table 2.2 and Fig. 2.2)

The mean annual species richness of benthic fauna was 5.3±0.68 species/quadrat at WIR, 5.74±0.82 species at TIR while 4.12±0.52 species at JIR over the whole study period. The variations in the annual species richness was not significant ($P>0.05$; $F_{(2.72)}1.49$).

<u>Seasonal</u> (Table 2. 2 and Fig. 2. 2)

When the mean species richness was compared seasonally at WIR it was highest during winter with 8.67±1.31 species/quadrat. It started declining with mean 6.83±0.7 species during summer and reached to 1.67±0.67 species during monsoon and increased to

3.0±0.27 species during post-monsoon. The seasonal variations were highly significant ($P<0.0001$; $F_{(3,19)}14.26$).

At TIR also similar trend in the seasonal comparison of mean species richness was recorded with high species richness during winter at10.0±2.67 species/quadrat, during summer at 6.44±0.69 species, during monsoon at 2.33±0.49 species and during post-monsoon at 3.75±0.63 species, with significantly significant differences ($P<0.001$; $F_{(3,21)}5.33$). However, at JIR, the species richness was comparatively low with 5.14±0.8 species during summer and 5.11±1.06 species in winter, while 2.8±0.49 species in post-monsoon and 1.75±0.48 species in monsoon. No significant seasonal variations were noted ($P>0.05$; $F_{(3,21)}2.87$).

<u>Among the reservoirs (Table 2. 2)</u>

When species richness was compared among the reservoirs, it was found to be higher at WIR and TIR during summer and lower at JIR with no significant differences ($P>0.05$; $F_{(2,19)}1.34$). While it was non-significantly higher at TIR during monsoon ($P>0.05$; $F_{(2,10)}0.49$). During post-monsoon also the mean species richness was almost same with no significant differences ($P>0.05$; $F_{(2,14)}1.14$) while in winter highest mean species richness was noted at TIR followed by WIR and lowest at JIR but again with no significant differences ($P>0.05$; $F_{(2,18)}2.52$).

Mean Density

<u>Annual</u> (Table 2.3 and Fig. 2.3)

The annual mean density at WIR was 1089.0±286.9 individuals/m^3, at TIR 888.7±128.2 individuals/m^3 and at JIR 699.4±82.53 individuals/m^3. No significant differences were noted among the three irrigation reservoirs ($P > 0.05$, $F_{(2,72)}$ 1.14).

<u>Seasonal</u> (Table 2.3 and Fig. 2.3)

When the seasonal comparison in mean density was carried out, at WIR it was noted to be 1240±374 individuals/m^3 during winter, highest 2339±834 individuals/m^3 during summer, 172±58.38 individuals/m^3 during monsoon and 382.5±98.42 individuals/m^3 during post-monsoon, with significant differences ($P<0.05$; $F_{(3,19)}3.96$).

Mean density at TIR was highest during post-monsoon with 1640±388.3 individuals/m^3 followed by winter with 992.7±216.2 individuals/m^3, summer with 768.1±163.2 individuals/m^3 and lowest during monsoon with 510.3±238.2individuals/m^3. Significant differences were noted ($P<0.05$; $F_{(3,23)}3.29$).

At JIR like WIR, the mean seasonal density was high during summer (788.3±115.7 individuals/m^3). It decreased to the lowest during monsoon (453.0±104.7 individuals/m^3) increased in post-monsoon (648.2±291.7 individuals/m^3) as well as in winter (777.3±142.4 individuals/m^3). No significant differences were noted ($P>0.05$; $F_{(3,21)}0.69$).

<u>Among the reservoirs</u>

When mean density was compared among the reservoirs, in summer significant variations ($P<0.05$; $F_{(2,20)}4.59$) were noted while no significant differences were noted in monsoon ($P>0.05$; $F_{(2,11)}0.53$). However, for post-monsoon significantly significant differences with $P<0.001$; $F_{(2,14)}$ 7.43 and for winter no significant differences ($P>0.05$; $F_{(2,18)}0.91$) were noted.

Jaccard's Similarity Index (J) (Table 2.5, Fig. 2.5, 2.6)

The annual Jaccard's similarity index was maximum between WIR + TIR with 44% species similar, followed by 33% between WIR + JIR and minimum 30% between TIR + JIR.

The seasonal Jaccard's similarity index was maximum during summer between WIR + TIR with 22% similarity followed by 21% between JIR + WIR and minimum 13% between TIR + JIR. However, during monsoon though the similarity was maximum between WIR + TIR with 14%, it was 13% between JIR + WIR and minimum 7% between TIR + JIR. In post-monsoon 12% similarity was noted between WIR + TIR as well as JIR + WIR while TIR +JIR showed 25% similarity. During winter similarity between TIR + JIR and WIR+JIR was 27% each and between TIR+WIR 26%.

Percentage occurrence of orders at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir (Table 2.5, 2.6 and Fig. 2.5, 2.6)

<u>Annual</u>

When percentage of occurrence of eleven orders was compared at the three irrigation reservoirs, at WIR maximum 39% were Coleopterans followed by 12% Hemipterans, 13% order Trombidiformes, 7% order Araneae, orders Hymenoptera and Megadrilacea (Phylum: Annelida) 8% each, while order Diptera 4.81%, orders Odonata and Orthoptera 1% each and order Ephemeroptera 0.96%.

As noted for WIR, at TIR also the highest percentage of occurrence was found for Coleopterans (51%). This was followed by Hemipterans with 13%. Hymenoptera, Trombidiformes and Araneae at 6% each, Order Diptera and order Megadrilacea occurred at 5% each, while Orthoptera and Odonates occurred at 2% and 2% respectively and order Trichoptera was observed only once at 0.72%.

At the third reservoir, JIR, Order Coleopterans occurred with highest 27% followed by Hemiptera with 26%. However, here order Diptera had 10% occurrence. Orders Megadrilacea occurred at 9%, Hymenoptera and Araneae at 8% each, Trombidiformes at 5.95% occurence while Orthoptera, Ephemeroptera and Odonata occurred at 1% each.

Seasonal

When seasonal percentage occurrence was considered at WIR, Coleopterans dominated during summer with 47%, followed by 11% each of Hemipterans and Araneae, 8% each of Hymenoptera and Trombidiformes, while order Megadrilacea at 5% and 2% each of Diptera, Orthoptera and Ephemeroptera. Representatives of order Odonata were not recorded amongst the benthos of summer. During monsoon order Hemipterans dominated with 40% followed by Diptera, Araneae and Trombidiformes with 20% each while other groups were not recorded. Post-monsoon was dominated by coleopterans occurring with 27%. At 18% and 13% respectively occurred Megadrilacea and Hymenoptera followed by 9% occurrence of orders Hemiptera, Araneae and Trombidiformes each. Orders Diptera, Orthoptera and Odonata occurred with 4% each at the reservoir. Winter was also dominated by Coleopterans with 41% occurrence. Order Trombidiformes occurred with 18% and Hemiptera with 11%. Hymenoptera, Araneae and Megadrilacea each had 6% occurrence. Dipterans had an occurrence of 4% while Odonata 2%. Ephemeropterans occurred at WIR only during summer.

The benthic fauna at TIR was also dominated by coleopterans. During summer they occurred at 56% whereas other orders had low % Occurrence with Hemipterans at 9%.

Order Trombidiformes and Megadrilacea at 7% each, Orthopterans at 5% while Dipterans, Hymenopterans and Araneae each occurred at 3%. Odonates were least observed with 1% at this irrigation reservoir. During monsoon 64% Coleopterans dominated at TIR. Diptera and Araneae each occurred at 11%, Orthoptera and Hymenoptera at 5% each, while Hemipterans, Megadrilacea and Trombidiformes were completely absent. In post-monsoon also Coleopterans dominated the reservoir with 53%. Hymenoptera followed with 15% while other orders *i.e.* Megadrilacea, Trombidiformes, Araneae and Diptera were encountered at 7% each and Orhtoptera, Odonata and Trichoptera were not encountered. During winter, the benthos was again dominated by Coleoptera with 41%. Here, Hemipterans occurred at 25% followed by Araneae and Trombidiformes at 7% each, Diptera and Hymenoptera at 5% each while Odonata and Megadrilacea each at 3%. Trichoptera was observed only once during the whole study period (1%) while Orthopterans were not encountered in this season.

At JIR, the overall occurrence of species of benthic fauna was lower as compared to WIR and TIR. However, here also during summer the occurrence of Coleopterans and Hemipterans were higher with 28% and 21% respectively. This was followed by Megadrilaceans with an occurrence of 12%, Dipterans and Trombidiforms at 6% each and orders that occurred least were Odonata and Ephemeroptera at 3% each with the absence of Orthopterans. During monsoon, the Coleopterans and Hemipterans occurred with 28% and 42% respectively while Megadrilacea and Diptera with 14% each. In post-monsoon however, the occurrence of Coleopterans and Hemipterans were same with 21% followed by 14% of Diptera and Trombidiforms each. All other orders *i.e.* Araneae, Hymenoptera, Orthoptera and Megadrilacea occurred at 7% each. During winter, the

Hemipterans and Coleopterans dominated the reservoir with 30% each. Dipterans occurred at 13%, Hymenopterans and Araneae (spiders) with 10% each while the orders Trombidiformes and Megadrilaceans had 3% occurrence and Orthoptera, Odonata and Ephemeroptera were not recorded in this season.

Occurrence of families at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir (Table 2.7)

The families of benthic fauna were rated according to the number of times they were observed during the study period (Table 2.4, Annexure 2). At WIR, families Carabidae and Staphylinidae (Coleoptera) were frequent while Formicidae (Hymenoptera) and Hydrachnidae (Trombidiformes) were noted to be uncommon. All other 29 families comprising Coleopteran families such as Cleridae, Chrysomelidae, Coccinellidae, Hydrophilidae, Noteridae, Corixidae, Cercopidae, Mesovallidae, Pleidae, Gerridae, Gelastocoridae, Ochteridae, Hebridae, Nepidae, Notonectidae from order Hemiptera, Chironomidae, Culicidae of Diptera, order Orhoptera comprising Gryllotalpidae, Tridactylidae, Lestidae and two unidentified families of order Odonata, an unidentified family of order Ephemeroptera, spider family including three unidentified families, Lycosidae, Araneidae, Salticidae and order Megadrilacea comprising families Naididae, Megascolecidae were rare.

At TIR also, families Carabidae and Staphylinidae were frequent but Chrysomelidae, Hydrophilidae, Culicidae, Formicidae, Araneidae, Hydrachnidae and Naididae was noted to be uncommon at the reservoir. All other 27 families Cleridae, Coccinellidae, Noteridae, Corixidae, Cercopidae, Mesovallidae, Pleidae, Gerridae, Gelastocoridae, Ochteridae, Hebridae, Nepidae, Notonectidae from order Hemiptera, Chironomidae, Gryllotalpidae, Tridactylidae, Lestidae and two unidentified families of order Odonata, Hydropsychidae (Trichoptera), spider family including three unidentified families, Lycosidae, Salticidae and order Megadrilacea comprising families Megascolecidae were noted to be rare.

However, at JIR, family Naididae of order Megadrilacea was abundant at the reservoir. Family Hebridae was frequent while Carabidae, Chrysomelidae, Formicidae were uncommon. The other 28 families which were noted to be rare were Cleridae, Coccinellidae, Noteridae, Corixidae, Cercopidae, Mesovallidae, Pleidae, Gerridae, Gelastocoridae, Ochteridae, Nepidae, Notonectidae from order Hemiptera, Chironomidae, Gryllotalpidae, Tridactylidae, Lestidae and two unidentified families of order Odonata, an unidentified family of order Ephemeroptera, spider family including three unidentified families, Araneidae, Lycosidae, Salticidae, Tetragnathidae and order Megadrilacea comprising families Megascolecidae were noted to be rare.

Correlations with physico-chemical properties of water and soil (Table 2.8 and 2.9)

When correlation of benthic fauna was attempted with physico-chemical properties of water (Table 2.6) and soil (Table 2.7), negative correlations at 0.05 level were noted for salinity and sulphates in water while positive correlation at same level with soil acidity and percent coarse sand for WIR. For TIR positive correlation was noted at same level with nitrite in water and water temperature only whereas for JIR no correlation for water or soil parameters could be obtained at any level.

Table 2.1. Number of species in each of the eleven orders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Orders / Site	Total	Phylum: Annelida	Phylum: Arthropoda									
		Class: Oligochaeta; Sub-class: Haplotaxida	Class: Arachnida		Class: Insecta; Sub-class: Pterygota; Infra class: Neoptera							
		Megadrilacea	Ara	Tro	Col	Hem	Dip	Odo	Ort	Eph	Tri	Hym
WIR	49	5	4	2	13	11	2	2	2	1	0	7
TIR	55	5	4	2	21	8	2	2	2	0	1	8
JIR	33	2	4	2	9	5	1	1	1	1	0	7

Meg- Megadrilacea; Ara- Araneae; Tro- Trombidiformes; Col- Coleoptera; Hem- Hemiptera; Dip- Diptera; Odo- Odonata; Ort- Orthoptera; Eph- Ephemeroptera; Tri- Trichoptera; Hym- Hymenoptera

Table 2.2. Species Richness of benthic fauna at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Mean Species Richness	**WIR**	**TIR**	**JIR**
Annual (ns) $\mathbf{F_{(2,72)}}$ **1.49**	5.3 ± 0.68	5.74 ± 0.82	4.12 ± 0.52
Seasonal	**(***)** $\mathbf{F_{(3,19)}}$**14.26**	**(**)** $\mathbf{F_{(3,21)}}$**5.33**	**(ns)** $\mathbf{F_{(3,21)}}$**2.87**
Summer (ns) $\mathbf{F_{(2,19)}}$**0.29**	6.83 ±0.7	6.44± 0.69	5.14 ± 0.79
Monsoon (ns) $\mathbf{F_{(2,10)}}$**0.49**	1.67 ±0.67	2.33 ± 0.49	1.75 ± 0.48
Post-monsoon (ns) $\mathbf{F_{(2,14)}}$ **1.14**	3.0 ±0.27	3.75 ± 0.63	2.8 ± 0.49
Winter (ns) $\mathbf{F_{(2,18)}}$**2.52**	8.67 ± 1.31	10.0 ± 2.67	5.11 ± 1.06

Table 2.3. Annual and seasonal Density of benthic fauna at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Density	**WIR**	**TIR**	**JIR**
Annual (ns) $\mathbf{F_{(2,72)}}$**1.14**	1089.0 ± 286.9	888.7 ± 128.2	699.4 ± 82.53
Seasonal	**(*)** $\mathbf{F_{(3,19)}}$**3.96**	**(*)** $\mathbf{F_{(3,23)}}$**3.29**	**(ns)** $\mathbf{F_{(3,21)}}$**0.69**
Summer (*) $\mathbf{F_{(2,20)}}$**4.59**	2339.0 ± 834.0	768.1 ± 163.2	788.3 ± 115.7
Monsoon (ns) $\mathbf{F_{(2,11)}}$**0.53**	172.0 ± 58.38	510.3 ± 238.2	453.0 ± 104.7
Post-monsoon (**) $\mathbf{F_{(2,14)}}$**7.43**	382.5 ± 98.42	1640.0± 388.3	648.2 ± 291.7
Winter (ns) $\mathbf{F_{(2,18)}}$**0.91**	1240.0 ± 374.0	992.7 ± 216.2	777.3 ± 142.4

Table 2.4. Annual and seasonal Jaccard's Similarity Index (J) between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Jaccard's Similarity Index (J)	WIR+TIR	TIR+JIR	JIR+WIR
Annual	44 %	30 %	33 %
Seasonal Jaccard's Similarity Index			
Summer	22 %	13 %	21 %
Monsoon	14 %	7 %	13 %
Post-monsoon	12 %	25 %	12 %
Winter	26 %	27 %	27 %

Table 2.5. Annual percentage occurrence of the eleven orders of benthic fauna at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Order / Site	Meg	Tro	Ara	Col	Hem	Dip	Ort	Odo	Eph	Tri	Hym
WIR	8.65	13.46	7.69	39.42	12.5	4.81	1.92	1.92	0.96	-	8.65
TIR	5.04	6.48	6.48	51.07	13.66	5.03	2.88	2.16	-	0.72	6.47
JIR	9.52	5.95	8.33	27.38	26.19	10.71	1.19	1.19	1.19	-	8.33

Meg- Megadrilacea; Ara- Araneae; Tro- Trombidiformes; Col- Coleoptera; Hem- Hemiptera; Dip- Diptera; Odo- Odonata; Ort- Orthoptera; Eph- Ephemeroptera; Tri- Trichoptera; Hym- Hymenoptera

Table 2.6. Seasonal percentage occurrence of eleven orders of benthic fauna at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Order	Sites	Summer	Monsoon	Post-monsoon	Winter
Megadrilacea	WIR	5.56	0.00	18.18	6.98
	TIR	7.55	0.00	7.69	3.57
	JIR	12.50	14.29	7.14	3.33
Trombidiformes	WIR	8.33	20.00	9.09	18.61
	TIR	7.55	0.00	7.69	7.14
	JIR	6.25	0.00	14.29	3.33
Araneae	WIR	11.11	20.00	9.09	6.98
	TIR	3.77	11.76	7.69	7.14
	JIR	9.38	0.00	7.14	10.00
Coleoptera	WIR	47.22	0.00	27.27	41.86
	TIR	56.6	64.71	53.85	41.07
	JIR	28.13	28.57	21.43	30.00
Hemiptera	WIR	11.11	40.00	9.09	11.62
	TIR	9.43	0.00	0.00	25.00
	JIR	21.88	42.86	21.43	30.00
Diptera	WIR	2.77	20.00	4.54	4.65
	TIR	3.77	11.76	7.69	5.36
	JIR	6.25	14.29	14.29	13.33
Hymenoptera	WIR	8.33	0.00	13.63	6.97
	TIR	3.77	5.88	15.38	5.36
	JIR	9.38	0.00	7.14	10.00
Orthoptera	WIR	2.78	0.00	4.55	0.00
	TIR	5.66	5.88	0.00	0.00
	JIR	0.00	0.00	7.14	0.00
Odonata	WIR	0.00	0.00	4.54	2.33
	TIR	1.89	0.00	0.00	3.57
	JIR	3.13	0.00	0.00	0.00
Ephemeroptera	WIR	2.78	0.00	0.00	0.00
	TIR	0.00	0.00	0.00	0.00
	JIR	3.13	0.00	0.00	0.00
Trichoptera	WIR	0.00	0.00	0.00	0.00
	TIR	0.00	0.00	0.00	1.79
	JIR	0.00	0.00	0.00	0.00

Table 2.7. Occurrence of families of benthic fauna encountered at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Study area	Abundant	Common	Frequent	Uncommon	Rare
WIR	0	0	2	2	29
TIR	0	0	2	7	27
JIR	1	0	1	3	28

Table 2.8. Correlation of benthic fauna with various physico-chemical properties of water and wader density at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	WIR	TIR	JIR
Acidity	-0.147	0.263	-0.298
Chlorides	-0.220	0.094	-0.126
Dissolved oxygen	0.340	-0.083	-0.026
Free CO_2	0.249	-0.041	-0.050
Bicarbonate alkalinity	-0.115	-0.171	-0.198
Inorganic Phosphates	0.214	-0.084	0.206
Kjeldahl Nitrogen	-0.312	-0.094	0.254
Nitrate	0.166	-0.165	-0.057
Nitrite	-0.254	0.415*	0.129
Hydroxyl alkalinity	-0.208	0.040	-0.144
pH	0.177	0.014	-0.145
Salinity	-0.452*	0.094	-0.126
Sulphate	-0.470*	-0.041	-0.121
Water temperature	0.346	0.437*	0.148
Total phosphorus	-0.310	-0.266	0.224
Water cover	-0.380	-0.195	0.190
Waders	0.310	0.025	-0.208

Table 2.9. Correlation of benthic fauna with various physico-chemical properties of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	WIR	TIR	JIR
Calcium	0.088	-0.147	0.159
% Coarse sand	0.585*	-0.043	-0.295
% Fine sand	-0.321	-0.299	0.071
Magnesium	-0.193	-0.307	0.440
pH	0.158	-0.407	-0.111
%Silt+Clay	0.002	0.105	0.203
Total Nitrogen	0.237	0.197	0.057
Total organic carbon	0.233	-0.425	0.416
Total phosphorus	-0.007	-0.105	-0.243
%Very fine sand	-0.423	0.640*	0.216

Fig. 2.1. Species composition of different orders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

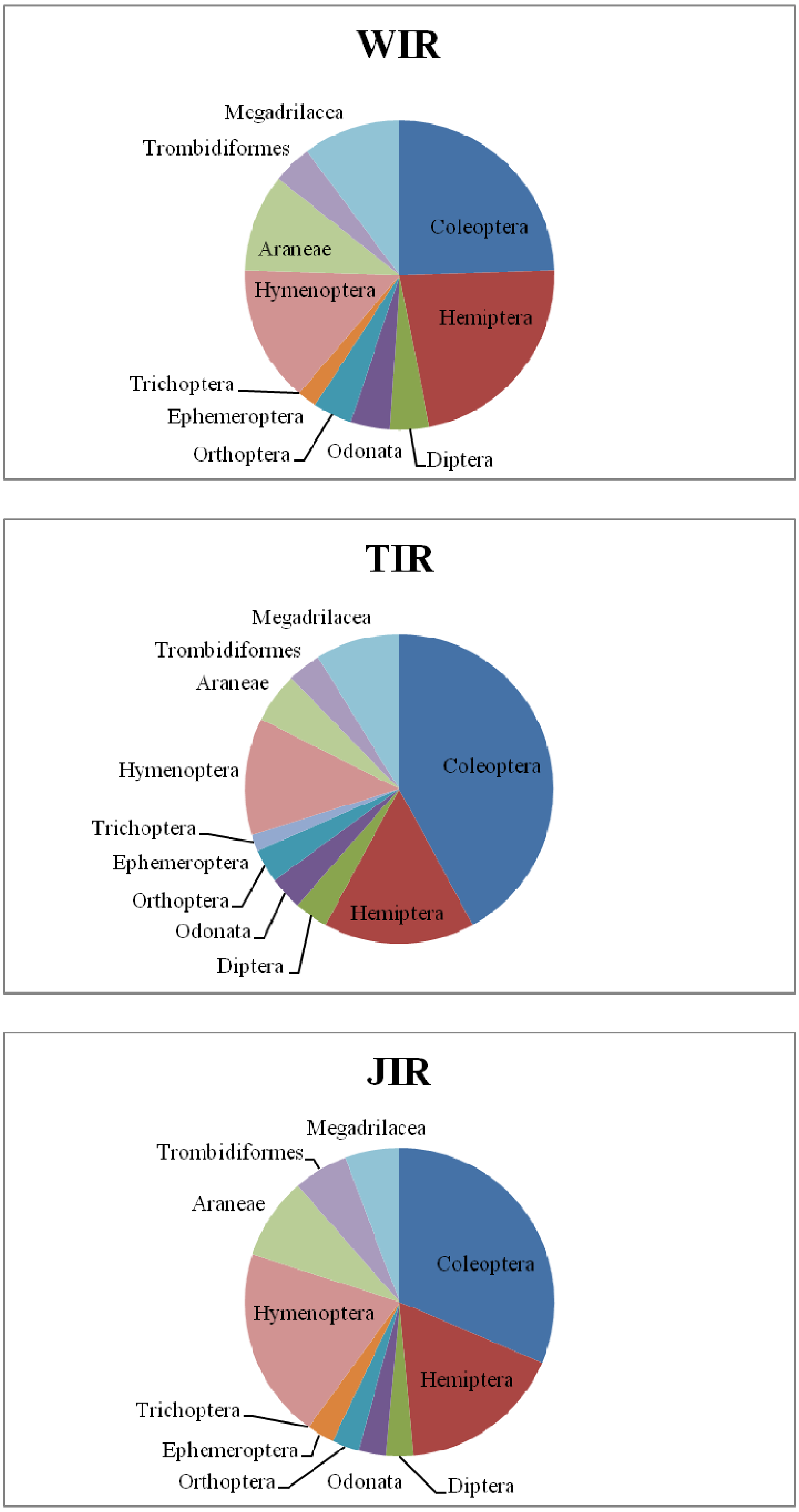


Fig. 2.2. Annual and seasonal mean species richness of benthic fauna at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

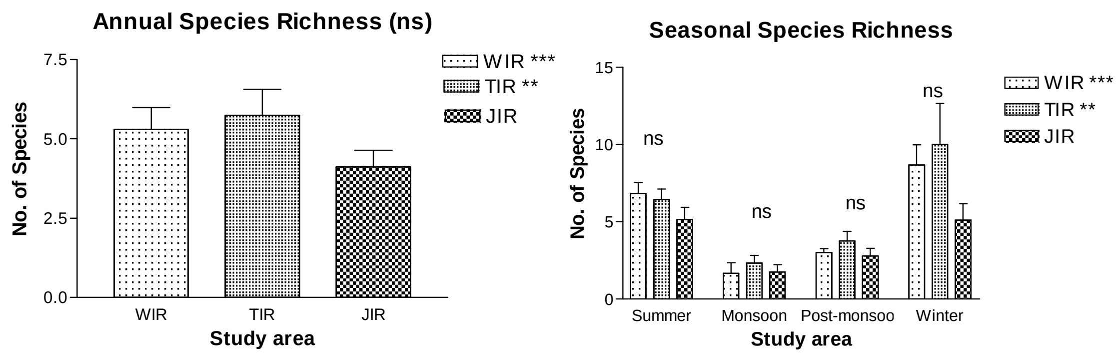


Fig. 2.3. Annual and Seasonal Density of different orders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

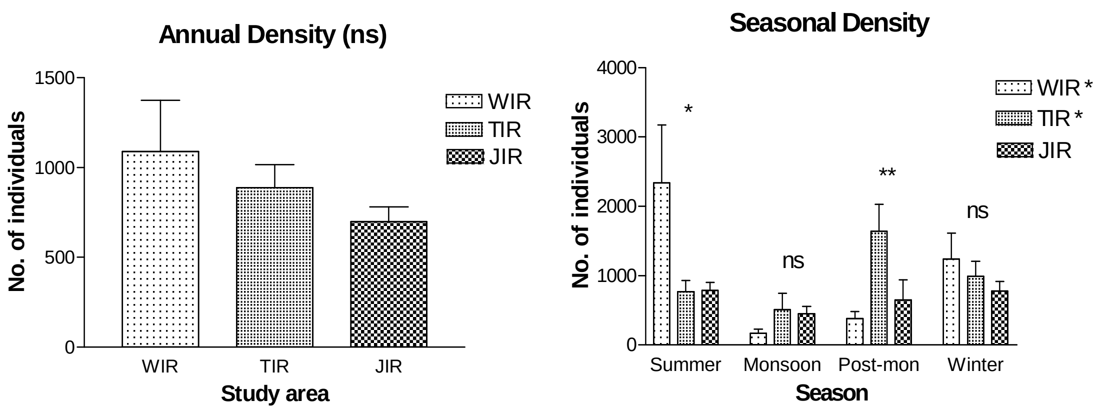


Fig. 2.4. Annual and seasonal Jaccard's similarity index between Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

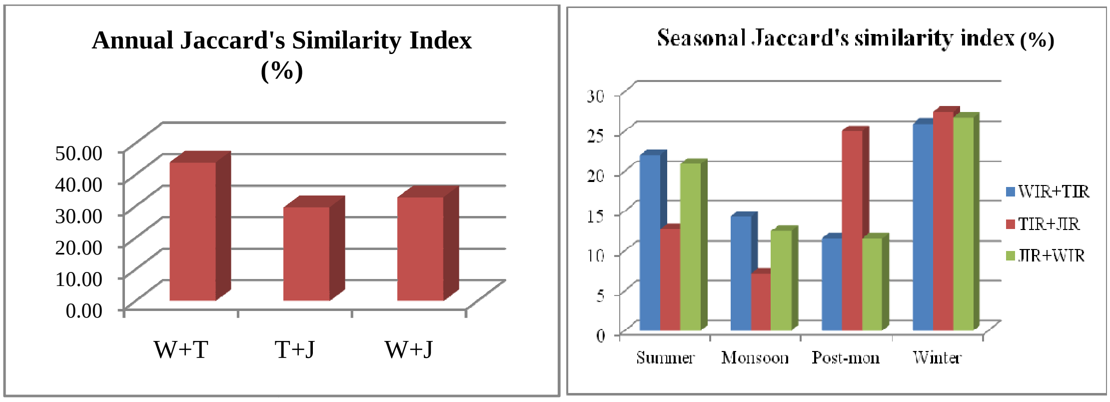


Fig. 2.5. Annual percentage occurrence of eleven orders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

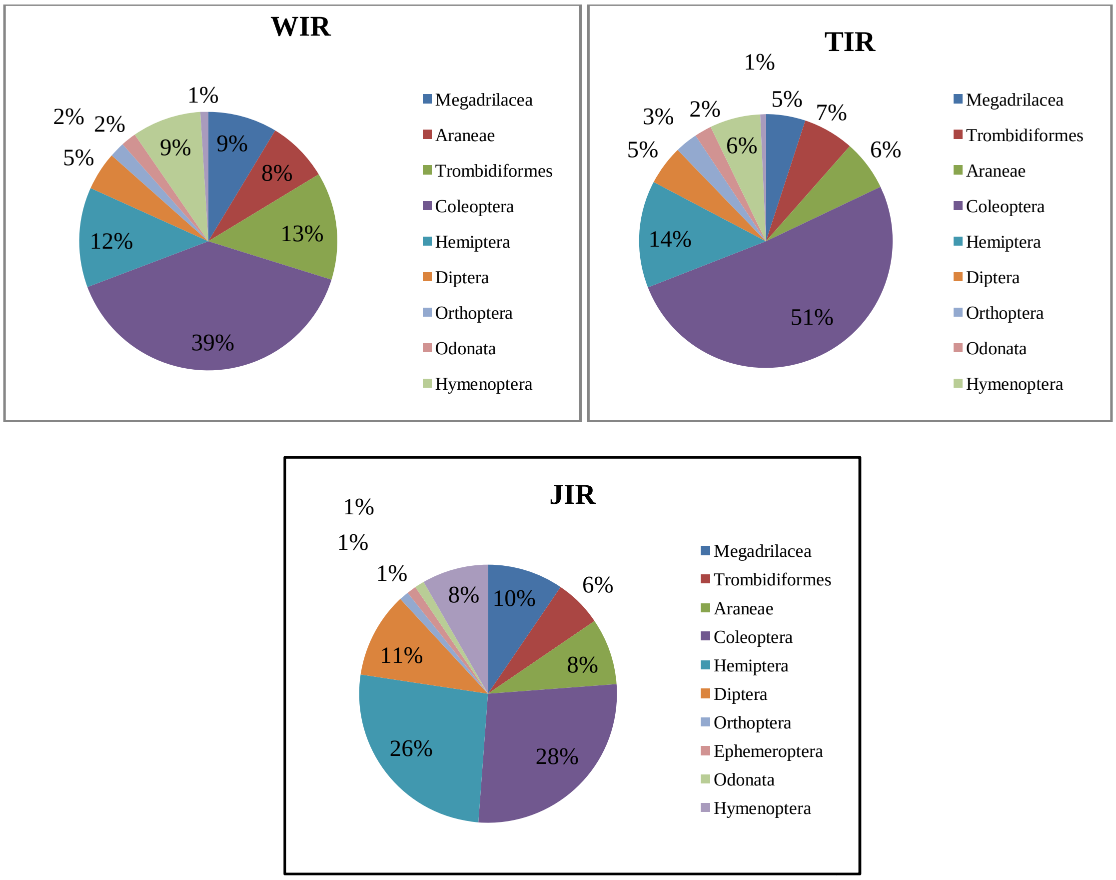
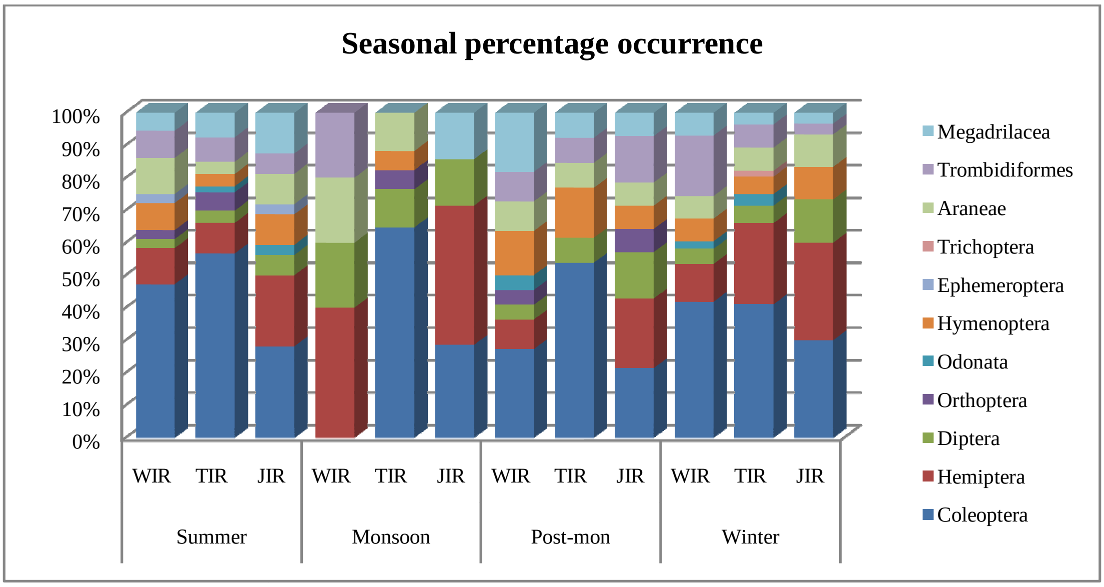


Fig. 2.6. Seasonal variation in the percentage occurrence of eleven orders at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



Discussion

Although many studies have been conducted on the marine and coastal invertebrates of Gujarat (Sarvanakumar *et al.*, 2007; Anbuchezhian *et al.*, 2009; Pandya and Vachchrajani, 2010) studies on freshwater benthic fauna are scarce (Sivaramakrishnan, 1996; Deshkar, 2008; Molur *et al.*, 2011) while the studies of benthic fauna as prey base for water birds in the region are nil. Hence, the community structure, characteristics of the macrofauna, seasonal changes in their density and diversity, and environmental parameters are dealt within the present study. Samples collected from the offshore water shows presence of 79 macrobenthic taxa belonging to 38 families of phylum Annelida and Arthropoda excluding mollusca. Studies being sparse many of these could not be identified upto species level. However, majority of these families were rare (Table 2.2), several uncommon, few frequent, none common and only one abundant. One family abundant at JIR explains the difference in the habitat at local level.

Significant seasonal changes found in species richness (Table 2.2) and density (Table 2.3) of many species of the macrozoobenthic fauna at the three irrigation reservoirs indicate their dependency on environmental factors. These changes are highly pronounced at the reservoirs under prominent Narmada inundation (WIR $P<0.0001$; & TIR $P<0.001$) compared to non inundated reservoir, JIR (ns; $P>.05$; Table 2.2, 2.3 Fig. 2.2, 2.3) indicating additional influence of Narmada water. This is also reflected as higher similarity in benthic fauna of WIR and TIR against only 33% similar species between WIR and JIR and 30% between TIR and JIR (Table 2.5). Similarity is maximum in winter when species richness is high.

Though the dominant taxa in the present study were coleopterans and hemipterans (Table 2.7), dipterans were also frequent (JIR) mainly because of the presence of larvae of *Culex sp*. In the terrestrial habitats around the three reservoirs studied, Gandhi, (2012) has reported presence of 13 species of coleopteran and 18 species of hemipterans, many of which have aquatic larval forms. The majority of the population density of coleopterans was due to representation of family carabidae at the three reservoirs. These insects are ground dwellers preferring moist soil. For example, *Apotomus sp.*, *Tachys sp.* and *Bembidion sp.* These were very common at WIR and TIR. Though, the carabids are strictly terrestrial and their legs are used for running, in a few genera, the front pair, are modified for digging. Most of these long-lived adult carabids feed either on vegetable matter or are predacious and do not show strong seasonal fluctuation (Lindroth, 1974). Hence, coleopterans occurred at the three reservoirs in all the seasons except at WIR in monsoon. WIR being the largest of the three, coleopterans probably got more distributed due to incoming rain water. Gandhi, (2012) has recorded total 13 species of coleoptera on the terrestrial habitats around the three reservoirs with six, eleven and five species at WIR, TIR and JIR respectively.

Among the coleopterans, staphylinid beetles were frequent enough to further influence the overall population size of coleopterans at WIR and TIR although they were less common at JIR. Also known as Rove beetles this group is currently recognised as the largest family of beetles with thousands of species found in the world (Campbell and Davies, 1991). They live in soil, ground litter, decomposing organic matter preferring moist habitats. Many of them known to feed on small insects are considered important for biological control. *Paederus sp.* was most abundant species found all over the year while *Bledius sp.* was noted only at WIR.

At JIR, chrysomelid beetles surpassed carabids in richness in the present study. The presence of these leaf beetles at the reservoir may be due to the highly vegetated surroundings of the earthen dam which may have led to their inclusion in the samples. They are basically terrestrial phytophagous agricultural pests of various crops (Hunt *et al.*, 1996). The three sites studied, being irrigation reservoirs, are surrounded by agricultural matrix and hence the occurrence of these beetles is noted.

The hydrophilids or the water scavenger beetles were more common at TIR in comparison to WIR and JIR. Around 400 species of 60 genera are reported from oriental realm (Hansen, 1999). Their adult and larval stages are either phytophagous, saprophagous and / or predacious (Hendrich *et al.*, 2004). They were found over the whole year except during summer when water was very less in the reservoirs due to dry conditions. Many of them are aquatic or semi-aquatic but some live among decaying leaves, dung and in soil feeding on fungi, decomposing vegetable matter and dead animal tissues (Jaiswal, 2010).

Dytiscidae is a group of aquatic beetles. Also known as predacious diving beetles, these beetles have been recently excluded from the family hydrophilidae. These beetles travel to water surface to take up atmospheric air. The dytiscids represented at TIR by *Hydaticus sp*. and *Laccophilus sp*. and one unidentified species each from JIR and TIR, but not noted from WIR. The incoming Orsang / Narmada Canal and five distributing irrigation canals of WIR probably produced a strong flow in water not preferred by this group of insects. Hence, this group was not recorded at WIR.

Family Noteridae is another family of order coleoptera found in the present study and comprising of true water beetles. It is a small family mainly found in the warmer parts of the world. Only about 23 species of this family have been reported from Southeast Asia (Vazirani, 1977). Noterids usually inhabit the margins of more-permanent, plant-rich and shallow ponds, swamps and ditches the habitats available at the three reservoirs. Not much is known about their feeding habits but both adults and larvae are known to be carnivorous (Hendrich *et al.*, 2004). Although the noterids represented by genus *Canthydrus* was found at three reservoirs, it was not very common during present study.

Family curculionidae comprising of snout beetles was noted only at TIR and JIR represented by *Lissorhptrus sp.* which might have accidentally entered the samples as members of this family are all terrestrial and plant feeders. Gandhi, (2012) has recorded five species of this family in the area. Another family which was rare in study area and occurred only at WIR samples is family coccinellidae represented by *Stethorus sp*. The representatives of family limnichidae comprising of small semi-aquatic beetles frequently living in riparian habitats were found only at TIR. Adults are reported to occur near the waterline over stream banks or in riffles and on rocks in streams; some are even reported to be marine (Spangler *et al.,* 2001). The occurrence of *Stethorus sp.* of family coccinellidae at WIR, *Byrrhinus sp.* of family limnichidae at TIR was rare. The first is a terrestrial species whereas *Byrrhinus sp.* is an aquatic species adapted for marshy habitats. One species of family limnichidae remained unidentified.

Order Hemiptera comprising of true bugs include both aquatic and semi-aquatic taxa mainly relying on dissolved oxygen in water. Hence, exist in water bodies with low levels of DO. Most family of this order, mainly found at JIR is Hebridae with *Hebrus sp.* seen frequently. Also known as the velvet bugs, they are ideal indicators of wetlands, as they are only found in or on the surface of water or in damp areas (Epler, 2006). They were found at other two reservoirs too but rarely.

Nymph of *Bofylus sp.* of family Cercopidae of this order also known as the family of ‘Frog-hoppers’ was found only once at WIR during the whole study period. Gandhi, (2012) has reported 188 species of nine orders around terrestrial habitats of WIR, TIR and JIR and could not find any cercopids in her study of terrestrial insects.

Mesovelia sp. of Mesovellidae, the water traders skating across water with high agility were observed at WIR but only once during the study period. They prey on invertebrates along the shore or near water surface generally associated with floating mats of detritus and vegetation or at the margins of ponds, marshes and streams (Bouchard, 2004). Family Pleidae of this order was represented by three different species at the three study sites indicating their habitat specific nature. Genus *Paraplea sp.* was observed at WIR and a nymph at TIR. Pleids are found in shallow standing and slow moving waters generally in association with emergent vegetation, a typical habitat in the shallow regions of the reservoirs studied. They feed on small invertebrates such as mosquito larvae.

Gerris sp. (Water striders) of family Gerridae, seen on the water surfaces at all the three study areas may have also mistakenly entered in sample during collection. They are generally found on the surface of water in ponds, lakes, marshes, *etc*. and observed skating on the water surface using their mid and hind legs. Family Gelastocoridae represented by *Nerthra sp.* are very secretive and hence found only once each at WIR and TIR. Also known as Toad bugs, most gelastocorids are shore line insects. *Nerthra* sp. can also be found in water under floating wood and under stones, in addition to terrestrial debris and rotting plants and it rarely moves unless disturbed and hence often plated with dirt and detritus covering their body (Epler, 2006) which was also noted while collecting samples.

Ochterus sp. of family Ochteridae, the inhabitant of shore lines, was rare and noted only at WIR. This group of "velvet shore bugs" is known to occur in the open as well as among grasses and predate on gelastocorids (Bobb, 1951). These prey species were also uncommonly observed at WIR and TIR. Because of their cryptic nature, ochterids are poorly encountered in biological surveys (Chandra and Jehamalar, 2012).

Super family corixoidea, the group of truly aquatic bugs are found in stagnant waters or parts of streams with very little current and hence found at the shallow regions of WIR and TIR where very little movements in the water occur. Representatives of this super family belonging to family corixidae though rare, when occurred they were plenty at both the above mentioned reservoirs. They are predominantly tropical (Nieser, 2004). Most corixids feed by disturbed soft sediments and detritus with their scoop-like forelegs and consume organisms stirred up from the sediment (Bouchard, 2004).

Occurrence of notonectid bugs, though unidentified, rarely found at WIR and TIR and not at JIR may be associated with presence of Grey Herons which commonly preferred notonectid bugs as part of their natural diet (Exnerova and Bohac, 1991). Grey Herons though in small numbers are regularly observed at the said reservoir (Chapter I). They are strong predators, easily identified by their typical hind legs that are long and heavily fringed, rowed like oars, notonectid bugs occur in all habitats of still and slow flowing water bodies many preferring moderate to rich macrophyte growth (Bouchard, 2004). The vegetation in the shallow areas of WIR and TIR probably supported this family. The family aphidiidae which comes under this order was an accidentally sampled family at TIR. Family nepidae is an aquatic species but its occurrence was rare during the study. The rare occurrence of representatives of families aphididae and lygaeidae in the samples from any of the three reservoirs can be accidental as these are the families of terrestrial insects. These three families are recorded in the terrestrial habitats around the three reservoirs by Gandhi, (2012). Of the two families of order diptera, family culicidae represented by larva of *Culex sp*. though rated as rare and uncommon, occurred with high density. Whenever present, especially during monsoon. Whereas, rare occurrence of second family chironomidae, preferring polluted water gives indication of health of the aquatic bodies studied with a caution that care needs to be taken to avoid any kind of pollution in which chironomids can flourish. *Chironomus sp.* is an ecologically important genus of aquatic insects often occurring in high densities and diversity in polluted water

(Al-Shami *et al.*, 2010). Perez-Hurtado *et al.*, (1997) have described in their work the presence of chironomids as an important diet of shorebirds although the chironomids were not very common during the study period.

Two families of orthoptera found during the study period, family gryllotalpidae and tridactylidae were also rare. The former family include mole crickets; cylindrical bodied insects with shovel-like forewings for burrowing. These are omnivores, feeding on larvae, worms, roots, and grasses. They are relatively common, but because they are nocturnal and spend nearly all their lives underground in extensive tunnel systems, they were probably rarely seen. They were found at all the three reservoirs hidden beneath the soil. Family tridactylidae noted only at WIR and TIR include species which are mostly less than 10mm in length. Their worldwide distribution is patchy and hence probably rare. Their typical habitat is moist, sandy soil near water, such as dams, lakes, streams, and sometimes the sea. In such places they dig small tunnels, in which they live (Folkerts, 1989).

Among odonates, though 27 species of dragonflies and 18 species of damselflies have been recorded from the three reservoirs (Gandhi, 2012), larvae of only 4 species could be recorded from benthos because of their aquatic or semi-aquatic nature (Odonates lay their eggs in water or on vegetation near water or wet places). Nymphs of sub-family Lestinae of damselflies were observed at WIR. Damselfly nymphs breathe through external gills on the abdomen, while dragonfly nymphs respire through an organ in their rectum (Hoell *et al.,* 1998). The moults of dragon flies were very commonly found on short grasses at all the three study areas. Identification of nymphs is difficult upto the lower classification level hence one species each found at the three reservoirs went unidentified.

One of the major families of order hymenoptera is formicidae which includes ants. These social insects preferring moving on ground are well represented with 19 species at the three reservoirs (Gandhi, 2012), of these six species of Genus *Camponotus* and three more species were found moving on the moist soils of the three reservoirs. Most ants are generalist predators, scavengers, and indirect herbivores (Wilson and Holldobler, 2005).

Order ephemeroptera commonly known as mayfly have nymphs that are benthic macroinvertebrates. They are found in lakes, wetlands, streams and rivers and are common in lotic habitats (Bouchard, 2004). One larval species was also sighted during present study. This order noted only at WIR and JIR may be linked to Redshanks as its diet consists of mayflies, dragonflies, larva of heteropterans (corixidae, notonectidae, *etc.*), ants, flies and larvae of trichopterans alongwith molluscs and worms (Nethersole-Thompson and Nethersole-Thompson, 2010). Both these groups are rare in the area.

However, order trichoptera of caddis flies with aquatic larvae were also poorly represented and noted only at TIR with an unidentified species of family hydropsychidae. The hydropsychid larvae, like most trichoptera larvae, are entirely freshwater. These small moth-like insects having two pairs of hairy membranous wings are found in water bodies of varying qualities. The species-rich caddisfly assemblages are generally thought to indicate clean water (Nessimian and Dumas, 2010). Together with stoneflies and mayflies, caddisflies feature importantly in bio-assessment surveys of streams and other water bodies. However, at the three reservoirs their occurrence was rare. Trichopterans being aquatic in habit were not recorded by Gandhi, (2012).

Spiders of class Arachanida known to occupy microhabitats on or near ground were occasionally collected with the benthos samples. Eight species collected were found at one, two or all three habitats of the study. These air-breathing arthropods with eight legs, chelicerae and venomous fangs rank seventh in total species diversity among all group of organisms (Sebastin and Peter, 2009). These ancient animals are known to occur in greater abundance and are widely distributed in almost all ecosystems having very significant role in ecology by being exclusively predatory they help maintain ecological equilibrium (Meshram, 2011). Siliwal *et al.,* (2005) has described 1442 species, out of which 1002 are endemic to the Indian mainland. Family Salticidae of jumping spiders, predominantly known to capture prey located on the ground (Bardwell and Averill, 1997), was noted only in the microhabitats at WIR. A number of species of jumping spiders (Salticidae) are also behaviorally adapted to feeding on ants on ground (Nyffeler *et al.,* 1994) and hence occurred in the samples. Various web-weaving spiders, despite having the ability to capture pest insects such as weevils, and leaf beetles, usually capture aphids and small flies. Hence, representation of family araneidae was rare during the study period. This family includes orb-web building spiders for prey capture. Tetragnathid spiders are a fairly large family. They live in grassy places and are particularly common on borders of swamps and corresponding habitats. This family was noted only at JIR where the earthen dam is covered with vegetation and hence found near the edges of the water body. Like araenids, these spiders also build orb webs for capturing prey.

Water mites of family hydrachnidae (Order: Trombidiformes) are close relatives of spiders recorded at all three reservoirs. They are a diverse group that is not well studied. Water mites live all over the globe, except Antarctica. At present, more than 5000 Hydrachnidia species are known in the world, representing more than 300 genera, 50 families and 8 super families (Viets, 1955). Adults are predators and eat the eggs of insects, their larvae, small crustaceans and fish. They were uncommon in samples collected but when found, were observed swimming vigorously at all the three study areas. All species of the group in the larval stage are ectoparasites and thus, the hydrachnidae exert a significant role in the aquatic food chains from the zoobenthic communities (Smith and Cook, 1991).

Representatives of Phylum Annelids are also present at the three reservoirs with 3 families. They are key components of the benthic communities of many freshwater ecosystems. As the digestive tract of most aquatic worms is much simpler than those of terrestrial, they get food by ingesting the soft substrate *i.e.* detritus (Smith and Kaster, 1986). Family Naididae, formerly known as Tubificidae was represented by *Tubifex tubifex* the most common species found at all the three irrigation reservoirs. *Dero sp.* was observed only once at WIR during the whole study period as they are found only at certain depths in the soil while *Stylaria sp.* was uncommonly noted at JIR in the soil collected from the reservoir. Megascolecids are larger than Naidids and commonly found near water bodies. Only one species was found at all the three reservoirs *i.e. Perionyx sp.* and was not very common while two remained unidentified.

Mean Species richness

A stable environment involves a higher degree of organization, more species and more niches as well as complexity of the food web (Margalef, 1958) while environmental changes influence species richness (Legendre and Legendre, 1998). The species richness around the three reservoirs clearly indicated that the number of species present here greatly depend on their microclimate. It is apparent that at WIR the size whereas at TIR vicinity to urban conditions may have provided varied microhabitats supporting higher species richness. In addition fluctuating water levels due to Narmada Inundation probably keep on changing microhabitats resulting in availability of varied habitats over the seasons supporting diverse groups of organisms and hence increasing species richness. Another factor influencing the species richness which cannot be ruled out is anthropogenic pressures. WIR is mainly undisturbed large habitat hence the number of species present therein may be positively influenced whereas TIR facing moderate human disturbances and urban expansion support urban adaptors too influencing species richness. At JIR, the reservoir with moderate size and low human impact such conditions do not prevail and hence supports moderate species richness (Table 2.1).

High species diversity indicates that such community has their resources more finely distributed among individuals of many species (Smith, 1977). In tropics, on an average the activity patterns of the insects are longer and many species are active all round the year and hence major seasonal peaks are absent (Silva *et al*., 2011). However in present study of sub tropics seasonal comparison revealed highest richness during winters at all the three irrigation reservoirs. This could be due to species observed in moderate warming up weather of February. Carabids, Staphylinids and Hydrophilids occurred at WIR and TIR while a higher number of Staphylinids and Hebrids were present at JIR. Although there was decline in mean species richness at WIR and TIR not much difference was noted during summer at JIR. JIR, though not inundated with Narmada water seepage from nearby canal and minimal alteration in the type of macrophytic vegetation lead to good species richness during summer. However, it was low compared to winter as the dry season is likely to force many species to undergo hibernation or diapause. Surface water level fluctuation adversely affects littoral invertebrate diversity and community assemblage (Shah *et al.,* 2011). Sporka *et al.,* (2006) found significantly higher autumn index scores due to the summer emergence of some taxa in mountains of Central Europe. For example caddisflies are known to have adaptations that allow them to survive during the dry season (Anderson and Dietrich, 1992).

A great deal of overlap occurs in the fauna of perennial and temporary habitats (Banks, 2005). WIR and TIR though not temporary were almost completely dry during the first year of the study but recovered as soon as precipitation started. The reservoirs selected in the present study are located in subtropics where distinct wet season is observed only in July and August *i.e.* monsoon when species richness was observed to be lowest at all the reservoirs. Benthic macroinvertebrates are sensitive to changes in temperature, precipitation, and the associated flow regimes (Bunn and Arthington, 2002). The species richness might also be low because of the increase in the water level during monsoon and hence their migration to suitable places in the region and absence from the samples. As precipitation stopped and water levels stabilized, the richness started developing in post-monsoon which could be due to successful breeding in wet surface area and habitat types. Shah *et al.*, (2011) also recorded slightly higher number of taxa for post-monsoon than pre-monsoon (summer) in a reservoir in Nepal. This recovery can be attributed to higher abundance in food and changes in the microhabitats at the reservoirs. In addition, it could also be due to the life cycle length, etc.

Mean Density

The reservoir where aquatic macroinvertebrates were found to be high in density was undisturbed and rich in aquatic vegetation *i.e.* WIR. The valued ecological attributes, such as water storage capacity, biogeochemical cycling, biotic productivity, and biodiversity, are integral to the structure and function of a wetland ecosystem and its ecological integrity (Stevenson and Hauer, 2002). Further, the seasonal variations in the abundance of tropical insects are a common phenomenon (Pinheiro *et al*., 2002). Further, the highest annual density noted at WIR may also be attributed to the size of the study area. Larger area supports more species (Oertli *et al.*, 2002) may stand true for the reservoir. Overall decline in benthic fauna from post-monsoon to winter and there after increase till February, stresses on influence of climatic conditions on the benthic invertebrates. Similar observations are also made by Jana *et al.* (2009), in a pond in Midnapore town of West Bengal and by Cui, *et al.* (2008) at a freshwater lake in China. Further, the maximum number of individuals belonging to class Insecta in March and minimum in December at WIR can be due to their annual life cycle too, with retardation of development process due to low winter temperature. As they keep themselves hidden within rotten weeds and mud they are often difficult to collect. During winter increased predation and competition for space with food scarcity may also be one of the reasons for lower density.

However, at TIR, the case was a different where higher density of invertebrates was observed in post-monsoon and winter in comparison to summer. TIR being in close vicinity of one of the major cities of Gujarat, *i.e.* Vadodara, the temperatures are comparatively warmer here (Deshkar, 2008) probably making it more difficult to survive in summer. Beche *et al*. (2006) found that the abundance and composition of macroinvertebrates are sensitive to rainfall. Different groups, however, increase in number in different months which indicates some sort of temporal niche separation *e.g.* very high densities of Carabids during post-monsoon. Khan and Ghosh, (2001) in West Bengal also found Coleoptera to be the most common order quantitatively. The densities at JIR during summer and winter were similar. Profuse aquatic vegetation in this pond provides spatial heterogeneity which helps in harbouring different species without severe competition in the form of ecological guild and hence not much change seasonally was observed in the densities at this reservoir.

Jaccard's Similarity index

The higher annual Jaccard's similarity index between WIR and TIR could be not only due to the shorter distance between the two where species can be easily transferred by higher taxa like birds but also due to prolonged and fluctuating hydro-spread and hydro-period. At the third reservoir JIR, almost 50-60 km away comparatively different microclimatic conditions prevail. The differences in hydrology, vegetation and isolation are the mechanisms responsible for variation in macroinvertebrate distributions. Further, the water chemistry also plays a role in limiting distributions of benthic fauna.

Though WIR shared its species almost equally in percentage with TIR and JIR the later two reservoirs showed fluctuations with low similarity in monsoon and high during post-monsoon indicating fluctuations at the microhabitat level as the seasons change. While WIR and TIR shared good species richness, it was not that apparent with JIR during all the seasons except during monsoon. At JIR, the presence of very dense macrophytic vegetation may have lead to an increase in the benthic fauna which prefer roots of vegetation as a substrate. This dominance of vegetation preferring species may have led to a decrease in species preferring moist soil for their survival. JIR was dominated by Hemipterans which prefer vegetation a clear difference in the available habitats leading to differences in species present. During post-monsoon as the temperature is favourable and the food is plenty for the benthic fauna, their breeding success is probably increased. During summer though, the conditions become hostile as temperature increases and water levels decreases, the macrophytic vegetation starts drying up and hence the benthic fauna become restricted to the microclimatic conditions of the reservoirs decreasing similarity indices which is also noted by Gandhi, (2012) in her study on terrestrial insects in the same region.

Percentage occurrence of orders

Percentage occurrence is a biological method that can be used for measuring species encountered in a particular area or during particular season. Here occurrence is used to understand the presence, absence and for understanding wetland use by benthos in the study area.

The most dominant group encountered during the whole study period was coleoptera at all the three reservoirs. Many ground dwelling coleopterans prefer moist/wet soils. Gandhi, (2012) has also reported large numbers of coleopterans around the three reservoirs but in terrestrial habitats. Carabid species of this order are long-lived in the adult stage and therefore do not show the strong seasonal fluctuation as shown by many other insects (Lindroth, 1974). The next order, hemiptera, could also find better habitats at the three reservoirs where vegetation occurs till the top of the earthen dam. Among the three reservoirs, maximum hemipterans occurred at JIR which is having more emergent vegetation. Aquatic and semi-aquatic hemipterans prefer burrowing as well as swimming in water. This resulted as the samples were taken from the soil at the edges of the reservoirs and hence hemipterans were encountered frequently in the samples. Gandhi, (2012) has reported 19 species of hemiptera at the three reservoirs. However, at WIR, order trombidiforms (aquatic mites) dominated over hemipterans. These mites probably occurred in the open waters at WIR which supported this group of arthropods. At JIR, where extensive emergent vegetation was noted, the percentage occurrence of this group was very low.

Earthworms, the annelids of order megadrilacea occurred at all the three reservoirs as these burrowing forms need moisture, as they could get good habitats at the reservoirs studied. However, at the reservoirs with low vegetation and more water (WIR and TIR) they could not be found during monsoon, when their presence at JIR was maximum. Probably at the end of monsoon and beginning of post-monsoon which is likely to be their breeding season they flourished at WIR with 18% occurrence. Gandhi, (2012) has reported 19 species of ants of family formicidae, Order Hymenoptera at the three reservoirs with their density and species richness fluctuating with the seasons and vegetation composition. However, on the moist and wet soil of the three reservoirs nine species were encountered with moderate percentage occurrence. Formicids did not occur in monsoon at WIR and JIR when the density is also known to be low. Their occurrence in the other seasons was fluctuating, with maximum at WIR during moderate climate of winter. Araneae (Spiders) though not actually are considered to be benthic, was also present on the soils of all the three reservoirs. These spiders were ground dwelling as said earlier; hence their occurrence with the sediments may not be surprising. Araneae (air-breathing) were probably drawn towards the sediments at WIR and TIR increasing their percent encounter whereas the vegetation of JIR supported the group by providing them shelter hence very low occurrence of spiders were encountered.

The larvae of *Culex sp.* and *Chironomous sp.* of order Diptera also occurred at all the three reservoirs with moderate percentage. *Culex sp.* contributed maximally to percentage occurrence during monsoon at all the three reservoirs whereas all throughout the year at JIR. The other species known to be associated with polluted water occurred with very low frequency indicating that the three reservoirs studied are not at all polluted. Other groups of benthos (Orthoptera, Odonata, Ephemeroptera and Trichoptera) occurred at low to very low percentage occurrence and were not recorded all throughout the year, indicating their preference of aquatic habitats. Ephemeropterans are known to be active in summers (Anderson and Dietrich, 1992) and hence found in this season at WIR and JIR.

Correlation benthic fauna with Physico-chemical properties of water

Most of adult benthic insects and their larval forms are reported to be tolerant to wide range of physico-chemical parameters (Sharma and Belsare, 1997). Of these the most important factors affecting the benthos distribution are Water temperature, Dissolved oxygen, Nitrate, Phosphate, Alkalinity, Calcium, Magnesium, Chloride, Depth, % organic matter and composition of soil (Habeeba *et al.*, 2012).

Benthic macroinvertebrate communities have the capability of adapting to various habitats due to their extra ordinary structural organization especially those belonging to orders Hemipterans, Coleopterans and Odonates (Merrit and Cummins, 1984). Though acidity has been shown to influence the population of benthos (Earle and Callaghan, 1998) its significant influence has not been found at any of the three reservoirs studied.

The density of benthos is inversely proportional with acidity and water level. However, in present study no single factor affecting the density was determined. Hence further investigations are needed.

The organisms adapt to certain range of water temperature and dissolved oxygen due to their osmoregulatory and respiratory requirements (Perkins, 1974). In the present study, warmer water temperatures seemed to affect the diversity of benthic fauna. Although water temperature was positively correlated at all the three reservoirs it was significant only at TIR the reservoirs in closer vicinity of urban area indicating moderate water temperature favoring density of benthic fauna. Similarly the higher DO levels, fluctuating with water input had no significant influence on benthic fauna. Though oxygen levels are also known to reduce through over-fertilization of aquatic plants due to run-off, containing phosphates and nitrates (the ingredients in fertilizers), from agriculture fields (Sharpley *et al.*, 2001) and affect the distribution of benthic fauna in a water body, such situation is not arising at the water bodies studied. Very few organisms are expected to survive in sediments rich in CO_2 and poor in O_2. Under the fluctuating water levels and diffusion with atmosphere such situations also do not arise at the reservoirs studied.

In fresh waters salinity, calculated according to the levels of chlorides in water, remains quite low and can increase due to the contribution of agricultural runoff, sewage and industrial effluents. Absence of these contributors may have led to its insignificant correlation with benthic fauna. It is known that the total biomass of the submerged communities decreases exponentially and also the species richness decreases linearly with increasing salinity (Grillas *et al*., 1993). Salinity is not a major issue of inland freshwater bodies of present study. Though Deshkar, (2008) reported highly significant seasonal variations in the salinity and chlorides subsequent to initiation of Narmada inundation, as the changed system started establishing with inundations, the seasonal variations were significant at on 0.05 level (Chapter IV).

Macroinvertebrates are also affected by nutrients such as nitrates and phosphates (Balachandran *et al.,* 2012). Genera within the orders of Hemiptera and Coleoptera have been found to be most abundant at sites with the greatest NH_4, (a product of breakdown of nitrate) and total phosphorus (TP) (Maul *et al.*, 2004). In present study also these insect orders were most dominant and contributed maximum to benthos of the three reservoirs. However, density of benthos had variable correlation with significantly positive relation of nitrites only at TIR. Due to very unstable nature of nitrite it shows no definite pattern of its seasonal cycle (Patra *et al.*, 2010). Also it is an intermediate compound of nitrogen reduction. Further, in summer, breakup of nitrates into nitrites and ammonia by denitrifying bacteria is high (Munawar, 1970) while in winter the activities of these bacteria go down resulting in higher nitrate value (Kaur *et al*., 1996). Though, an opposite trend was noted in the study, the results seem to favour the proliferation of benthic invertebrates at all the three study areas. The relationship of nitrite was positive with significance at 0.05 level only at TIR indicating probable difference in the microclimatic conditions. A significant negative correlation of sulphates and benthos density was noted at WIR while non-significant at other two reservoirs. Sulphate in water body increases because of increase in hardness due to rain run-off and also affects benthic organisms negatively in ponds (ENSC502, 2009). Its negative correlation (but non-significant) with benthos supports the above report.

Water level fluctuations create a distinctive habitat which differs from the natural marsh in duration of flooding, diversity of vegetation, and sediment chemistry and hence affect the invertebrate fauna (Wenner and Beatty, 1988). Though, the fauna correlated insignificantly with water cover, negatively at WIR and TIR while positively at JIR, it indicates the influence of Narmada inundation at the former two where it is pronounced.

Correlation with Physico-chemical properties of soil

Sediment hardness, oxygen penetration, and particle size particularly affect benthic epifaunal (living on the sediment surface) and infaunal (living in the sediments) invertebrates. Particle size in turn determines how water and oxygen penetrate sediments and the interstitial space available (Little, 2000). Thus, sediment and hydrologic characteristics of wetlands affect invertebrate communities. Further, sediment organic content and water transparency affect the production of bacteria and algae upon which many invertebrates feed (Robinson *et al.*, 2000) while amount of undecomposed vegetation in sediments affects the structural complexity of invertebrate habitats (Minshall, 1984). These different aspects have varying impact in determining the structure and complexity of macrobenthic communities of any lake, reservoir or stream as they are generally categorized as substrate-dependent communities (Finn *et al.*, 2008). Similarly, granulometry or particle size composition also plays a highly important role in structuring the aquatic macro-invertebrate community (Gayraud and Philippe; 2001).

Although not much seasonal variations were observed in the percentage of sediments during the present study, it has been found that increase in silt adversely impact macrobenthic community especially during monsoon. This occurs primarily because its deposition in the rock crevices, between pebbles and soil interstices inducing physical clogging of sediments (Brunke, 1999) and leading to decrease in oxygen concentrations and reduction of microhabitats (Sarriquet *et al*., 2007). Subsequently, the addition of coarse sediments in the bottom of water bodies increases surface water-interstitial water interaction, and thus have a positive effect on aquatic invertebrates (Gayraud and Philippe, 2003). Scrub vegetation in the catchment area of JIR probably prevents soil erosion during rains restricting sand, silt and clay deposition to the reservoir. However, in monsoon, rain also washes away and exposes the sand at all the three reservoirs increasing significantly the percentage of coarse sand in the sediments (Chapter IV). The percent coarse sand significantly and positively correlated with benthic fauna only at WIR whereas very fine sand only at TIR at 0.05 level. WIR being large reservoir receives more water both during monsoon as well as Narmada inundation directly via canal exposing coarse sand, while at TIR the water is released on the land bringing in fine sand with it.

When more silt- and clay-sized particles are present in substratum the total phosphorus concentrations are reported to be greatest (Mau, 2001). These nutrients produce limiting effects on the productivity in the ecosystem and the consequently the faunal (prey) distribution and abundance (Nagarajan and Thiyagesan, 1996), Further, the highest values of TP, finer particles and decreasing organic matter both have been shown to produce species richness and diversity (Specchiulli *et al.,* 2010). However, the present freshwater reservoirs receiving Narmada water showed though non-significant opposite results while the reservoirs without Narmada inundation showed positive non-significant correlations only with fine sand and organic matter. At all the three reservoirs the density of benthic fauna is moderate as phosphate enrichment is not observed. The benthic fauna in the area depends on local environmental characters supporting varied species reflected as overall lower similarity indices (Table 2.4).

In addition to Phosphorous, nitrogen also increases primary productivity which regulates benthic biomass (Herman *et al.,* 1999). In present study also a positive correlation of benthos and total nitrogen was observed. Various studies have been carried out to study interrelationship between benthos and various other factors. Herman *et al.,* (1999) has positive relation between benthos and nitrogen.

Both magnesium and calcium are very important for benthos distribution (Habeeba *et al.,* 2012). However, in the present study no significant correlations were established among these factors and benthos population.

These results indicate that WIR and TIR regularly inundated with Narmada water share several of their fauna with microhabitats and show the influence of inundation on physicochemical parameters of soil and water in turn influencing the macrobenthic fauna while, JIR though in same climatic regime has the microhabitat of its own comparatively supporting few macrobenthic species. Further, as far as correlation between benthic fauna and various physicochemical parameters of soil and water are concerned, the system fluctuating due to Narmada inundation is not yet stabilized hence no one particular parameter is found to influence benthic fauna.

Conclusion

79 species belonging to 38 families of 11 orders noted at the three reservoirs indicates presence of good diversity in benthos. The similarity in the macrobenthos was overall high between WIR and TIR because of the similarities in the habitats due to extended but fluctuating water cover and hydro-period. The physico-chemical properties of water and

soil correlated variably with benthic fauna. Narmada inundation and different agricultural practices lead to the mixing of water further changing the soil and water chemistry. Under such circumstances benthos undergoing aestivation/hibernation can survive for longer duration. The conditions are more pronounced at WIR and TIR.

PLATE 6

PHYLUM: ANNELIDA

SUB-CLASS: OLIGOCHAETA

ORDER: MEGADRILACEA

FAMILY: NAIDIDAE

Stylaria sp.

Tubifex tubifex

FAMILY: MEGASCOLECIDAE

Perionyx sp.

Unidentified sp.

PHYLUM: ARTHROPODA

CLASS: ARACHNIDA

<u>ORDER: ARANEAE</u>

FAMILY: ARANEIDAE

Argiope sp.

FAMILY: SALTICIDAE

Plexippus sp.

FAMILY: LYCOSIDAE

Paradosa sp.

FAMILY: TETRAGNATHIDAE

Tetragnatha sp.

<u>ORDER: ARANEAE (Contd.)</u>

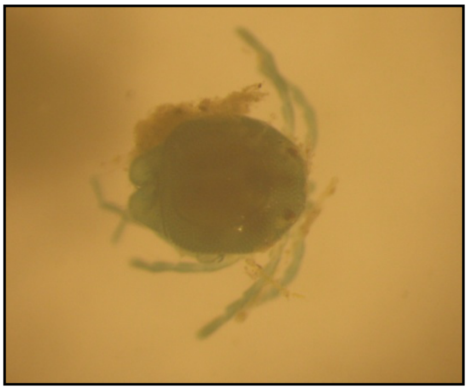
Unidentified sp.

<u>ORDER: TROMBIDIFORMES</u>

FAMILY: HYDRACHNIDAE

Hydrachna sp.

Unidentified sp.



CLASS: INSECTA

<u>ORDER: COLEOPTERA</u>

FAMILY: CARABIDAE

Apotomus sp.

Bembidion pygidium

Tachys luxus

Casnoidea indica

ORDER: COLEOPTERA (Contd.)

FAMILY: STAPHYLINIDAE

Paederus fucipes

Paederus sp.

FAMILY: STAPHYLINIDAE (Contd.)

Bledius sp.

Unidentified sp.

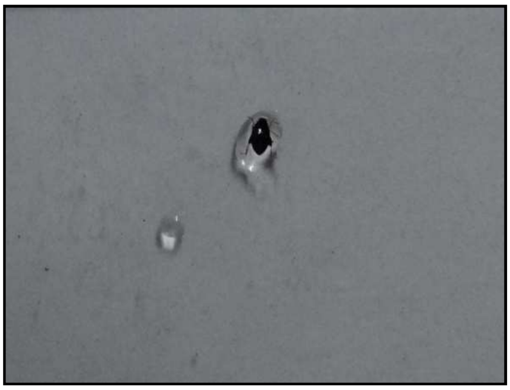
FAMILY: CLERIDAE (*Unidentified sp.*)

ORDER: COLEOPTERA (Contd.)

FAMILY: CHRYSOMELIDAE

Aphthona sp.

Chaetocnema basalis



FAMILY: CHRYSOMELIDAE (Contd.)

Cryptocephalus sp.

FAMILY: COCCINELLIDAE

Stethorus sp.

ORDER: COLEOPTERA (Contd.)

FAMILY: HYDROPHILIDAE

Unidentified sp.

Unidentified sp.

Hydrophilus sp.

FAMILY: NOTERIDAE

Canthydrus sp.

Unidentified sp.

<u>ORDER: COLEOPTERA (Contd.)</u>

FAMILY: DYTISCIDAE

Laccophilus sp.

Hydaticus sp.

Unidentified sp.

Unidentified sp.

FAMILY: LIMNICHIDAE

Byrrhinus sp.

Unidentified sp.

<u>**ORDER: COLEOPTERA (Contd.)**</u>

FAMILY: CURCULIONIDAE

Lissorhptrus sp.

ORDER : HEMIPTERA

FAMILY: HEBRIDAE

Hebrus sp.

Unidentified sp.

FAMILY: CERCOPIDAE

Bofylus sp.

FAMILY: MESOVALLIDAE

Mesovalia sp.

ORDER: HEMIPTERA (Contd.)

FAMILY: PLEIDAE

Paraplea sp.

Unidentified sp.

Unidentified Nymph

FAMILY: GERRIDAE

Gerris sp.

FAMILY: GELASTOCORIDAE

Nethra sp.

FAMILY: OCHTERIDAE

Ochterus sp.

FAMILY: NEPIDAE

Nepa sp.

FAMILY: CORIXIDAE

Micronecta sp.

FAMILY: NOTONECTIDAE

Unidentified sp.

ORDER: DIPTERA

FAMILY: CULICIDAE

Culex sp.

FAMILY: CHIRONOMIDAE

Chironomous sp.

ORDER: ORTHOPTERA

FAMILY: GRYLLOTALPIDAE

Gryllotalpa africana

FAMILY: TRIDACTYLIDAE

Xya sp.

ORDER: ODONATA

SUB-FAMILY: LESTINAE

Unidentified nymph

ORDER: HYMENOPTERA

FAMILY: APHIDIIDAE

Aphis sp.

FAMILY: FORMICIDAE

Camponotus compressus

FAMILY: FORMICIDAE (Contd.)

Camponotus sericeus

Monomorium minimum

ORDER: EPHEMEROPTERA

Unidentified nymph

ORDER: TRICHOPTERA

FAMILY: HYDROPSYCHIDAE

Unidentified sp.

MOLLUSCAN DENSITY AND DIVERSITY AT THE THREE RESERVOIRS

Introduction

Wetlands are the second most productive ecosystem next to tropical rain forest. However, these supporting diverse communities are being lost at an alarming rate on one side due to their destruction (Noss *et al.*, 1995; Semlitsch and Bodie, 1998; Detenbeck *et al.*, 1999) while several new are created at the shallow ends of water reservoirs constructed for human needs. This has led to a potential compromise in ecosystem function (Vitousek *et al.*, 1997; Chapin *et al.*, 2000; Pimm and Raven, 2000), particularly in regions where only small and scattered wetlands remain (Gibbs, 1993, 2000). These effects are especially pronounced in semi-arid and arid regions where irrigated agriculture as well as tourism directly competes with wetlands for water (Angeler and Garcia, 2005). One unique biotic component of these ecosystems is benthic fauna available at various depths, feeding on detritus as well as plant matter and being predated by higher taxa, this group of fauna forms important components linking producers and higher consumers.

The density of these prey species along with the properties of the substrate are important factors in habit selection of higher taxa mainly shorebirds (Grant, 1984). Many authors have correlated the density of waterbirds with the presence of aquatic invertebrates (Goss-Custard, 1970; Murkin *et. al.*, 1982; Puttick, 1984; Phillips, 1991; Hockey *et al.*, 1992; Velasquez, 1992; Yates *et al.*, 1993; Sanders, 1999). However, conservation strategies for wetland invertebrates are still poorly developed, and, in general, there are few case studies on the conservation of this large, diverse and important group (Watson and Ormerod, 2004).

Among benthic fauna, Molluscs form most diverse and dominant group performing key role in the functioning of aquatic ecosystem. Like other benthic fauna they are of great significance because they feed on vegetation as well as detritus and also form the food of many species of birds. Hence, their productivity plays an important link in the food chain. Thus, molluscs with calcareous shell not only play an important role in the aquatic eco-webs but also provide large quantity of calcium required for egg shell formation (McMahon and Bogan, 2001; Garcia *et al.*, 2006; Fagundes *et al.*, 2008) and other calcium needs of vertebrates (Cummins and Bogan, 2006). The freshwater ecosystems in India harbour a rich diversity of molluscs, representing about 212 species belonging to 21 families (Subba Rao, 1989; Kumar and Vyas, 2012). Clarke (1979) has attempted to use molluscs in primary classification of the lakes as per their various trophic status stages. Further, Choubisa, (1992) has studied the molluscan diversity in Rajasthan and has suggested mollusc as the indicator of the oligotrophic lakes. Lakes, ponds and reservoirs in central region of Gujarat have shallow areas which form good wetland habitats. Very few investigations have been carried out in this region on freshwater molluscs (Padate, 2002 (unpublished data); Deshkar, 2008; Parikh and Mankodi, 2009). The study areas selected belong to this region, which is also wintering grounds for migratory shorebirds (Deshkar, 2008). Subsequent to Narmada inundation, Deshkar, (2008) carried out studies on molluscs in the two reservoirs, out of three, selected for present study.

Hence, the main goal of this study was to determine how much variation in mollusc richness and composition is explained by area, soil and water quality and dominant aquatic vegetation when temporary monsoon dependant reservoirs are changing into almost perennial reservoirs.

Materials and methods

The study sites selected are irrigation reservoirs: Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation reservoir (JIR). All the reservoirs were visited twice a month from March 2009 to February 2011.

During each visit molluscs were collected by quadrat sampling. A quadrat of 30 cms. x 30 cms. upto a depth of 5 cms. was selected randomly for collection of molluscs. The samples were washed, sorted and preserved in 4% formalin for further identification. Identification was carried out as per the key provided by Subba Rao (1989). The data collected was analysed for calculating the density of molluscs per quadrat using formula: Number of individuals / Size of quadrate x depth. The data for 3 months is pooled into 4 seasons Summer, Monsoon, Post-monsoon and Winter and the Mean and standard error of mean (SEM) were calculated for each season. Further the data was applied to One-way ANOVA (Fowler and Cohen, 1995) with No post test for density of mollusc per quadrat (m^3) for four seasons were performed using GraphPad Prism version 3.00 for Windows, (GraphPad Software, San Diego California USA). The p value for ANOVA is non significant if $P > 0.05$ (ns), significant if $P < 0.05$ (*), significantly significant (**) if P is <0.001 and highly significant (***) if $p< 0.0001$.

The percentile dominance of each species was calculated as summation of No. of individuals of each species / summation of no. of individuals of total species X 100. This percentile was given dominance rating according to DAFOR score according to Hill *et al* (2005) as Dominant: 91-100%; Abundant: 51-90%; Frequent: 21-50%; Occasional: 6-

20%; Rare: < 5%. Pearson correlation was performed between the density of molluscs and physico-chemical parameters of water and soil along with waders using SPSS software 7.5.

Results

Total five species of freshwater molluscs (Table 3.1) were found around the three irrigation reservoirs belonging to class Gastropoda and Bivalvia. The gastropods include *Bellamya bengalensis* (Order: Architaenioglossa, Family Viviparidae); *Indoplanorbis exustus* (Order: Hygrophila, Family: Planorbidae); *Thiara granifera* (Order: Sorbeoconcha, Family: Thiaridae); *Lymnaea auricularia* (Order: Hygrophila, Family: Lymnaeidae) while Class: Bivalvia include a single species *Lamellae consobrinus* (Order: Unionoida Family: Unionidae). All the 5 species were found at WIR, while 4 at TIR and 3 at JIR. *L. auricularia* was not found at TIR as well as JIR whereas *L. consobrinus* was absent at JIR. *Pila globosa* was found only once at WIR and hence not included in the data analysis.

Percentile distribution of mollusc according to DAFOR score (Table 3.1, Fig .3.1)

The percentile distribution according to DAFOR score revealed that *Bellamya bengalensis* was abundant at WIR (68%) and TIR (63%), while frequent at JIR (36%). However, *Indoplanorbis exustus* was frequent at WIR (31%) and TIR (21%) while abundant at JIR (61%). *Thiara granifera* was a rare species at all the three irrigation reservoirs with only 0.5% (WIR), 1.69% (TIR) and 1.92% (JIR). *Lymnaea auricularia* was also rare with 0.33% at WIR and was not recorded among the benthos of TIR and JIR. The bivalve *Lamallae consobrinus* was also rare at WIR (1.09%), but occasional at TIR (13%) and not recorded at JIR.

Mean density at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir (Table 3.2, Fig.3.2)

Annual

The mean annual density was highest at WIR with 2456±205.2 mollusc/m^3, followed by TIR with 1951±236.7 mollusc/m^3 and lowest at JIR with 362±64.92 mollusc/m^3. The differences among the reservoirs were highly significant ($p<0.0001$, $F_{(2,70)}$ 19.79).

Seasonal

At WIR, the mean seasonal density was highest with 3315±480.1 individuals/m^3 during post-monsoon and lowest 1868±239.1 individuals during monsoon. In winter it was 2135±295.4 individuals/m^3 while in summer, it was 2435±425.7 individuals/m^3. The seasonal variations were not significant ($P>0.05$, $F_{(3, 26)}$ 1.71). At TIR also, the mean density was highest with 2674±565.7 individuals/m^3 during post-monsoon, lowest with 1132±129.9 individuals/m^3 during monsoon, 1466±176.8 individuals/ m^3 during winter and 2271±503 individuals/m^3 during summer. The seasonal variations were not significant ($P>0.05$, $F_{(3, 23)}$ 2.79). However, at JIR highest mean density of molluscs was noted during winter *i.e.* 453.70±76.63 individuals/m^3, lowest 95.90±21.69 individuals/m^3 in monsoon while it was 402.20±106.40 individuals/m^3 during post-monsoon and 119.1±0.00 individuals/m^3 in summer. Significant seasonal variations were noted at JIR ($P<0.05$, $F_{(3,10)}$ 4.52).

Among the reservoirs

When seasonal differences of density were compared among the three reservoirs studied, no significant differences were noted during summer ($P>0.05$, $F_{(2, 12)}$ 3.47) while highly significant differences were noted during monsoon ($P<0.0001$, $F_{(2, 11)}$ 16.99). However, during post-monsoon ($P<0.001$, $F_{(2, 17)}$ 6.37) and Winter ($P<0.001$, $F_{(2, 20)}$ 9.76) significantly significant variations among the reservoirs were noted.

Mean species richness at Wadhwana irrigation reservoir, Timbi irrigation reservoir and Jawla irrigation reservoir (Table 3.3, Fig. 3.3)

<u>Annual</u>

The annual mean species richness per visit was highest at WIR 2.2±0.14 species, followed by 1.96±0.16 species at TIR and lowest 1.5±0.13 species at JIR. The differences among the reservoirs were significant ($P<0.05$, $F_{(2, 70)}$ 3.94).

<u>Seasonal</u>

The mean seasonal species richness of molluscs was high at WIR with 2.85±0.4 species per visit during summer and 2.6±0.24 species per visit in monsoon, low 1.75±0.16 species per visit during post-monsoon as well as winter (1.9±0.1 species). The seasonal variations were significantly significant ($p < 0.001$, $F_{(3, 26)}$ 5.26). At TIR, the mean species richness was highest with 2.2±0.3 species per visit during monsoon followed by 2.13±0.35 species per visit during post-monsoon, lowest during winter with 1.78±0.15 species per visit while 1.83±0.48 species per visit during summer. The seasonal variations were not significant ($P>0.05$, $F_{(3, 24)}$ 0.4). The species richness at JIR was 2.00±0.00 species per visit during summer as well as winter, while 1.33±0.21 species per visit during post-monsoon and 1.00±0.00 species per visit during monsoon.

<u>Among the reservoirs</u>

When seasonal differences in the species richness were compared among the three reservoirs studied, no significant differences were noted during post-monsoon ($P>0.05$, $F_{(2, 19)}$ 2.11) and winter ($P>0.05$, $F_{(2, 21)}$ 0.72) but significant differences were noted during monsoon ($P<0.05$, $F_{(2, 10)}$ 6.15).

Correlation of mollusc density with wader density, physico-chemical properties of water and soil (Table 3.4, 3.5)

No correlation could be established between the density of Mollusc and density of waders at the two reservoirs inundated with Narmada water *i.e.* WIR and TIR of semi-arid zone of Gujarat. However it was correlated positively at the level of 0.05 at JIR. Among the parameters of water, acidity and chlorides in water were correlated with mollusc density positively at the level of 0.05 and 0.01 only at WIR while dissolved oxygen only at TIR and Kjeldahl nitrogen only at JIR both at 0.05 levels. All other physicochemical parameters of water showed varied insignificant correlations with mollusc density. Among these Free CO_2, pH and total phosphates are negatively correlated while DO, Kjeldahl nitrogen, nitrite, sulphates, water temperature are positively correlated at the three reservoir.

When the soil parameter studies are considered, as noted with water they also variedly correlated with the density of mollusc and was significant at 0.05 positively only with calcium and percent coarse sand at WIR, pH at TIR and negatively with chlorides at JIR.

However, calcium, fine sand and Magnesium were correlated non-significantly positively with molluscan density while only Chlorides negatively at all the three reservoirs. Other parameters showed varied non-significant positive or negative correlations with molluscan density at the three reservoirs.

Table 3.1. The percentile dominance of molluscs according to DAFOR score at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Species	WIR	TIR	JIR
Bellamya bengalensis	Abundant (68.86%)	Abundant (63.11%)	Frequent (36.54%)
Indoplanorbis exustus	Frequent (31.97%)	Frequent (21.66%)	Abundant (61.54%)
Thiara granifera	Rare (0.5%)	Rare (1.69%)	Rare (1.92%)
Lymnaea auricularia	Rare (0.33%)	Absent	Absent
Lamellae consobrinus	Rare (1.09%)	Occassional (13.54%)	Absent

Dominant: 91-100%; Abundant: 51-90%; Frequent: 21-50%; Occasional: 6-20%; Rare: < 5%

Table 3.2. Annual and seasonal Density of molluscs at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Density	WIR	TIR	JIR
Annual (***) $\mathbf{F_{(2,70)}}$ **19.79**	2456±205.2	1951±236.7	362±64.92
Seasonal	**ns;** $\mathbf{F_{(3,26)}}$ **1.71**	**ns;** $\mathbf{F_{(3, 23)}}$ **2.79**	***;** $\mathbf{F_{(3,10)}}$ **4.52**
Summer (ns) $\mathbf{F_{(2,12)}}$ **3.47**	2435±425.7	2271±503	119.10±0.00
Monsoon (***) $\mathbf{F_{(2,11)}}$ **16.99**	1868±239.1	1132±129.9	95.90±21.69
Post-monsoon (**) $\mathbf{F_{(2,17)}}$ **6.37**	3315±480.1	2674±565.70	402.20±106.40
Winter (**) $\mathbf{F_{(2,20)}}$ **9.76**	2135±295.4	1466±176.8	453.70±76.63

Table 3.3. Annual and seasonal species richness of molluscs at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Species richness	WIR	TIR	JIR
Annual (*) $\mathbf{F_{(2, 70)}}$ **3.94**	2.2±0.14	1.96±0.16	1.5±0.13
Seasonal	****;** $\mathbf{F_{(3, 26)}}$ **5.26**	**ns;** $\mathbf{F_{(3, 24)}}$ **0.40**	**-**
Summer	2.85±0.40	1.83±0.48	2.00±0.00
Monsoon (*) $\mathbf{F_{(2,10)}}$ **6.15**	2.60±0.24	2.2±0.3	1.00±0.00
Post-monsoon (ns) $\mathbf{F_{(2,19)}}$ **2.11**	1.75±0.16	2.13±0.35	1.33±0.21
Winter (ns) $\mathbf{F_{(2,21)}}$ **0.72**	1.90±0.10	1.78±0.15	2.00±0.00

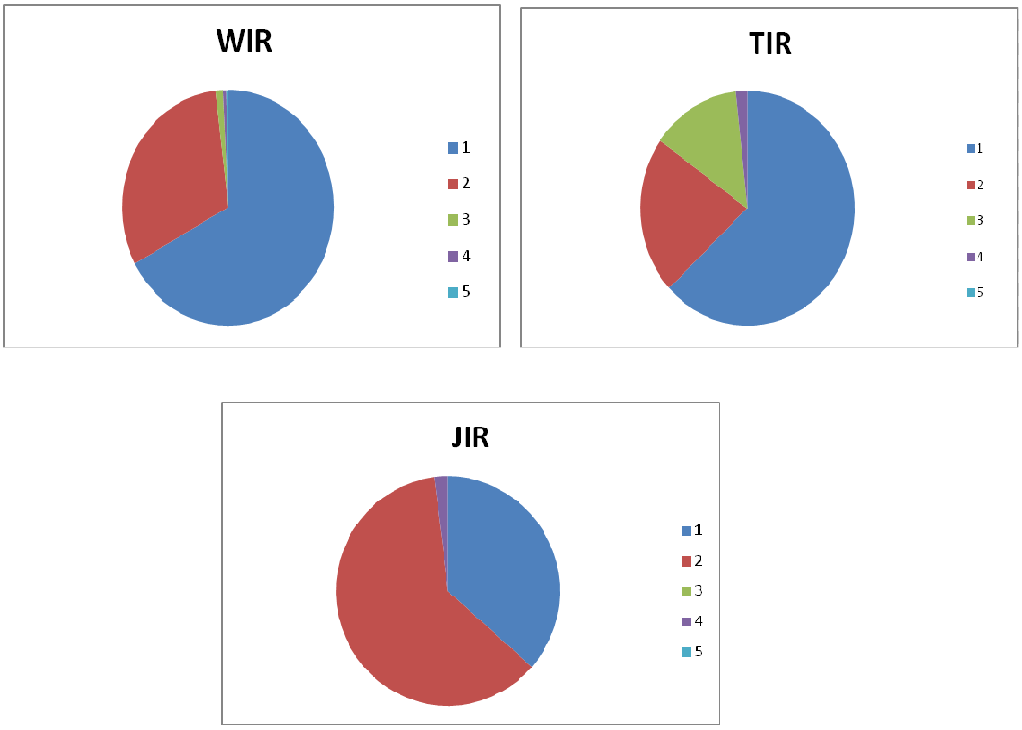
Table. 3.4. Correlation of density of Molluscs with wader density and various physico-chemical properties of water at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Parameters	WIR	TIR	JIR
Acidity	0.368*	-0.166	-0.048
Chlorides	0.433**	-0.123	0.182
Free carbon dioxide	-0.105	-0.150	-0.064
Dissolved oxygen	0.106	0.122*	0.250
Bicarbonate Alkalinity	0.015	0.014	-0.080
Inorganic phosphates	-0.165	-0.098	0.142
Kjeldahl nitrogen	0.212	0.047	0.110*
Nitrate	0.120	-0.197	-0.079
Nitrite	0.084	0.185	0.082
Hydroxyl Alkalinity	0.207	0.156	-0.122
pH	-0.040	-0.064	-0.059
Salinity	0.201	-0.123	0.182
Sulphate	0.075	0.190	0.097
Water temperature	0.360	0.037	0.129
Total phosphates	-0.266	-0.222	-0.322
Waders	0.051	-0.078	0.377
Water cover	0.485*	0.062	0.350

Table. 3.5. Correlation of Mollusca with various physico-chemical properties of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

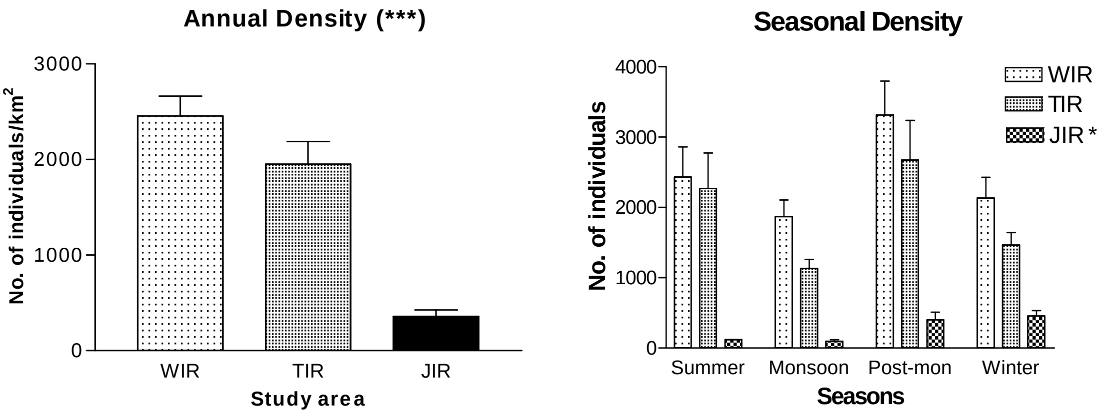
Parameters	WIR	TIR	JIR
Calcium	0.178*	0.271	0.130
% Coarse sand	0.273*	0.477	-0.232
%Fine sand	0.254	0.441	0.016
Magnesium	0.217	0.238	0.502
pH	0.126	0.050*	-0.357
%Silt +clay	-0.297	-0.807	0.375
Total N	0.010	-0.176	-0.078
Organic matter	-0.368	0.395	0.618
Total P	-0.336	-0.109	0.029
%Very fine sand	0.500	-0.398	-0.014

Fig. 3.1. Percentile dominance of mollusc species at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



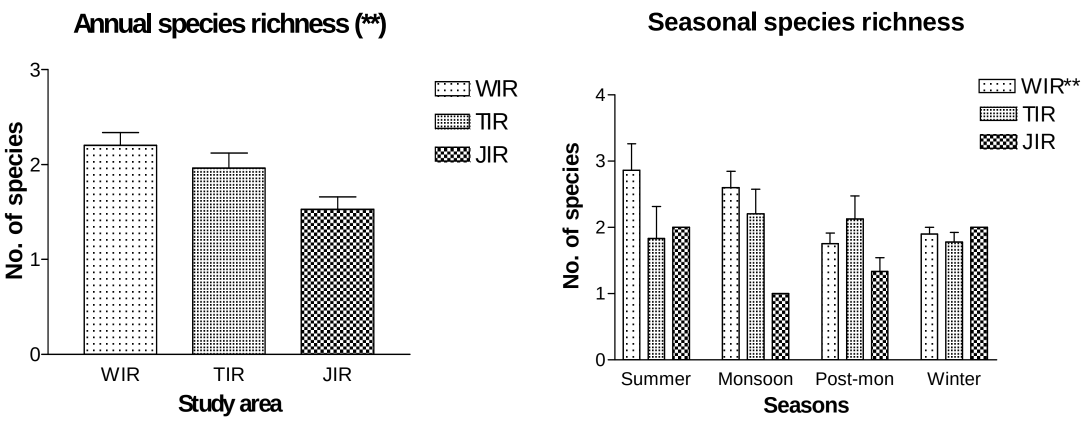
1: *Bellamya bengalensis*, 2: *Indoplanorbis exustus*, 3: *Lamellidens consobrinus*, 4: *Thiara granifera* and 5: *Lymnaea auricularia*

Fig. 3.2. Mean Annual and seasonal Density of molluscs at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



*for ANOVA * (P<0.05), ** (P<0.001) and *** (P<0.0001)

Fig. 3.3. Mean annual and seasonal Species richness of molluscs at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



*****for ANOVA * (P<0.05), ** (P<0.001) and *** (P<0.0001)

Discussion

In India, very scant attention has been given to the biology and ecology of molluscs, and therefore the ecological needs of a great majority of the Indian freshwater molluscs are not known (Subba Rao, 1989). Apart from Volume IV of Fauna of British India by Preston, (1928), there are only two other books (Subba Rao, 1989; Ramakrishna and Dey, 2007) that deal with listing and distribution of Indian freshwater molluscs. Hence, it is very important to assess molluscan density and diversity in the monsoon dependent semi-arid zone of central Gujarat where the rain water is stored in the reservoirs. As soon as the monsoon gets over the evaporation starts which leads to change in the physico-chemical properties of water as well as soil and also organic matter and nitrogen content in the bottom sediments.

Molluscs are represented in freshwater bodies by only 2 classes, Gastropoda and Pelecypoda (Mackie, 1998). Many freshwater molluscs of Western ghats are habitat generalists and are widely distributed, *viz., Pila, Thiara* and *Lymnaea* (Mavinkurve *et al.*, 2004). However, these species were either rare or absent in present studies as well as study carried out by Deshkar, (2008).

In present study the presence of *Bellamya bengalensis* at all the sites indicates that the species is well acclimatized with the semi arid zone at WIR compared to other two reservoirs (JIR and TIR). It is known to be abundantly distributed throughout India and is common to occur in the western zone (Subba Rao, 1989, Mavinkurve *et al.*, 2004). It is reported to be a major species of fresh water molluscs among the benthic fauna (Shrivastava, 1956, 1959; Michael, 1968; Gupta, 1976; Krishnamoorthi, 1979, Sharma, 2006). *Indoplanorbis exustus* also a common species of Western Ghats adapted to polluted water was abundant at JIR; which is farthest from the northern boundary of Western Ghats *i.e.* Narmada River; among the three reservoir. Its maximum occurrence (61.54 %) at the reservoir can be attributed to the higher organic input from animal source. (Chapter IV). Deshkar, (2008) and Mavinkurve *et al.*, (2004) has also reported its occurrence in polluted water.

Thiara granifera is primarily a benthic species and has been collected on a variety of substrata in both natural and artificial waterbodies in South Africa, e.g. sand, mud, rock, concrete bridge foundations and the concrete walls and bottoms of reservoirs, irrigation canals and ornamental ponds (Appleton *et al*., 2009). Many of these habitats are vegetated and associated vegetation included many types of emergent monocotyledons (e.g. *Cyperus sp.*, *Typha* sp.) and dicotyledons (e.g. *Nymphaea nouchali*). The presence of these semi aquatic and aquatic species of plant at the three reservoirs can be the reason of its occurrence. Although its occurrence was rare at all the three study sites among the three it was higher at JIR which is having dense vegetation. Some of the Thiaridae species have high tolerance to brackish habitats (Subba Rao, 1989) and hence this can also be the reason of its rarity in the region.

Lymnaea auricularia another species of gastropod recorded as rare species and only at WIR is usually found in freshwater lakes and ponds with mud bottoms (Subba Rao, 1989). This species can live on vegetation in low or high-flow environments, and is capable of tolerating anoxic conditions, but it tends to prefer lentic waters in lakes where there is silt as substrate (Clarke, 1981; Jokinen, 1992; Peckarsky *et al.*, 1993). It has also been found in environments with a pH from 6.0–7.1 (Jokinen, 1992; Maqbool *et al.*, 1998). The three reservoirs have 4 to 13% of silt+clay, alkaline pH very low flow of water in shallow areas and good oxygen levels (Chapter IV) and, moderately hard water (Deshkar, 2008) and hence this species was rare in the study areas and is found only at one study site *i.e.* WIR.

Lamellae consobrinus was the only species of mussels found at the three study sites. Freshwater mussels are often very abundant in substrates of shallow pools and protected coves or among reeds and provide important ecosystem services and are a powerful management tool for maintaining and reclaiming water quality (McMahon and Bogan, 2001, Kreeger *et al.*, 2004). They can play a significant role in local food webs by increasing the flux of organic and inorganic matter to water bodies, which in turn influences macroinvertebrate assemblages (Howard and Cuffey, 2006). It occurred rarely at WIR but was abundant at TIR. It prefers vegetated areas with soft substrates and is well adapted to fluctuations in water levels. Though Deshkar, (2008) reported *Lamellae consobrinus* at the same study area as rare. It was found to be occurring with 13.5% TIR.

This species is probably trying to adapt the habitat at TIR having extended hydroperiod and hydrospread but probably not found much at other two.

The high numbers of molluscs found at WIR can be related to the large area of the reservoirs. During winter the predation pressure is high due to presence of large number of migratory as well as resident species of birds, at WIR and TIR (Chapter-1) which is likely to decrease the abundance of prey base. Many species of wading birds feed on mollusc (Bolduc and Afton, 2004) and large number of migratory population of wading birds visit WIR during winter (Deshkar, 2008). This is the period when molluscan density is low at WIR and TIR. During winter the temperature declines forcing molluscs to hibernate/move to deeper soil. At the third reservoir, JIR, vegetation probably protects them. However, here more resident larger waders are observed that prefer feeding on epifauna, hence, such decline may not be observed. Further, the lower temperature of winter is likely to push mollusc deeper in soil as is also suggested by Deshkar (2008). The density of mollusc in general was always high in the present study with non-significant variations at the reservoir with Narmada inundation where hydroperiod and hydrospread both have increased. At the third reservoir the seasonal variations significant at $P<0.05$ may be related to the influence of the environmental changes on the smaller population of mollusc which was always below 500 individuals/m^3. On the basis of this it may be suggested the seasonal drying of the wetland is expected to lead to more diverse habitat conditions while the perennial wetlands may support the same density of organisms throughout the year. Further, according to Balla and Davis, (1995) the change in the water level and water cover favours the species richness. The highest density at WIR and TIR observed during the post-monsoon, when the water level is high, probably favours the growth of the vegetation and breeding performance of molluscs, when temperature is also favourable. On the basis of this it may be suggested that the change in the water cover brings about a significant change in the density of mollusc whereas the fluctuations in the water level have no significant influence on the molluscan density. Although the conditions are different at JIR because of presence of extensive vegetation cover, the mollusc probably continue to flourish in winter too. This could be attributed to the decrease in water level during winter at the reservoir and hence good density is observed. The increasing water level in the monsoon dependent reservoir of the region submerges the vegetation. Vegetation is required for growth of attachment of the mollusc (Macan, 1950) hence during monsoon when hiding place for them decreases a decline in the density is noted (Bronmark, 1985).

Correlation with Physico-chemical characteristics of water

Colinearity between molluscan fauna and environmental variables are likely to differ according to different habitats at different locations (Deshkar, 2008) which holds true for the present study too. The higher density of molluscs during post-monsoon and summer has been related to two reasons: 1. A huge area of decomposed settled organic matter and also the macrophytes at the bottom of the water body; 2. Increased water temperature activating the process of decomposition of these organic sediments (Malhotra *et al.*, 1996).

Hydroperiod is regarded as a crucial factor structuring molluscan communities (Jurkiewicz-Karnkowska, 2011). A significant and positive correlation of water cover with molluscs was noted at WIR probably due to high water cover with highest density of mollusc in post-monsoon. This reservoir also receives higher river discharges (inundation) than other two. Higher river discharge rich with nutrients is conducive to the development of species rich communities by facilitating their breeding and dispersal (Jurkiewicz-Karnkowska, 2011). Further, the rise in water cover is likely to lead to increase the alkalinity levels in the water, a habitat preferred by mollusc. Martins-Silva and Barros (2001), reported that molluscs preferred alkaline habitats and do not survive beyond a pH of <5.

In an estuarine area salinity is a major factor in mollusc assemblage (Bruyndoncx *et al.*, 2002). Since the study areas are of fresh water in nature chloride levels were minimal. The substrate water interface affects the distribution and activity of benthic organisms resulting into species specific mortalities. Decaying of dead organisms can result into oxygen depletion and hypoxic conditions (Kolar and Rahel, 1992). Invertebrates in general respond to such altered declining benthic oxygen by decreasing their overall activity. The three reservoirs having moderate to high oxygen levels correlated positively but significantly only at TIR, where maximum density of bivalves were noted. DO and food availability are known to be the factors controlling the distribution of bivalves (Hallam, 1996). Further, DO is also limiting factor for the distribution of mollusc (Pennak, 2004).

According to Jurkiewicz-Karnkowska, (2011) seepage from river infiltration makes a water body nutrient rich. The inundation of Narmada water at WIR and TIR can be said to have made a positive influence on mollusc populations. Though a positive correlation of Kjeldahl nitrogen found at all the three study sites supports the above results, a significant relation at JIR can be attributed to the high nutrient input from other sources which has led to high vegetation cover. Vegetation provides substratum for attachment of mollusc and hence an increase in the density of mollusc during monsoon and post-monsoon at JIR too.

Physico-chemical characteristics of soil

Though the total amounts of carbon, nitrogen and calcium stored in molluscs are comparable to those contained in the water column; much smaller than those are contained in surficial sediments when they are numerous and have high biomass. They play a significant role both in accumulation and circulation of N, C (Jurkiewicz-Karnkowska, 2005). A positive significant correlation of molluscs with soil-Ca at WIR explains their high density during the study. Because of calcareous protective covering, calcium is very important in the life-cycle of molluscs (Chokor and Oke, 2011; Sulikowska-Drozd and Horsák, 2007).

Further, with calcium soil pH is also considered as limiting factor (Boycott, 1934; Cameron, 1973; Radea and Mylonas, 1992). The fact questioned by those authors, who have either not found a direct relationship or have found other factors to be more important in structuring molluscan community (Levin and Gage, 1998; Maltchik *et al.*, 2010). Ondina *et al.*, (2004) showed direct influence of species distribution of molluscs with various environmental variables such as soil Ca content, soil pH, coarse sand, which supports our results noted at TIR.

There are other factors like organic matter and nitrogen content that differ in bottom sediments in temporary and permanent sites significantly (Jurkiewcz and Kornskowcka, 2011) while coarse sand, fine sand, silt and clay (Ondina *et al.*, 2004; Sanders and Maloney 1994; Ysebaert *et al.*, 2003; Herman *et al.*, 2001) indicates influence of soil characteristics on the density and distribution of mollusc. However, in the present study where the habitat is undergoing change due to Narmada inundation, these studies are expected to help future studies when the wetland becomes perrenial.

Conclusion

Molluscs are one of the major prey base for several species of birds especially water birds as they are major source of calcium for egg shell production. In the present study of the semi arid zone only six species of mollusc belonging to five families were noted. All the reservoirs studied showed different abiotic factors correlated with molluscan density. Correlation regarding the soil physico-chemical parameters and the mollusc density indicated a significant relationship of molluscan density to calcium content needed for their growth and development and with soil pH as they need alkaline environment for survival.

PLATE 7

PHYLUM: MOLLUSCA

CLASS: GASTROPODA

FAMILY: VIVIPARIDAE

Bellamya bengalensis

FAMILY: PLANORBIDAE

Indoplanorbis exustus

FAMILY: LYMNAEIDAE

Lymnaea auricularia

FAMILY: THIARIDAE

Thiara granifera

PLATE 7 (Contd.)

CLASS: BIVALVIA

FAMILY: UNIONIDAE

Lamellae consobrinus

PHYSICO-CHEMICAL CHARACTERISTICS OF WATER AND SOIL

Introduction

All organisms and their communities are directly or indirectly affected by the physical characteristics of their environment (Gillis *et al.*, 2008). Thus, the study of interactions between biotic and abiotic factors becomes essential to understand the community structure of an ecosystem (Dunson and Travis, 1991). For human beings water and land are the two important useful natural resources. Human society depends on freshwater systems for drinking water, hydropower, irrigation, cooling and cleaning; products such as food, plants, wildlife, and minerals; and services such as recreation, waste purification, transportation, and aesthetics (Murkin, 1998). Even though 70% of earth is covered with water, only 0.2 percent fresh water is available for life on land (Aydemir *et al.*, 2005). This water is available in rivers, streams, ponds and lakes as well as reservoirs constructed by man for his various needs. According to the Ramsar Convention, the shallow regions of these water bodies form wetlands, one of the most productive ecosystems of the world next to the tropical rain forests. Wetlands are defined as 'lands transitional between terrestrial and aquatic ecosystems where the water table is usually at or near the surface or the land is covered by shallow water (Mitsch and Gosselink, 1986). The value of the world's wetlands are increasingly receiving due attention as they contribute to a healthy environment in many ways. They retain water during dry periods, thus keeping the water table high and relatively stable. Inspite of being useful the natural wetlands are being disturbed and destroyed by various practices like road building, urban and rural development, agriculture, and surface mining (Tiner, 1984; Salvesen, 1990) and also for betterment of human life. However, new wetlands are created to compensate for the loss of natural wetlands as a result of human land-use activities.

Wetland ecosystem has soil as its physical foundation. Much work has been carried out to compare soil and other environmental conditions within constructed and adjacent reference wetlands to assess the progress of the constructed wetlands towards a functional wetland (Stolt *et al.*, 2000). As wetlands serve as potential sinks for excess nutrients in agricultural and urban runoff (Bingham, 1994; Crumpton and Goldsborough, 1998), nutrients in waters are incorporated into flora, fauna, and sediments present within. This ability to remove nutrients from water has important implications for downstream water quality (Landers and Knuth, 1991; DeLaney, 1995). Further, the changes in the key physical and chemical parameters at landscape scale are known to affect the food web at primary and secondary production levels ultimately altering the corresponding aquatic community and ecosystem attributes such as species richness, distribution, dispersal and biodiversity (Wrona *et al*., 2006). The macrozoobenthic taxa composition at the base of food web is the result of complex interactions of diverse environmental variables (Elexova and Nemethova, 2003).

The seasonal changes in the environment with anthropogenic pressures change the quality of water bodies, especially in the semiarid zone where such changes are pronounced (Deshkar, 2008). There exists a close relationship between the water quality and bottom substrates. The nature of bottom substrates is one of the most significant environmental parameters that influence the biodiversity (Minshall, 1984) as soil properties such as organic matter content and texture affect hydrology of a wetland (Stolt *et al.*, 2000). The present chapter is to understand the influence of annual environmental changes on the quality of water and soil of the three reservoirs selected in the semi arid zone of Gujarat, India on bases of which effect on biota can be studied. For the water analysis, the parameters studied are divided as physical properties, chemical properties, and inorganic non-metallic constituents. The physical and chemical properties of water studied include water temperature, water cover, pH, Acidity, Bicarbonate Alkalinity (HCO_3^-), Hydroxyl Alkalinity (OH^-), Salinity, Dissolved Oxygen (DO), Chlorides (Cl^-) and Carbon dioxide (CO_2). Inorganic non-metallic constituents include Sulphate (SO_4^{+2}), Kjeldahl nitrogen, Nitrate (NO_3^-), Nitrite (NO_2^-), Inorganic Phosphates (PO_4^{-3}) and Total phosphorus.

The physical and other aggregate properties of soil include soil texture, pH and Organic matter, while inorganic non-metallic constituents includes Total Nitrogen, Total Phosphorus, Calcium and Magnesium.

Physico-chemical properties

Temperature has a significant ecological impact. Temperature of a pond is of great significance because it affects the amount of dissolved oxygen inversely (Addy and Green, 1997).

pH is a measure of the acidity or alkalinity of water. Acidic pH accelerates absorption of phosphate by plants (Devlin and Witham, 1986), an important nutrient. Further, *Acidity* of the water is its capacity to neutralize a strong base to a fixed point. It is caused by the presence of strong mineral acids, weak acids and hydrolyzing salts of strong acids. However, in natural unpolluted freshwaters, the acidity is mostly due to the presence of free CO_2. Regular measurement of Acidity can reflect a change in the quality of water (APHA, 1998). The anthropogenic acidification is reported to change the vegetation and prey base resulting in change in higher communities like birds and create a new food web (Doherty *et al*., 2000).

Alkalinity is a measure of the capacity of water to neutralize a strong acid. The alkalinity in water is generally imparted by the salts of carbonates, bicarbonates, phosphates, nitrates, borates, silicates, *etc*. together with the hydroxyl ions in Free State. In freshwater, alkalinity is typically due to the presence of excess carbonate (from the weathering of silicate or carbonate rocks) and bicarbonate anions with little concentration of other alkalinity imparting ions. These ions when hydrolyzed produce OH^- (and neutralize H^+) as follows:

$$CO_3^{2-} + H_2O = HCO_3^- + OH^-$$

$$HCO_3^- + H_2O = H_2CO_3 + OH^-$$

These anions are primarily responsible for the capacity of water to neutralize acid. They are measured in the form of *bicarbonate* and *hydroxyl alkalinity*. Raw domestic waste water has an alkalinity less than or only slightly greater than that of the municipal water supply (APHA, 1998).

Salinity is another important component to measure the mass of dissolved salts in a given mass of solution (APHA, 1998). According to Grillas *et al*., (1993) the total biomass of the submerged communities decreases exponentially and also the species richness decreases linearly with increasing salinity.

Water cover also plays a profound role in the usage of wetland by organisms. Taylor *et al.*, (1992), reported that there is a great variation in numbers of shore birds on wet mud flats from week to week and from year to year, and at least some of these variations are caused by water level fluctuations and mudflats exposure timing. Hence, water cover is also considered in present study.

Dissolved Oxygen levels in natural and waste waters depend on the physical, chemical and biochemical activities in the water body. Estimation of dissolved oxygen is a key test in water pollution and waste treatment processes (APHA, 1998). Oxygen produced during photosynthesis by aquatic plants, algae and phytoplankton and that from the atmosphere that diffuses at the surface until the water is "saturated" spreads very slowly in water. Its distribution depends on the movement of aerated water by turbulence and currents caused by wind, water flow and thermal upwelling. The capacity to dissolve oxygen in water is limited by the temperature and salinity, and by the atmospheric pressure, in the soil. Oxygen availability affects mineralization by determining the microbial assemblage present. Reduction of organic matter at higher rates occurs in aerobic soils largely due to the increased efficiency of aerobic respiration over anaerobic respiration pathways (Reddy and Patrick, 1984; Hansen and Blackburn, 1991; Updegraff *et al.*, 1995). Hence DO is one of the important parameter estimated during water quality analysis.

Carbon dioxide content of water contributes significantly to corrosion (APHA, 1998). Supersaturation of CO_2 in surface water results from benthic respiration and pelagic mineralization (Jonsson, *et al.,* 2003) as well as from terrestrial respiration and weathering products delivered by sub-surface or groundwater inflow. According to (Portner and Farrell, 2008), increased CO_2 levels in the ambient waters hinder the survival of organisms, hence CO_2 is important parameter in water quality assessment.

Chlorides in water occur in the form of chloride ions (Cl^-), one of the major inorganic anions (APHA, 1998). Chlorides constitute approximately 0.05% of the earth’s crust. In freshwater Chloride concentrations of between 1 and 100 ppm (parts per million) are acceptable. Chloride ions come into water from underground aquifers, geological formations that contain groundwater. Freshwater aquatic plants and freshwater invertebrates are most sensitive to chloride concentration. Hence chlorides are also estimated in present study.

Inorganic non-metallic constituents

Among the inorganic non-metallic constituents, *Sulfate* (SO_4^{-2}), an anion, is derived from rocks and soils containing gypsum, iron sulfide and other sulfur compounds (Joeckel *et al.*, 2007). Sulfate is widely distributed in nature and is used by all aquatic organisms to build proteins. It is also widely used in industry and agriculture. *Calcium* (Ca^{+2}), the cat ion in water is one of the most abundant substances in surface water because it dissolves easily. The main source of calcium in surface water is from the weathering of lime stone rocks that are primarily composed of calcium compounds (APHA, 1998). *Magnesium* (Mg^{+2}) the eighth most abundant element on earth is a common component of all surface water. Contribution of magnesium from natural sources is maximum than all other human activities combined. Calcium and magnesium are the causes of hardness of water (APHA, 1998). Hence, Sulfates, Calcium and Magnesium are evaluated in water quality analysis.

Other important non-metallic constituent and a nutrient is *Nitrogen (N)*. Nitrogen in soils occurs in many forms, both organic and inorganic. The former fraction, composed mostly of plant and microbial remains, is variable in composition. It is reported to be substantial in actual and relative amounts in soils of temperate regions (Miller, 1981). With increasing aridity, however, organic and total soil N tends to decrease. In soil the inorganic phase of N is composed of ammonium (NH_4^+), nitrate (NO_3^-), and nitrite (NO_2^-) forms. Oxygen availability, organic matter, nitrate supply and temperature are reported to have the most significant influence over biological denitrification in wetland sediments (Wang *et al.*, 2007).

Phosphorus the other nutrient, occurs in natural and waste water almost solely as phosphates. Being major constituent of many commercial cleaning preparations larger quantities of phosphates are added when the water is used for laundering or other cleaning, (APHA, 1998).

Soil organic matter represents the roots, plant material and soil organisms in various stages of decomposition and synthesis, and is variable in composition. Different aspects of sediments have a varying impact in determining the structure and complexity of macrobenthic communities of any lake, reservoir or stream as they are generally categorized as substrate dependent communities (Hoey *et al.*, 2004). Sediment organic load (TOC) associated with high fine fraction percentage influences the macrobenthos community structure, in both, abundance and diversity indices (Specchiulli *et al.*, 2010).

A CCA analysis carried out by Habeeba *et al.,* (2012) indicates that, in a pond the most important factors affecting on the benthos distribution are Water temperature, Dissolved oxygen, Nitrate, Phosphate, Alkalinity, Calcium, Magnesium, Chloride, Depth, *etc*. with % organic matter, composition of Silt and Clay. Stolt *et al.,* (2000) have also stressed on soil properties such as percent sand, clay, carbon or nitrogen to be important factors in the function and health of a constructed wetland. Hence, with water and soil analysis a soil texture analysis was also carried out to understand the distribution and effects on the faunal diversity and densities at the three study sites.

Materials and methods

To analyze physico-chemical parameters standard methods described by APHA (1998), Trivedi and Goel, (1984) and GPCB, (2003) were used. Six water samples were collected from each reservoir once in a month and analysed in the laboratory.

Physical and chemical properties of water

Temperature was measured at the site itself by using a mercury thermometer and was noted in ºC.

Water cover was taken as visual estimate of the whole area of reservoir covered with water.

pH was also measured at site using a portable Milwaukee pH meter.

Salinity

Salinity is calculated on the basis of chloride value (Page 10).

Salinity = mg Cl/ lit × 1.805

mg Cl^- /lit as calculated for the chloride content in sample is multiplied by 1.805.

Acidity (Titrimetric Method)

Acidity is determined by titrating the sample with a strong base such as NaOH using phenolphthalein as an indicator. To estimate acidity, in 10ml or 50ml of sample, 2 to 4 drops of Phenolphthalein are added and titrated against 0.02 N NaOH solution. Whenever necessary the samples are made colourless with charcoal.

Calculation of Acidity:

$$\text{Acidity, as } CaCO_3 \text{ mg / l} = \frac{\text{B.R.} \times 1000}{\text{Amount of Sample Taken (ml)}}$$

where, B.R. = Burette reading (Amount of titrant used)

Alkalinity (Titrimetric Method).

Total alkalinity is the sum of Hydroxyl Alkalinity and Bicarbonate Alkalinity.

Hydroxyl ions present in a sample as a result of hydrolysis of solutes react with addition of standard acid. Alkalinity depends on the end-point and pH of the indicator used. To estimate hydroxyl alkalinity, 3 to 4 drops of phenolphthalein indicator are used for 50 ml sample. If pink colour is developed then it is titrated against 0.02 N H_2SO_4 to the perfect point of pH 8.3 when mixture becomes colourless. If no colour is developed, the phenolphthalein alkalinity is considered as zero.

Calculation of Hydroxyl Alkalinity:

Hydroxyl Alkalinity, as $CaCO_3$ mg / l = $\frac{A \times N \times 50 \times 1000}{\text{Amount of Sample taken (ml)}}$

A= Burette reading (Amount of titrant used)

N= Normality of H_2SO_4

50= equivalent weight of $CaCO_3$

Bicarbonate Alkalinity

Few drops of methyl orange indicator are added to the sample in which the phenolphthalein alkalinity was determined. This mixture is titrated against 0.02 N H_2SO_4 to the colouration corresponding to the end point. The Calculation for Bicarbonate Alkalinity:

$CaCO_3$ mg / l = $\frac{B \times N \times 50 \times 1000}{\text{Amount of Sample taken (ml)}}$

Where,

B= Total ml of titrant used for neutralizing sample to reach the second end point

N= Normality of Sulphuric acid (0.02).

50= equivalent weight of $CaCO_3$

Dissolved Oxygen (Winkler's Method)

The manganese sulphate ($MnSO_4$) reacts with the alkali (KOH) to form white precipitates of manganese hydroxide. In the presence of oxygen, highly alkaline solution of the white manganese hydroxide is oxidized to brown coloured manganese oxyhydrate. This occurs in direct proportion to the amount of oxygen present. In strong acidic medium manganese ions are freed and they react with the iodine ions of potassium iodide to release free iodine. The amount of free iodine is equivalent to the oxygen present in the solution. The amount of iodine can be determined by titration with sodium thiosulphate by using starch as indicator.

To estimate dissolved oxygen, the water is collected with care in BOD bottles without bubble formation. The DO is then fixed at the site itself by adding 1 ml each of Manganese Sulphate and Alkali-iodide azide reagents. The precipitates formed are dissolved by adding 2 ml of concentrated sulphuric acid. 10ml or 50ml of this sample is taken and known amount of Sodium thiosulphate is added until pale yellow colour develops. To this mixture 2 to 4 drops of Starch solution are added as indicator which develops blue colour. This mixture is then titrated further till the disappearance of blue colour.

Calculation for Dissolved oxygen:

$$\textbf{D.O.} = \frac{B.R \times N \times 1000}{\text{Amount of Sample taken (ml)}}$$

B.R. = Burette reading (Amount of titrant used)

N= Normality of Sodium thiosulphate (0.1N).

Carbon dioxide (CO_2)

Surface water normally contains less amount of free carbon dioxide as compared to ground water. Free carbon dioxide reacts with sodium hydroxide to form sodium bicarbonate.

To 50 ml of sample, 2 to 3 drops of phenolphthalein are added and titrated against 0.02 N sodium hydroxide. The end point is noted as colour change from pink to colourless.

Calculation for Carbon dioxide:

$$\text{mg } CO_2 \text{ /l} = \frac{B.R. \times N \times 44 \times 1000}{\text{Amount of Sample taken (ml)}}$$

Where, B.R. = Burette reading (Amount of titrant used)

N = Normality of Sodium Hydroxide (0.02 N)

44 = equivalent weight of CO_2

Chloride (Cl^-)

In a neutral or slightly alkaline solution, potassium chromate indicates the end point of the silver nitrate titration of chlorides. Silver chloride is precipitated quantitatively before red silver chromate is formed. To 10ml or 50ml sample 1 ml Potassium Chromate is added as an indicator and titrated against 0.0282 N Silver Nitrate. Red precipitates developed from pale yellow colour indicate end point. When necessary the sample is made colourless by adding the charcoal.

Calculation for Chloride:

$$mg\ Cl^-/l = \frac{A \times N \times 35.45 \times 1000}{\text{Amount of Sample taken (ml)}}$$

Where, A = Burette reading (Amount of titrant used)

N = Normality of Silver Nitrate

35.45 is the equivalent weight of Chloride.

Inorganic non- metallic Constituents

Nitrogen

Total Kjeldahl Nitrogen

The digestion of the sample with Sulphuric acid and potassium sulphate, converts all the organic nitrogen and ammonia into ammonium sulphate. Sodium chloride is added to prevent the partial reduction of nitrate to ammonia which converts the NO_3 into NOCl. The nitrogen in the form of ammonium sulphate can be determined by distillation at higher pH. To estimate N in 10ml or 50 ml of sample in 100 ml Kjeldahl flask 4 ml. H_2SO_4 is added with 10 drops of $CuSO_4$ solution, 6 g of solid potassium sulphate and 1 ml of 10% NaCl solution. The flask is heated on a hot plate to avoid loss through foaming. After the water boils, the sample turns dark due to decomposition of organic matter by H_2SO_4. As the digestion proceeds, the colour of the sample turns pale green. The heating is continued for additional 30 minutes and then the colour developed is measured at 410 nm on a spectrophotometer.

Nitrates (NO_3^-)

Nitrates react with phenol disulfonic acid to form a nitro-derivative which in alkaline medium develops a yellow colour. The concentration of NO_3^- is measured by a spectrophotometric method. An equivalent amount of Silver sulphate solution is added to 10 ml or 50 ml of sample to remove chlorides. The mixture is then slightly heated and the precipitates of AgCl are filtered. The filtrate is evaporated in a porcelain basin to dryness. The contents are diluted with Distilled Water to 50 ml. and cooled. To the dissolved sample 2ml Phenol disulfonic acid and 6 ml of liquid ammonia are added which develops a yellow colour. The intensity of the colour developed is measured at 410 nm in spectrophotometer.

Calculation for Nitrate (NO_3^-):

$$NO_3^-N \text{ mg/l} = \frac{\text{O.D X Factor}}{\text{Amount of Sample taken (ml)}}$$

O.D is Optical Density

Potassium nitrate is used as standard solutions having concentration of 1 ml = 10 µg NO_3^- concentration. Factor is obtained by preparing a standard curve by plotting absorbance of standards of various concentrations against NO_3- N Concentration.

Nitrites (NO_2^-) (Colorimetric Method)

Nitrites (NO_2^-) are determined by diazotizing it with Sulfanilamide and coupling with N-(1-naphthyl)-ethylenediamine dihydrochloride to form highly coloured azo dye that is measured colorimetrically. A correction is made for any NO_2^- present in the sample by analyzing without the reduction step. Thus, Nitrites are determined by the formation of reddish purple azo dye produced at pH 2.0-2.5 with colour reagent.

To estimate Nitrite, 10ml or 50ml of sample was taken in a beaker and 2 ml colour reagent was added to it. The colour developed was read immediately at 543 nm with a spectrophotometer indicating O.D. A standard graph was plotted to obtain factor. A reagent blank was run to set the instrument. Potassium nitrate is used as standard solutions having concentration of 1 ml = 10 µg NO_3^-concentration.

Calculation for nitrite:

$$NO_2^- N \text{ mg/l} = \frac{\text{O.D X Factor}}{\text{Amount of Sample taken (ml)}}$$

O.D is Optical Density

Factor is obtained by preparing a standard curve by plotting absorbance of standards against NO_2- N Concentration. $NaNO_2$ is used as standard solution having concentration of 1 ml = 0.5 µg N concentration.

Inorganic Phosphates

When Ammonium molybdate is added to the sample, molybdophosphoric acid is formed. This is reduced by stannous chloride to intensely coloured molybdenum blue and measured colorimetrically. To measure inorganic phosphates, in a conical flask 50ml of sample is taken to which 4ml strong acid and 4ml of Ammonium molybdate are added followed by 10 drops $SnCl_2$. The blue colour developed is measured after 10 minutes at 690 nm. with a spectrophotometer indicating O.D. Anhydrous KH_2PO_4 is used as standard solution having concentration of 1 ml = 50.0 µg PO_4^{3-}P concentration. A reagent blank is run to set the instrument. Factor is obtained by preparing a standard curve by plotting absorbance of standards against Phosphate concentration.

Calculation for phosphates:

$$\text{Amount of } PO_4^{3-} \text{ as mg/l} = \frac{\text{O.D X Factor}}{\text{Amount of Sample taken (ml)}}$$

O.D is Optical Density

Total Phosphorus

The sample is digested in a flask by the Kjeldahl method mentioned above but without the addition of NaCl. 20 ml of distilled water and 1 drop phenolphthalein are added to the digest. This solution is neutralized by titrating with 5N NaOH to a pink end-point. Determination of phosphorus is done further with the same method used for determination of inorganic phosphorus.

Calculation for phosphates:

$$\text{Amount of } PO_4^{3-} \text{ as mg/l} = \frac{\text{O.D X Factor}}{\text{Amount of Sample taken (ml)}}$$

O.D is Optical Density

Factor is obtained by preparing a standard curve by plotting absorbance of standards against Total Phosphorus (1 ml = 50.0 µg PO_4^{3-}—P) Concentration.

Sulphate (SO_4^{2-}) (Turbidimetric method)

Sulphate ions are precipitated in the form of Barium sulphate by adding Barium chloride in Hydrochloric acid medium. The concentration of the Sulphate can be determined from the absorbance of the light by Barium sulphate and then comparing it with a standard curve. To estimate sulphates, to 10 ml or 50 ml sample 5.0 ml of conditioning reagent is added. The sample is stirred on a magnetic stirrer. While stirring, a spoonful of $BaCl_2$ crystals is added. The intensity of colour developed is measured at 420 nm in a spectrophotometer after 4 minutes.

Calculation for sulphate:

$$SO_4^{2-} \text{ mg/l} = \frac{\text{O.D X Factor}}{\text{Amount of Sample taken (ml)}}$$

Factor is obtained by preparing a standard curve by plotting absorbance of standards against various Sulphate Concentrations.

Soil sampling and methods for estimation of various components of soil

Soil sampling was carried out by quadrat sampling method where a quadrat of size 30 cms x 30 cms was selected randomly. Soil was sub-sampled upto a depth of about 5 cms. with the help of a scoop. Total six sub-samples were collected once in a month. Soil was collected in a plastic bag labeled properly and taken to the laboratory. It was air dried for further analysis as described by Carter and Gregorich, (2008). For the estimation of the level of major soil macronutrients, ***viz.*** nitrogen, phosphorus, calcium and magnesium, the composite soil samples were analysed at the Soil Testing Laboratory at the Faculty of Technology and Engineering, The M.S. University of Baroda, Vadodara. Other parameters like Organic matter and Soil pH were measured in the laboratory as described by Trivedy and Goel, (1984); APHA, (1998).

Analysis of Soil texture was carried out by mechanical analysis as described by Folk (1957), ASTM D3976-92, (2000) and US EPA, (2001). 150, 200 and 250 micrometer sieves were used for this analysis and the results are reported as the percentage in total content in each sample. The classification of soil particles was as follows: coarse sand, 0.5-1 mm; fine sand, 0.02-0.2 mm: silt, 0.002-0.02 mm; clay, <0.002 mm (Michael, 1986). Pearson correlation was carried out between the above mentioned physico-chemical parameters of water and soil using SPSS software 7.5.

Physico-chemical properties and inorganic non-metallic constituents of soil

pH of the soil sample was measured by immersing portable pH meter into the beaker containing sample in which distilled water was added and reading was noted.

Chloride contents were measured in the water extract of soil with the same procedure as used in analysis in water. It was calculated as mg/100g.

Organic matter content (Walkley-Black) method

For the estimation of organic matter content in soil, 0.5 gms of dried soil is weighed. To this10ml of 0.167M K_2Cr_2O7 solution is added. Later, 20 ml of H_2SO_4 solution is added and swirled gently. This mixture is allowed to stand for 30 minutes, after which 200 ml of water is added to the suspension. Into this suspension, 10ml of 85% H_3PO_4 and 1 ml of diphenylamine indicators are added and titrated with 0.4N Ferrous ammonium sulphate solution to attain brilliant green endpoint.

Organic matter (%)= 3.951/gms. of soil sample x (1-T/S) x 1.724

T= Sample titration

S= Blank titration

Statistical analysis

For the convenience of analysis the monthly data is pooled for four seasons. Total 6 visits were made per season at both the water bodies, amounting to 24 visits per site in two years. The four seasons are pre-winter (September to November), winter (December to February), summer (March to May) and monsoon (June to August). The results given are in the form of Mean ± SEM. The data collected for three water bodies are compared as well as seasonal variations at each water body are analyzed using ANOVA (Graph Pad Prism 3 and Excel). The p value is insignificant if $P > 0.05$, significant if $P < 0.05$ (*), significantly significant if $P < 0.001$ (**) and highly significant if $P < 0.0001$ (***) as described by Fowler, J and Cohen, L. (1998). Pearson correlation is carried out to correlate the water quality parameters with each other and soil parameters also with each other at all the three study areas. Pearson correlation was carried out between the above mentioned physico-chemical parameters of water and soil using SPSS software 7.5.

Results

Physico-chemical properties of water

The seasonal variations and differences in inorganic physical, chemical and non-metallic constituents of three reservoirs studied are given in Table 3.1 a, b, c and Fig. 3.1 a, b, c.

At WIR, mean surface *Water temperature* (Table.3.1a) was highest during summer (26.33±0.2^{o}C) and lowest during winter (22.5±0.56^{o}C). During monsoon and post-monsoon water temperatures were 25±0.41^{o}C and 24.33±0.67^{o}C respectively. Significantly significant variations (P< 0.001, $F_{(3,18)}$ 7.52) across the seasons were noted. However, water temperature at TIR was high not only during summer (25.33±0.21^{o}C), but also in monsoon (25.6±0.68^{o}C) as well as post-monsoon (25.5±0.22^{o}C) while low during winter (22.9±0.81^{o}C) also with significantly significant seasonal variations (P< 0.001, $F_{(3,18)}$ 6.12). Similar trend was noted at JIR with almost constant water temperatures during summer (25.83±0.17^{o}C), monsoon (25.2±0.2^{o}C) and post-monsoon (25.4±0.24^{o}C) and lowest during winter (22.17±0.6^{o}C) (P< 0.0001, F $_{(3,18)}$ 21.8). However, No significant difference were noted when comparisons were carried out among the three reservoirs.

At WIR, Mean *Water cover* (Table 3.1a, Fig. 3.1a) was found to be high during post monsoon and winter (90%) while lowest during summer *i.e*. 27%. During monsoon it was 77% (P<0.0001, $F_{(3,18)}$ 24.17). However, at TIR, water cover was maximum during post-monsoon (88%) which decreased in winter (77%) and reached to a minimum level in summer with 36% and increased to 64% during monsoon exhibiting highly significant seasonal variations (P< 0.0001, $F_{(3,19)}$ 8.5). Water cover at JIR followed a trend similar to that of TIR with highest water cover during post-monsoon (87%) followed by winter (78%) and lowest in summer (46%). In monsoon it increased to 65% ($P< 0.001$, $F_{(3,19)}$ 5.85). Water cover also did not show any significant differences among the study sites over all the seasons.

pH of water (Table 3.1a, Fig 3.1a) was always alkaline at the three reservoirs. At WIR, it was high during winter (8.7±0.13) and summer (8.71±0.1) while lowest in monsoon (7.64±0.31). In post-monsoon it was 8.46±0.09 ($P< 0.0001$, $F_{(3,100)}$ 7.27). At TIR, pH was highest during summer (8.81±0.09) which declined in monsoon (7.81±0.19), increased during post-monsoon (8.16±0.11) and was almost maintained in winter (8.21±0.14 mg/l). Highly significant seasonal variations ($P< 0.0001$, $F_{(3,85)}$ 7.93) were recorded. At JIR also trend in pH change was almost similar with high during summer (8.15±0.09), which declined during monsoon (7.31±0.15) and increased during post-monsoon (7.81±0.09) and maintained over winter (7.81±0.12) with highly significant differences ($P< 0.0001$, $F_{(3,96)}$ 7.93). When comparison was carried out among the three reservoirs studied, highly significant differences were noted in summer ($P< 0.0001$, $F_{(2,56)}$ 14.72), post-monsoon ($P< 0.0001$, $F_{(2,78)}$ 11.93) and winter ($P< 0.0001$, $F_{(2,100)}$ 12.11) while No differences were noted during monsoon.

Acidity, (Table 3.1b, Fig 3.1b) was highest during summer (10.4±1.83 mg/l), at WIR, which started decreasing through monsoon (8.0±2.53 mg/l), and post-monsoon (5.29±0.57 mg/l) and was lowest (3.67±0.48 mg/l) in winter. Significantly significant variations were recorded ($P<0.001$, $F_{(3,26)}$ 5.42) over the seasons. At TIR, though, acidity was highest during monsoon (13.00±2.37 mg/l), it declined to 5.67±0.5 mg/l during post-monsoon, increased to 10.55±0.68 mg/l in winter and further declined to 7.57±1.11 mg/l in summer. Significantly significant seasonal variations were noted ($P<0.001$, $F_{(3,33)}$ 5.14). At JIR also, acidity was highest during monsoon (15.5±3.95 mg/l), declined marginally over post-monsoon (14.0±4.03 mg/l) to winter (11.93±1.24

mg/l) and was lowest during summer (4.67±0.67 mg/l) with no significant seasonal differences ($P>0.05$, $F_{(3,56)}$ 0.91). Acidity did not show any significant seasonal differences among the reservoirs except during winter ($P<0.0001$, $F_{(2,50)}$ 10.45).

Hydroxyl alkalinity (Table 3.1b, Fig 3.1b) was highest during summer (9.53±0.99 mg/l), decreased in monsoon (7.71±0.81 mg/l), increased in post-monsoon (8.82±0.83 mg/l) and was maintained in winter (8.26±0.7 mg/l) at WIR with no significant seasonal variations ($P>0.05$, $F_{(3,78)}$ 0.52). Similarly, *Bicarbonate alkalinity* was also highest during summer (109.0±6.52 mg/l), decreased in monsoon (79.27±8.61 mg/l) but increased in post-monsoon (90.67±3.87 mg/l) and winter (97.94±5.29 mg/l) with significant seasonal differences ($P<0.05$, $F_{(3,103)}$ 3.36). At TIR, *Hydroxyl alkalinity* was high during post-monsoon (9.82±0.74 mg/l), winter (9.56±1.56 mg/l) and summer (8.38±0.9 mg/l) while significantly low ($P<0.001$, $F_{(3,83)}$ 5.03) in monsoon (4.82±0.39 mg/l). However, bicarbonate alkalinity was highest during summer (114.0±7.63 mg/l), declined in monsoon (98.4±13.63 mg/l) and post-monsoon (74.4±5.1 mg/l) while increased to 90.59±4.9 mg/l in winter and exhibited highly significant seasonal variation ($P< 0.0001$, $F_{(3,97)}$ 6.89). At JIR, *Hydroxyl alkalinity* was recorded only during summer (16.44±7.77 mg/l) and monsoon (6.8±1.2 mg/l) and hence computed by t-test. No significant differences were found. However, bicarbonate alkalinity was high during summer (156.0±5.32 mg/l), declined through monsoon (126.6±7.96 mg/l) to post-monsoon (79.6±3.23 mg/l) but increased in winter (93.58±8.94 mg/l); ($P< 0.0001$, $F_{(3,81)}$ 22.26). When three reservoirs are compared significantly significant differences for hydroxyl alkalinity ($P<0.001$, $F_{(2,26)}$ 6.29) were noted only during monsoon. The differences in Bicarbonate alkalinity among the three reservoirs were highly significant during summer ($P<0.0001$, $F_{(2,68)}$ 16.78),significantly significant during monsoon ($P<0.001$, $F_{(2,39)}$ 6.53) and significant during post-monsoon ($P<0.05$, $F_{(2,90)}$ 3.29) while no differences were found during winter.

Salinity (Table 3.1a, Fig 3.1a) which depends on chloride content oscillated at WIR with highest levels during winter (104.7±3.75 mg/l) which declined in summer (82.55±7.58 mg/l), increased in monsoon (98.64±9.11 mg/l) and declined again in post-monsoon (86.84±2.85 mg/l) with significant seasonal differences ($P<0.05$, $F_{(3,115)}$ 3.88). At TIR, salinity was highest during monsoon (103.7±3.15 mg/l), declined in post-monsoon (86.95±2.7 mg/l) increased in winter (89.88±2.36 mg/l) as well as in summer reaching to 93.14±5.33 mg/l with significant seasonal variations ($P<0.05$, $F_{(3,98)}$ 3.97). Water at JIR had non significantly higher salinity during post-monsoon (90.22±5.56 mg/l) and winter (91.42±2.56 mg/l) which declined in summer (80.12±3.8 mg/l) and increased in monsoon (85.61±7.65 mg/l) ($P>0.05$, $F_{(3,84)}$ 1.42). Significantly significant differences were noted among the three study sites ($P<0.001$, $F_{(2,90)}$ 6.22) only during winter.

Highest concentrations of *dissolved oxygen* were noted at WIR during winter (9.63±1.36 mg/l) which declined to the lowest during summer (5.55±0.98 mg/l) started increasing in monsoon (8.48±2.15 mg/l) and reached to 9.52±1.63 mg/l in post-monsoon. It showed no significant seasonal variations ($P>0.05$, $F_{(3,103)}$ 1.45). At TIR also, concentrations of dissolved oxygen were highest during winter (9.21±1.83 mg/l), it declined to lowest in summer (5.22±0.98 mg/l), increased to 6.08±1.31 mg/l in monsoon and reached to 8.55±1.16 mg/l in post-monsoon with non significant variations ($P> 0.05$, $F_{(3,100)}$ 1.79). At JIR, concentration of dissolved oxygen was highest during post-monsoon (8.85±1.4 mg/l) which non-significantly declined to 7.67±1.2 mg/l in winter to 4.99±1.06 mg/l in summer and increased marginally 5.3±0.88 mg/l in monsoon; ($P>0.05$, $F_{(3,82)}$ 1.8). No significant seasonal differences were observed in any season when the three reservoirs were compared for concentration of DO in water.

Free Carbon dioxide in water was found to be highest during summer (8.68± 3.26 mg/l) at WIR. It declined in monsoon (3.52±0.45 mg/l), increased in post-monsoon (4.22±0.43 mg/l) and winter (5.33±0.65 mg/l) with no significant seasonal variations ($P > 0.05$, $F_{(3,19)}$ 0.69). At TIR it was recorded in monsoon 3.52±0.00 mg/l, post-monsoon 4.84±0.84 mg/l and winter 4.27±0.36 mg/l but not in summer. No significant seasonal variations ($P > 0.05$, $F_{(2,10)}$ 0.86) were noted. At JIR, also free carbondioxide in water was highest during summer (8.29±0.84 mg/l), it declined in monsoon (5.28±0.56 mg/l) and post-monsoon (4.11±0.59 mg/l) and increased in winter (7.24±1.06 mg/l). No significant seasonal variations ($P > 0.05$, $F_{(3,48)}$ 1.15) were noted. No significant seasonal differences were noted when the three sites were compared.

At WIR, highest *chloride* contents were noted in winter (55.15±2.04 mg/l) and lowest in summer (45.74±4.2 mg/l). While during monsoon and post-monsoon chlorides were 54.65±5.05 mg/l and 48.11±1.58 mg/l respectively and exhibited no significant differences ($P > 0.05$, $F_{(3,109)}$ 2.36). At TIR, highest chloride contents were noted during monsoon (57.46±1.74 mg/l) and lowest in post-monsoon (48.17±1.5 mg/l) while in summer it was 51.6±2.95 mg/l and winter 49.79±1.31 mg/l with significant seasonal variations ($P < 0.05$, $F_{(3,98)}$ 3.97). At JIR highest chloride contents were observed during winter (50.65±1.42 mg/l) which declined in summer (44.39±2.1 mg/l), increased in monsoon (47.43±4.24 mg/l) and in post-monsoon (49.98±3.08 mg/l) with no significant seasonal variations ($P > 0.05$, $F_{(3,84)}$ 1.42). When the three reservoirs were compared highly significant seasonal differences ($P < 0.0001$, $F_{(2,91)}$ 11.4) were noted only during winter.

Sulphate (Table 3.1c, Fig 3.1c) concentrations were highest during monsoon (0.29±0.07 mg/l) at WIR which declined to 0.092±0.02 mg/l in post-monsoon and remained same at 0.093±0.01 mg/l in winter and increased to 0.14±0.02 mg/l in summer and showed highly significant ($P < 0.0001$, $F_{(3,173)}$ 6.56) seasonal variations. In TIR water also, sulphates were highest during monsoon (0.63±0.08 mg/l), declined in post-monsoon (0.19±0.03 mg/l) and winter (0.14±0.01 mg/l) and increased in summer (0.21±0.06 mg/l). Highly significant differences ($P < 0.001$, $F_{(3,90)}$ 23.49) were noted. At JIR, sulphate contents in water oscillated from 0.1±0.03 mg/l in post-monsoon to 0.05±0.003 mg/l in winter, increasing in summer to 0.07±0.02 mg/l and declining marginally in monsoon to 0.06±0.02 mg/l with no significant seasonal variations ($P>0.05$, $F_{(3,75)}$ 2.21). Among the three reservoirs, Sulphates showed highly significant differences during monsoon ($P<0.0001$, $F_{(2,39)}$ 21.55) and winter ($P<0.0001$, $F_{(2,96)}$ 47.83) while significant differences during post-monsoon ($P<0.05$, $F_{(2,74)}$ 4.02) and non significant differences in summer.

The *nitrogen* content estimated by Kjeldahl method was highest during summer (9.1±2.61 mg/l) at WIR, started declining from monsoon (5.86±0.86 mg/l) to post-monsoon (4.01±0.75 mg/l) and reached to the lowest concentration in winter (3.72±0.7 mg/l) with significant seasonal variations ($P < 0.05$, $F_{(3, 65)}$ 3.59). At TIR also, Kjeldahl nitrogen was highest during summer (10.76±3.63 mg/l), decreased in monsoon (6.18±0.81 mg/l) and post-monsoon (4.93±0.95 mg/l), while increased in winter (7.34±1.41 mg/l). No significant seasonal variations ($P >0.05$, $F_{(3, 79)}$ 1.62) were noted over the study period. At JIR, highest concentration of Kjeldahl nitrogen was recorded during post-monsoon (18.1±3.34 mg/l) which decreased in winter (15.25±1.95 mg/l) and summer (11.24±1.81 mg/l) and reached to the lowest in monsoon (9.22±1.76 mg/l). Significant seasonal variations ($P <0.05$, $F_{(3, 70)}$ 2.98) were recorded. Significant differences at P<0.001, $F_{(2,35)}$ 5.85, P<0.0001, $F_{(2,44)}$ 9.53, and P<0.0001, $F_{(2,60)}$ 21.6 while non-significant differences with $F_{(2,46)}$ 0.16 were noted during monsoon, post-monsoon, winter and summer respectively when differences among the three reservoirs for Kjeldahl Nitrogen were compared.

High *nitrite* concentrations were noted at WIR during monsoon (0.02±0.004 mg/l) which declined in post-monsoon (0.003±0.001 mg/l) while were maintained in winter (0.004±0.001 mg/l) and started increasing in summer (0.013±0.002mg/l). Highly significant variations (P < 0.0001, $F_{(3, 108)}$ 14.28) were noted during the study period. At TIR, high nitrite concentrations were noted during summer (0.013±0.002 mg/l) and monsoon (0.017±0.002 mg/l). It decreased in post-monsoon (0.008±0.001 mg/l) which was maintained in winter (0.008±0.001 mg/l) with highly significant seasonal variations (P <0.0001, $F_{(3, 97)}$ 8.71). At JIR, higher nitrite concentrations were noted during summer (0.009±0.002 mg/l) and monsoon (0.01±0.003 mg/l) while lower during post-monsoon (0.003±0.001 mg/l) and winter (0.002±0.0004 mg/l) with significantly significant variations (P < 0.001, $F_{(3, 74)}$ 5.62). During comparison among the three study sites, highly significant differences were noted only during post-monsoon (P<0.0001, $F_{(2,74)}$ 8.25) and winter (P<0.0001, $F_{(2,80)}$ 16.08).

The concentration of *Nitrate,* the third nitrogen derivative, in WIR water was 0.018±0.002 mg/l during summer, 0.013±0.001 mg/l in monsoon, 0.009±0.001 mg/l in post-monsoon and 0.015±0.002 mg/l in winter (P < 0.001, $F_{(3, 58)}$ 5.35). At TIR, nitrate concentrations during summer were 0.03±0.01 mg/l, in monsoon 0.01±0.002 mg/l, in post-monsoon 0.006±0.001 mg/l and in winter 0.014±0.003 mg/l. Highly significant seasonal variations (P < 0.0001, $F_{(3, 57)}$ 15.18) were recorded during the study period. At JIR, highest nitrate concentrations were recorded during post-monsoon (0.05±0.01 mg/l) which declined in winter (0.02±0.003 mg/l) but increased in summer (0.04±0.01 mg/l) and decreased again in monsoon (0.02±0.004 mg/l) with significantly significant seasonal variations (P < 0.001, $F_{(3, 46)}$ 6.1). Significant seasonal differences were noted in nitrate concentrations during summer (P<0.05, $F_{(2,35)}$ 4.3) and monsoon (P<0.05, $F_{(2,43)}$ 3.78) between the three reservoirs. However, in post-monsoon highly significant (P<0.0001, $F_{(2,47)}$ 36.59) and in winter non significant differences were noted.

Total phosphorus was high at WIR during post-monsoon (0.18±0.02 mg/l), it decreased in winter (0.12±0.02 mg/l), increased in summer (0.14±0.02 mg/l) and decreased again in monsoon (0.08±0.02 mg/l) but showed no significant (P>0.05, $F_{(3,79)}$ 2.3) seasonal variations. Similarly, total phosphorus was highest during post-monsoon (0.18±0.03 mg/l) at TIR, it declined significantly in winter (0.04±0.01 mg/l), increased in summer (0.11±0.02 mg/l) and decreased again in monsoon (0.06±0.02 mg/l (P< 0.001, $F_{(3,90)}$ 5.33). In JIR water also, total phosphorus were high during post-monsoon (0.32±0.03 mg/l) which declined in winter (0.18±0.02 mg/l) and was maintained in summer (0.17±0.02 mg/l) and monsoon (0.17±0.04 mg/l) with highly significant seasonal variations (P< 0.0001, $F_{(3,80)}$ 6.52). Total phosphorus was overall higher in JIR water but differences among the reservoirs were non significant except during winter when it was highly significant (P<0.0001, $F_{(2,76)}$ 14.18).

At WIR *Inorganic phosphates* were high during monsoon (0.1±0.03 mg/l) and low during post-monsoon (0.03±0.01 mg/l) and winter (0.02±0.01 mg/l) and summer (0.04±0.01 mg/l) and exhibited seasonal variations at P>0.0001, ($F_{(3,168)}$ 7.05). However, at TIR, highest concentrations of inorganic phosphates were recorded during summer (0.15±0.02 mg/l) followed by monsoon (0.11±0.03 mg/l), winter (0.07±0.01 mg/l) and lowest in post-monsoon (0.05±0.01 mg/l) and showed significantly significant (P< 0.001, $F_{(3,103)}$ 5.11) seasonal variations. In JIR water inorganic phosphates were almost maintained during summer (0.07±0.02 mg/l), monsoon (0.07±0.02 mg/l), and post-monsoon (0.08±0.02 mg/l) while it decreased insignificantly in winter (0.05±0.01 mg/l); ($P>0.05$, $F_{(3,82)}$ 0.67). When the three sites were compared, highly significant seasonal differences were noted during summer and winter with $P<0.0001$, ($F_{(2,132)}$ 22.48 and, $F_{(2,92)}$ 7.67 respectively) while significant differences were noted in post-monsoon with $P<0.05$, $F_{(2,73)}$ 4.34. The differences in the monsoon were non-significant.

Physico-chemical properties of soil

Soil texture (Table 3.2a) was classified into % Coarse sand, % Fine sand, % Very fine sand and % Silt+clay, % coarse sand at WIR, was highest during post-monsoon (45%) while in summer, monsoon and winter it was almost same with 40%, 41% and 39% respectively with no significant seasonal variations ($P>0.05$, $F_{(3,18)}$ 4.04). At TIR, however it was recorded to be high during winter with 39% and, post-monsoon with 37%, while low during summer and monsoon at 35% and 34% respectively with a significant seasonal variations ($P<0.05$, $F_{(3,18)}$ 5.3). In JIR soil, percentage of coarse sand was high during monsoon (41%), which declined in post-monsoon (36%) through winter (34%) and was low during summer (26%). JIR also showed significant seasonal differences ($P<0.05$, $F_{(3,18)}$ 5.4). When differences in % coarse sand was compared at the three study sites, the difference was significantly significant in summer ($P<0.001$, $F_{(2,15)}$ 24.57) and monsoon ($P<0.001$, $F_{(2,11)}$ 18.0) while significant ($P<0.05$, $F_{(2,14)}$ 9.36) in post-monsoon and non-significant in winter.

Fine sand particles showed significant differences among the three reservoirs. However, at WIR, it was high during summer (35%) and winter (36%) and low during monsoon (30%) while in post-monsoon it was 33% with significant seasonal differences ($P<0.05$, $F_{(3,18)}$ 4.85). At TIR also it was highest during summer (46%) but low during monsoon (44%). In post-monsoon and winter it was recorded at 44 % and 45% respectively, without any significant seasonal variations (P>0.05, $F_{(3,18)}$ 0.28). JIR also recorded highest percentage of fine sand particles during summer at 52% while in monsoon, post-monsoon and winter 46%, 46% and 46% of fine sand was recorded without significant seasonal variations (P>0.05, $F_{(3,18)}$ 0.5). The differences in % fine sand at the three study sites were significantly significant at (P<0.001, $F_{(2,15)}$ 22.1) in summer, highly significant (P<0.0001, $F_{(2,11)}$ 31.22) in monsoon and (P<0.0001, $F_{(2,14)}$ 32.15) post-monsoon while non significant in winter.

The percentage distribution of very fine sand particles was lower than that of the other sediment gradients. It was highest 17% at WIR during winter and lowest 14% during post-monsoon. In summer and monsoon it was 16% each. No significant seasonal variations were recorded at WIR (P>0.05, $F_{(3,18)}$ 2.33). TIR soil recorded high contents of very fine soil during summer, monsoon and post-monsoon was almost similar with 9% and no significant seasonal variations (P>0.05, $F_{(3,18)}$ 2.22). However, at JIR it was 13% during winter, 9% and 8% during summer and monsoon respectively and lowest 6% during post-monsoon without any significant seasonal variations (P>0.05, $F_{(3,18)}$ 1.03). When seasonal differences in % very fine sand was compared at the three study sites, during summer (P<0.0001, $F_{(2,15)}$ 56.73) highly significant differences and during monsoon (P<0.001, $F_{(2,11)}$ 24.61) and post-monsoon significantly significant (P<0.001, $F_{(2,14)}$ 26.03) differences were noted while during winter the differences were non-significant.

Percent of silt+clay was recorded to be highest during monsoon at WIR at 13%. While 8%, 8% and 7% of silt+clay was recorded during summer, post-monsoon and winter respectively with highly significant seasonal variations (P<0.0001, $F_{(3,18)}$ 16.23). TIR also had high percentile of silt and clay particles during monsoon with

13%, while 10% 10% and 8% were recorded during summer, post-monsoon and winter respectively with significant seasonal differences (P<0.05, $F_{(3,18)}$ 4.62). JIR soil exhibited a different trend with high silt + clay content during summer (11%) and post-monsoon (11%) and lower contents during monsoon (5%) and winter (6%). No significant seasonal differences were recorded (P>0.05, $F_{(3,18)}$ 3.55). % silt and clay showed significantly significant seasonal differences at the three study sites only during monsoon (P<0.001, $F_{(2,11)}$ 23.72).

pH of soil (Table 3.2b, Fig 3.2a) at the three reservoirs was alkaline across the seasons. It was maximum during monsoon (8.13±0.45), which decreased in post-monsoon (7.05±0.09), increased in winter (7.95±0.16) and decreased again in summer (7.38±0.2) with significant seasonal variations (P<0.05, $F_{(3, 18)}$ 3.64). At TIR also, soil was more basic during monsoon (8.25±0.46), winter (7.85±0.25), in summer (7.45±0.09) and while towards neutral in post-monsoon (7.05±0.0.03) with significant seasonal variations (P<0.05, $F_{(3, 18)}$ 3.79). pH of JIR soil also oscillated in similar pattern with maximum during monsoon (7.93±0.42), which declined in post-monsoon (7.18±0.12), increased in winter (7.8±0.43) and again declined in summer (7.55±0.06) but without any significance (P>0.05, $F_{(3, 18)}$ 1.15). No significant differences were noted for pH at the three study areas during four seasons.

Low percent of *organic matter* in WIR soil were recorded during summer (2%) and monsoon (2%) while higher during post-monsoon (4%) as the monsoon was over it started building up. In winter it was 3% with no significant seasonal variations (P>0.05, $F_{(3, 18)}$ 0.98). The organic matter also varied without any significant variations (P>0.05, $F_{(3, 18)}$ 1.64) at TIR with high amounts during winter (4%) and low in monsoon (2%). It was 3% in summer and 3% in post-monsoon. JIR soil had the highest amounts of organic matter during winter (8%) followed by summer (5%). It was lowest 3% in monsoon while 4% in post-monsoon. No significant seasonal variations (P>0.05, $F_{(3, 18)}$ 2.94) were noted. Organic matter did not showed any significant seasonal differences when comparison between the study sites was made.

Some of the inorganic non metallic ions important for various animals are *Calcium* and *magnesium* (Table 3.2b, fig 3.2b). Concentrations of calcium were maximum in WIR soil during winter (44.0±12.13 mg/100g) followed by summer (39.15±5.69 mg/100g), monsoon (35.75±3.47 mg/100g) and post-monsoon (27.78±3.67 mg/100g). However, no significant variations (P>0.05, $F_{(3, 18)}$ 0.91) were noted. Highest magnesium concentrations were also noted during winter (32.25±13.33 mg/100g), followed by summer (15.08±2.37 mg/100g). It declined further in monsoon (10.43±0.34 mg/100g) but increased in post-monsoon (13.48±0.06 mg/100g) without any significant seasonal variations (P>0.05, $F_{(3, 18)}$ 2.1). At TIR also, Calcium concentrations were maximum during winter (62.5±14.57 mg/100g), followed by summer (34.18±7.55 mg/100g), monsoon (30±1.16 mg/100g) and post-monsoon (26.88±3.61 mg/100g) but with significant seasonal variations ($P < 0.05$, $F_{(3, 18)}$ 3.77). Here, also magnesium was highest during winter (34.25±16.92 mg/100g), declined in summer (14.43±2.16 mg/100g) and monsoon (13.53±2.17 mg/100g) and increased in post-monsoon (19.58±2.19 mg/100g) without any significant variations ($F_{(3, 18)}$ 1.22). At JIR also the calcium concentrations were maximum during winter (33.67±13.42 mg/100g), which declined in summer (27.03±1.0 mg/100g) and monsoon (27.0 ±3.72 mg/100g) and increased in post-monsoon (32.25±3.07 mg/100g). No significant variations (P>0.05, $F_{(3, 17)}$ 0.35) were noted. Here, Magnesium content was high during post-monsoon (26.25±2.99 mg/100g) which declined in winter (13.0±1.53 mg/100g). In summer it increased to 17.5±4.09 mg/100g and again declined to 10.90±4.65 mg/100g in monsoon. No significant seasonal variations (P>0.05, $F_{(3, 17)}$

3.41) were noted. The differences in the seasonal comparisons at the three study areas were non-significant for calcium, while significantly significant ($P < 0.001$, $F_{(2, 14)}$ 8.67) for magnesium only during post monsoon.

Highest concentration of *total nitrogen* in WIR soil was noted during summer (123±21.68 mg/100g), followed by monsoon (53.5±14.93 mg/100g) and lowest in post-monsoon (18.0±2.27 mg/100g) which were maintained in winter (19.5±4.11 mg/100g). Highly significant seasonal variations ($P < 0.0001$, $F_{(3, 18)}$ 13.51) were noted during the study period. In TIR soil also, Total nitrogen was maximum during summer (77.2±13.82 mg/100g) followed by monsoon (35.75±6.005 mg/100g), minimum during post-monsoon (24.3±2.1 mg/100g) and 30.2±8.47 mg/100g in winter. Significantly significant seasonal variations ($P < 0.001$, $F_{(3, 18)}$ 7.61) were recorded. At JIR also, total nitrogen was maximum during summer (88.08±27.27 mg/100g) followed by monsoon (47.63±6.71 mg/100g) and it declined further in post-monsoon (30.0±0.0 mg/100g) but increased in winter (33.33±8.11 mg/100g). No significant seasonal differences ($P>0.05$, $F_{(3, 17)}$ 3.05) were noted. Total nitrogen did not show any significant seasonal variations when the three sites were compared except during post-monsoon ($P<0.001$, $F_{(2,14)}$ 11.47).

Total phosphorus concentrations in WIR soil was 6.93±6.03 mg/100g during summer, which decreased in monsoon (1.3±0.58 mg/100g) and was almost maintained in post-monsoon (2.68±0.69 mg/100g) and winter (1.4±0.63 mg/100g). No significant seasonal variations ($P>0.05$, $F_{(3, 18)}$ 0.74) were observed during the study period. However, significantly significant seasonal variations ($P < 0.001$, $F_{(3, 18)}$ 7.2) were noted for phosphorus concentrations of soil only at TIR. Here, highest concentrations were noted during summer (15.95±3.02 mg/100g) which declined in monsoon (4.13±2.12 mg/100g) and post-monsoon (3.21±1.06 mg/100g) and were maintained in winter (3.18±2.63 mg/100g). At JIR, also highest concentrations for total phosphorus were noted during summer (8.9±7.81 mg/100g) which decreased by monsoon (3.15±1.92 mg/100g) and post-monsoon (3.01±0.89 mg/100g) to lowest in winter (1.07±0.42 mg/100g) but with no significant seasonal variations ($P>0.05$, $F_{(3, 17)}$ 0.6). Differences among the three reservoirs were not significant in all seasons when the phosphate levels in waters were compared.

Correlations between physico-chemical parameters of water

As shown in Table 3.3, 3.4 and 3.5 majority of abiotic factors studied in relation to water showed variable correlations at the three reservoirs. Acidity was correlated with Nitrites positively at the level of 0.01 at all the three reservoirs. Further, it was correlated positively with free CO_2 at the level of 0.01 at WIR and TIR, while at 0.05 at JIR, with Kjeldahl nitrogen at 0.01 only at WIR and TIR while with bicarbonate alkalinity at TIR at 0.01 and JIR at 0.05 levels. Only at TIR it was correlated positively at 0.01. Salinity was negatively correlated with acidity at 0.01 levels only at WIR and JIR.

Chlorides were positively correlated with water cover at JIR (0.01) and WIR (0.05). Correlations of chlorides with other parameters at the three reservoirs were variable. Dissolved oxygen showed positive correlation with water cover at WIR and TIR (0.01) and with total phosphorus at TIR (0.05) and JIR (0.01), while negative correlation with nitrate at 0.01 levels at TIR and 0.05 levels at JIR. CO_2 was positively correlated with sulphates at 0.01 at WIR and TIR. The correlations with CO_2 were positively significant at JIR with several parameters like Inorganic phosphates, Nitrate, pH and Temperature whereas no significant correlations could be found at other two reservoirs.

Bicarbonate alkalinity was negatively correlated with total phosphate at 0.01at WIR while positively at TIR. However, it was positively correlated with inorganic phosphates at 0.05 at WIR as well as TIR, with Sulphates at 0.01 at WIR while at 0.05 levels at other two reservoirs and with Nitrites at JIR at 0.01 and TIR at 0.05 levels.

Inorganic phosphates, Nitrates, Nitrites Hydroxyl alkalinity and pH were variably correlated with the other abiotic factors of water at the three reservoirs. Hence no common correlation could be established. However, Kjeldahl nitrogen was positively correlated at 0.01 with sulphates at both WIR and TIR while with nitrates at 0.01 at TIR and 0.05 at WIR. While with Nitrite at 0.01 only at WIR. Salinity and sulphates are correlated negatively only with temperature at 0.05 at WIR, while temperature is correlated negatively (0.01) with water cover at the same reservoirs.

Correlations between physico-chemical parameters of soil (Table 3.6, 3.7, 3.8)

As noted for water the common correlations in abiotic parameters of soil could not be established at the three reservoirs except for total nitrogen and total phosphates which were correlated positively at the level of 0.01. Among other correlations magnesium was correlated with calcium positively at 0.01 at TIR and 0.05 at WIR, pH at 0.05 at WIR and JIR, Chloride with total nitrogen positively at 0.01 at TIR and 0.05 at other two reservoirs while Organic matter correlated positively with pH at WIR and TIR (0.05).

Table 3.1a. Seasonal variations and differences in water temperature, water cover, pH acidity and alkalinity of water at the three irrigation reservoirs

Parameters	Seasons	WIR	TIR	JIR	Significance between 3 sites
Water Temp (°C)	**Summer**	26.33±0.2	25.33±0.21	25.83±0.17	ns; $F_{(2,15)}$ 1.67
	Monsoon	25.0±0.41	25.6±0.68	25.2±0.2	ns; $F_{(2,11)}$ 0.39
	Post-mon	24.33±0.67	25.5±0.22	25.4±0.24	ns; $F_{(2,14)}$ 2.14
	Winter	22.5±0.56	22.9±0.81	22.17±0.6	ns; $F_{(2,14)}$ 0.31
		**; $F_{(3,18)}$ 7.52	**; $F_{(3,18)}$ 6.12	***; $F_{(3,18)}$ 21.8	
Percent Water cover	**Summer**	27.5±7.27	36.67±5.11	46.67±9.09	ns; $F_{(2,15)}$ 1.7
	Monsoon	77.5±11.64	64.0±14.09	65.0±12.45	ns; $F_{(2,11)}$ 0.31
	Post-mon	90.0±4.28	88.3±5.27	87.50±3.09	ns; $F_{(2,15)}$ 0.09
	Winter	90.83±2.71	77.5±6.02	78.0±2.0	ns; $F_{(2,15)}$ 3.26
		***; $F_{(3,18)}$ 24.17	***; $F_{(3,19)}$ 8.5	**; $F_{(3,19)}$ 5.85	
pH	**Summer**	8.71±0.10	8.81±0.09	8.15±0.09	***; $F_{(2,56)}$ 14.72
	Monsoon	7.64±0.31	7.81±0.19	7.31±0.15	ns; $F_{(2,47)}$ 1.68
	Post-mon	8.46±0.09	8.16±0.11	7.81±0.09	***; $F_{(2,78)}$ 11.93
	Winter	8.7±0.13	8.21±0.14	7.81±0.12	***; $F_{(2,100)}$ 12.11
		***; $F_{(3,100)}$ 7.27	***; $F_{(3,85)}$ 7.93	***; $F_{(3,96)}$ 7.93	
Acidity (mg $CaCO_3$/l)	**Summer**	10.4±1.83	7.57±1.11	4.67±0.67	ns; $F_{(2,12)}$ 3.13
	Monsoon	8.0±2.53	13.00±2.37	15.5±3.95	ns; $F_{(2,25)}$ 1.02
	Post-mon	5.29±0.57	5.67±0.5	14.0±4.03	ns; $F_{(2,28)}$ 2.28
	Winter	3.67±0.48	10.55±0.68	11.93±1.24	***; $F_{(2,50)}$ 10.45
		**; $F_{(3,26)}$ 5.42	**; $F_{(3,33)}$ 5.14	ns; $F_{(3,56)}$ 0.91	
Hydroxyl alkalinity (mg $CaCO_3$/l)	**Summer**	9.53±0.99	8.38±0.9	16.44±7.77	ns; $F_{(2,47)}$ 2.04
	Monsoon	7.71±0.81	4.82±0.39	6.8±1.2	**; $F_{(2,26)}$ 6.29
	Post-mon	8.82±0.83	9.82±0.74	0.0±0.0	ns; t=0.91
	Winter	8.26±0.7	9.56±1.56	0.0±0.0	ns; t=0.87
		ns; $F_{(3,78)}$ 0.52	**; $F_{(3,83)}$ 5.03	ns; t=0.91	
Bicarbonate alkalinity (mg $CaCO_3$/l)	**Summer**	109.0±6.52	114.0±7.63	156.0±5.32	***; $F_{(2,68)}$ 16.78
	Monsoon	79.27±8.61	98.4±13.63	126.6±7.96	**; $F_{(2,39)}$ 6.53
	Post-mon	90.67±3.87	74.4±5.1	79.6±3.23	*; $F_{(2,90)}$ 3.29
	Winter	97.94±5.29	90.59±4.9	93.58±8.94	ns; $F_{(2,84)}$ 0.37
		*; $F_{(3,103)}$ 3.36	***; $F_{(3,97)}$ 6.89	***; $F_{(3,81)}$ 22.26	

*** For ANOVA,* P< 0.05, **P< 0.001, *** P < 0.0001; + For t-test, + P< 0.05, ++P< 0.001, +++ P < 0.0001**

Table 3.1b. Seasonal variations and differences in DO, Free CO_2, salinity and chloride content of water at the three irrigation reservoirs

Parameters	Seasons	WIR	TIR	JIR	Significance between 3 sites
DO (mg/l)	Summer	5.55±0.98	5.22±0.98	4.99±1.06	ns; $F_{(2,55)}$ 0.07
	Monsoon	8.48±2.15	6.08±1.31	5.3±0.88	ns; $F_{(2,57)}$ 1.22
	Post-mon	9.52±1.63	8.55±1.16	8.85± 1.4	ns; $F_{(2,76)}$ 0.14
	Winter	9.63±1.36	9.21±1.83	7.67±1.2	ns; $F_{(2,97)}$ 0.55
		ns; $F_{(3,103)}$ 1.45	ns; $F_{(3,100)}$1.79	ns; $F_{(3,82)}$ 1.8	
Free CO_2 (mg/l)	Summer	8.68±7.14	0.0±0.0	8.29±0.84	ns; t=0.11
	Monsoon	3.52±0.45	3.52±0.0	5.28±0.56	ns; $F_{(2,10)}$ 3.85
	Post-mon	4.22±0.43	4.84±0.84	4.11±0.59	ns; $F_{(2,9)}$ 0.37
	Winter	5.33±0.65	4.27±0.36	7.24±1.06	ns; $F_{(2,38)}$ 1.49
		ns; $F_{(3,19)}$ 0.69	ns; $F_{(2,10)}$ 0.86	ns; $F_{(3,48)}$ 1.15	
Salinity (mg/l)	Summer	82.55±7.58	93.14±5.33	80.12±3.8	ns; $F_{(2,72)}$ 1.5
	Monsoon	98.64±9.11	103.7±3.15	85.61±7.65	ns; $F_{(2,59)}$ 1.75
	Post-mon	86.84±2.85	86.95±2.7	90.22±5.56	ns; $F_{(2,76)}$ 0.24
	Winter	104.7±3.75	89.88±2.36	91.42±2.56	**; $F_{(2,90)}$ 6.22
		*; $F_{(3,115)}$ 3.88	*; $F_{(3,98)}$ 3.97	ns; $F_{(3,84)}$ 1.42	
Chloride (mg/l)	Summer	45.74±4.2	51.6±2.95	44.39±2.1	ns; $F_{(2,72)}$ 1.5
	Monsoon	54.65±5.05	57.46±1.74	47.43±4.24	ns; $F_{(2,59)}$ 1.75
	Post-mon	48.11±1.58	48.17±1.5	49.98±3.08	ns; $F_{(2,77)}$ 0.48
	Winter	55.15±2.04	49.79±1.31	50.65±1.42	***; $F_{(2,91)}$ 11.4
		ns; $F_{(3,109)}$ 2.36	*; $F_{(3,98)}$ 3.97	ns; $F_{(3,84)}$ 1.42	

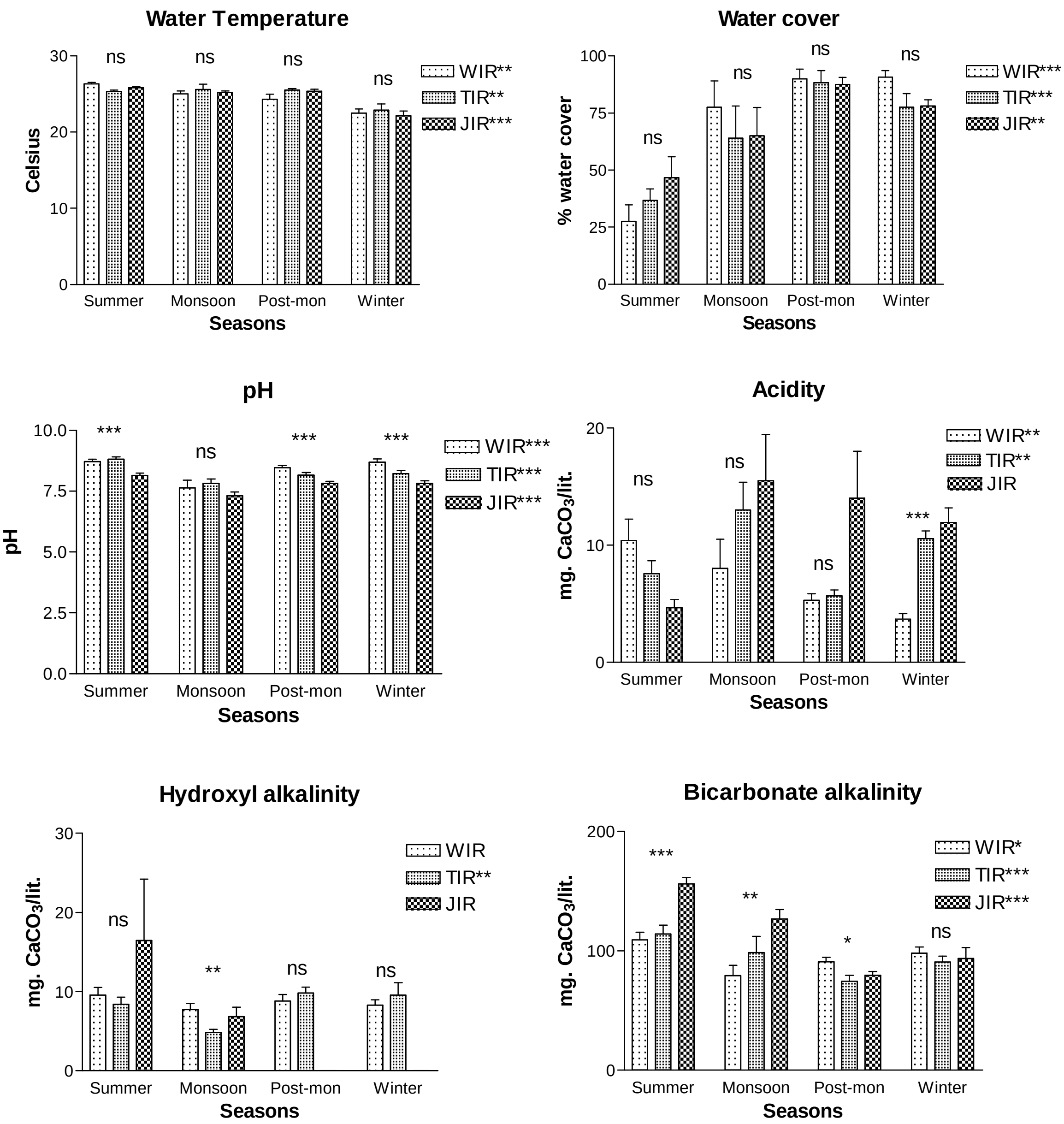
*** For ANOVA,* P< 0.05, **P< 0.001, *** P < 0.0001; + For t-test, + P< 0.05, ++P< 0.001, +++ P < 0.0001**

Table 3.1c. Seasonal variations and differences among the inorganic non-metallic constituents of water at the three irrigation reservoirs

Parameters	Seasons	WIR	TIR	JIR	Significance between 3 sites
Sulphate (mg/l)	**Summer**	0.14±0.02	0.21±0.06	0.07±0.02	ns; $F_{(2,129)}$ 2.91
	Monsoon	0.29±0.07	0.63±0.08	0.06±0.02	***; $F_{(2,39)}$ 21.55
	Post-mon	0.092±0.02	0.19±0.03	0.1±0.03	*; $F_{(2,74)}$ 4.02
	Winter	0.093±0.01	0.14±0.01	0.05±0.003	***; $F_{(2,96)}$ 47.83
		***; $F_{(3,173)}$ 6.56	***; $F_{(3,90)}$ 23.49	ns; $F_{(3,75)}$ 2.21	
Kjeldahl Nitrogen (mg/l)	**Summer**	9.1±2.61	10.76±3.63	11.24±1.81	ns; $F_{(2,46)}$ 0.16
	Monsoon	5.86±0.86	6.18±0.81	9.22±1.76	**; $F_{(2,35)}$ 5.85
	Post-mon	4.01±0.75	4.93±0.95	18.1±3.34	***; $F_{(2,44)}$ 9.53
	Winter	3.72±0.7	7.34±1.41	15.25±1.95	***; $F_{(2,60)}$ 21.6
		*; $F_{(3,65)}$ 3.59	ns; $F_{(3,79)}$ 1.62	*; $F_{(3,70)}$ 2.98	
Nitrite (mg/l)	**Summer**	0.013±0.002	0.013±0.002	0.009±0.002	ns; $F_{(2,68)}$ 0.86
	Monsoon	0.02±0.004	0.017±0.002	0.01±0.003	ns; $F_{(2,57)}$ 0.77
	Post-mon	0.003±0.001	0.008±0.001	0.003±0.001	***; $F_{(2,74)}$ 8.25
	Winter	0.004±0.001	0.008±0.001	0.002±0.0004	***; $F_{(2,80)}$ 16.08
		***; $F_{(3,108)}$ 14.28	***; $F_{(3,97)}$ 8.71	**; $F_{(3,74)}$ 5.62	
Nitrate (mg/l)	**Summer**	0.018±0.002	0.03±0.01	0.04±0.01	*; $F_{(2,35)}$ 4.3
	Monsoon	0.013±0.001	0.01±0.002	0.02±0.004	*; $F_{(2,43)}$ 3.78
	Post-mon	0.009±0.001	0.006±0.001	0.05±0.01	***; $F_{(2,47)}$ 36.59
	Winter	0.015±0.002	0.014±0.003	0.02±0.003	ns; $F_{(2,36)}$ 2.24
		**; $F_{(3,58)}$ 5.35	***; $F_{(3,57)}$ 15.18	**; $F_{(3,46)}$ 6.1	
Total Phosphorus (mg/l)	**Summer**	0.14±0.02	0.11±0.02	0.17±0.02	ns; $F_{(2,47)}$ 1.36
	Monsoon	0.08±0.02	0.06±0.02	0.17±0.04	ns; $F_{(2,48)}$ 3.12
	Post-mon	0.18±0.02	0.18±0.03	0.32±0.03	ns; $F_{(2,73)}$ 4.46
	Winter	0.12±0.02	0.04±0.01	0.18±0.02	***; $F_{(2,76)}$ 14.18
		ns; $F_{(3,79)}$ 2.3	**; $F_{(3,90)}$ 5.33	***; $F_{(3,80)}$ 6.52	
Inorganic Phosphates (mg/l)	**Summer**	0.04±0.01	0.15±0.02	0.07±0.02	***; $F_{(2,132)}$ 22.48
	Monsoon	0.1±0.03	0.11±0.03	0.07±0.02	ns; $F_{(2,49)}$ 0.72
	Post-mon	0.03±0.01	0.05±0.01	0.08±0.02	*; $F_{(2,73)}$ 4.34
	Winter	0.02±0.01	0.07±0.01	0.05±0.01	***; $F_{(2,92)}$ 7.67
		***; $F_{(3,168)}$ 7.05	**; $F_{(3,103)}$ 5.11	ns; $F_{(3,82)}$ 0.67	

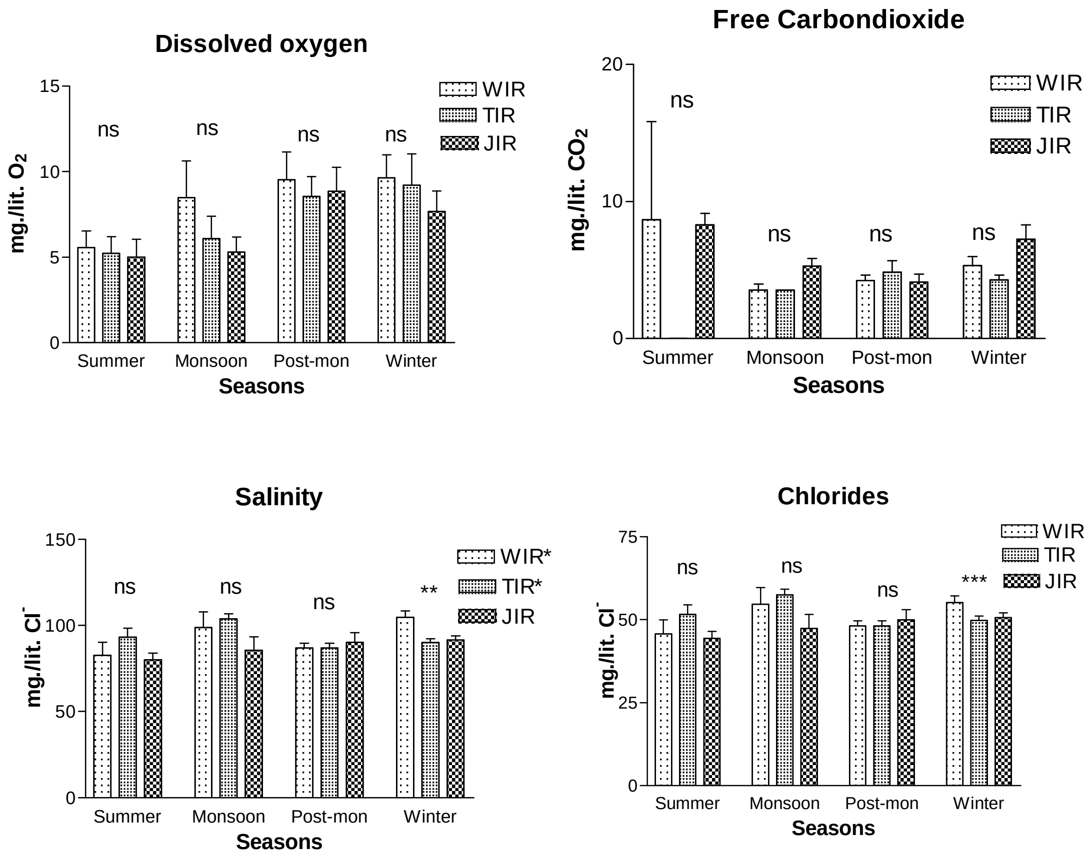
*** For ANOVA,* P< 0.05, **P< 0.001, *** P < 0.0001; + For t-test, + P< 0.05, ++P< 0.001, +++ P < 0.0001**

Fig. 3.1a. Seasonal variations in water temperature, water cover, pH acidity and alkalinity of water at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR).



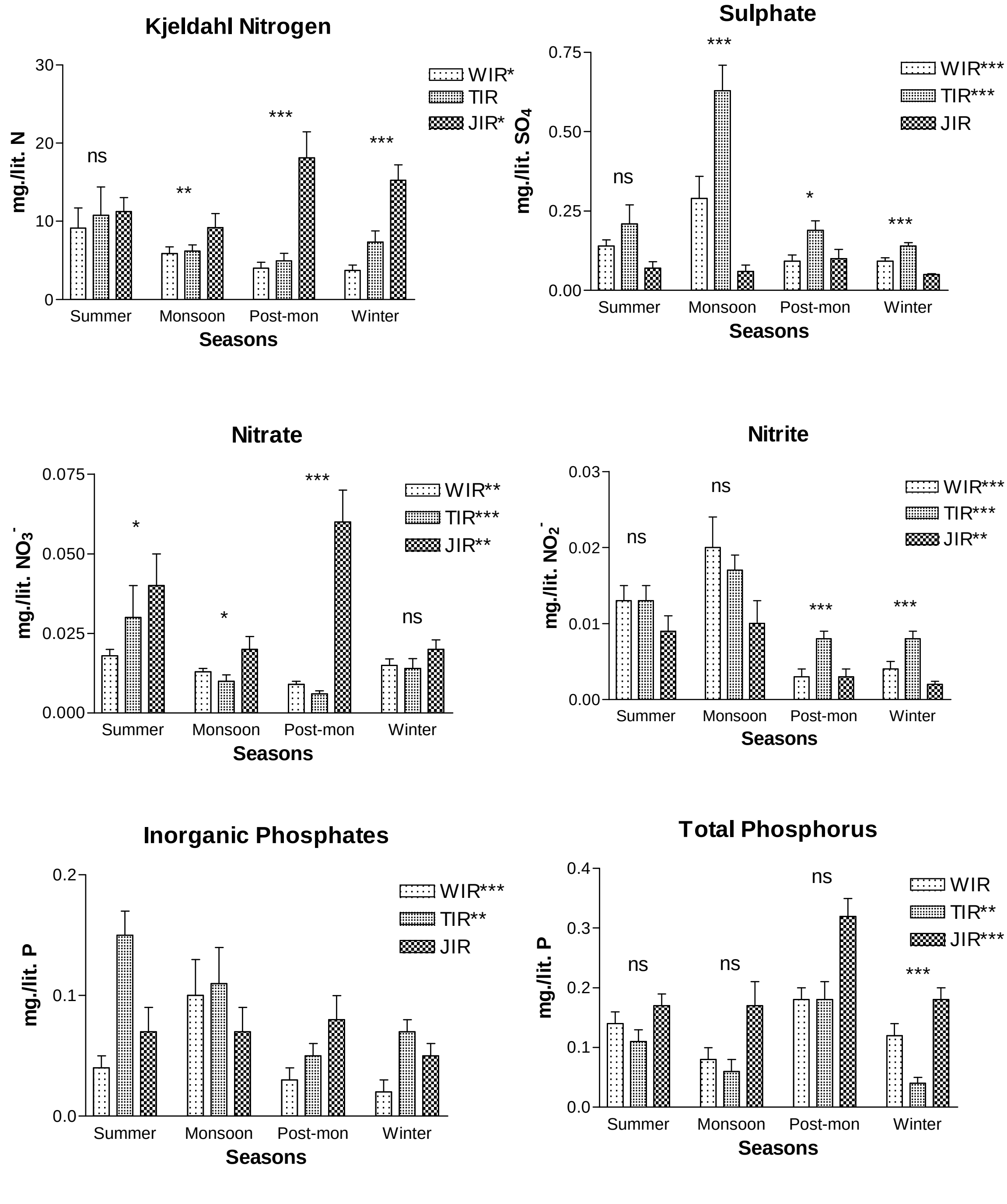
*** For ANOVA, * P< 0.05, **P< 0.001, *** P < 0.0001; + For t-test, + P< 0.05, ++P< 0.001, +++ P < 0.0001**

Fig. 3.1b. Seasonal variations in DO, Free CO_2, Salinity and Chlorides of water at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR).



*** For ANOVA, * P< 0.05, **P< 0.001, *** P < 0.0001; + For t-test, + P< 0.05, ++P< 0.001, +++ P < 0.0001**

Fig. 3.1c. Seasonal variations in inorganic non-metallic constituents of water at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR).



*** For ANOVA, * $P < 0.05$, **$P < 0.001$, *** $P < 0.0001$; + For t-test, + $P < 0.05$, ++$P < 0.001$, +++ $P < 0.0001$**

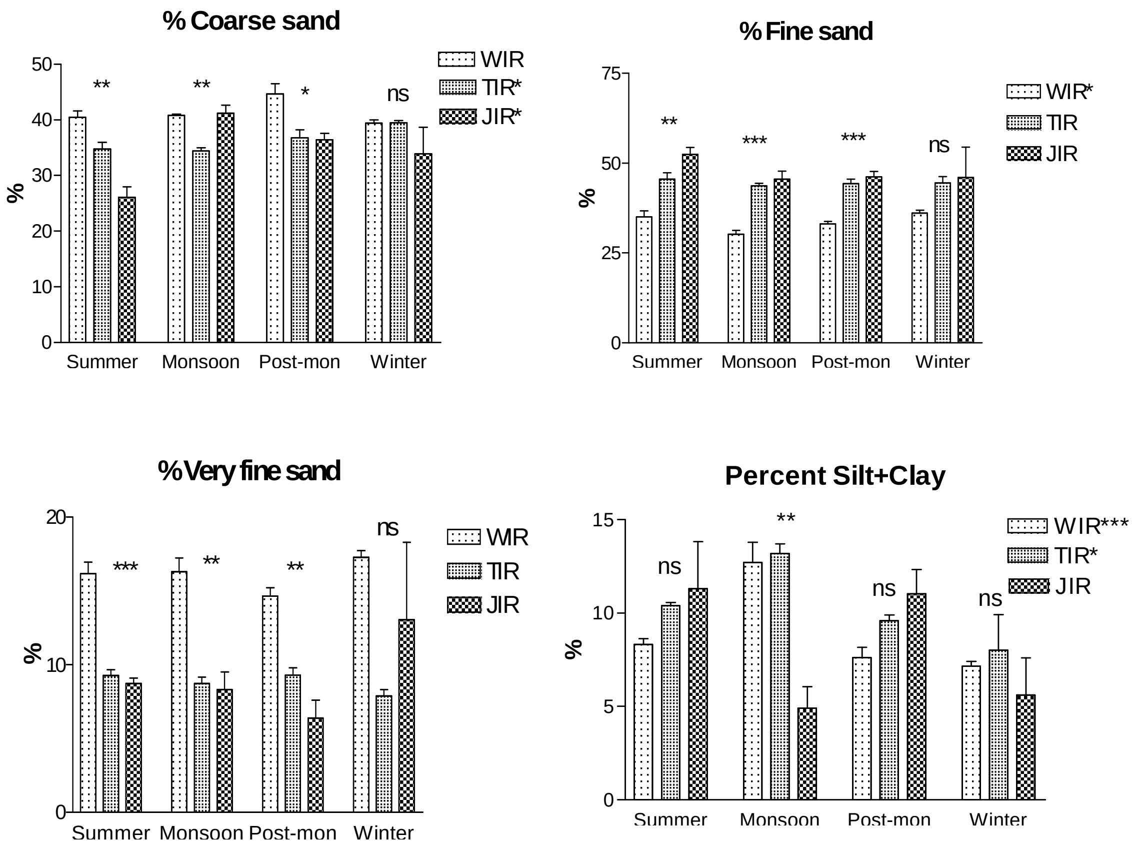
Table 3.2a. Seasonal variations in sediment texture at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Soil texture	Seasons	WIR	TIR	JIR	Significance among 3 sites
% Coarse sand	Summer	40.46±1.13	34.79±1.19	26.05±1.93	**; $F_{(2,15)}$ 24.57
	Monsoon	40.77±0.24	34.39±0.58	41.22±1.43	**; $F_{(2,11)}$ 18.0
	Post-mon	44.63±1.86	36.77±1.45	36.45±1.16	*; $F_{(2,14)}$ 9.36
	Winter	39.45±0.57	39.46±0.45	33.88±4.76	ns; $F_{(2,14)}$ 1.34
		ns; $F_{(3,18)}$ 4.04	*; $F_{(3,18)}$ 5.3	*; $F_{(3,18)}$ 5.4	
%Fine sand	Summer	35.05±1.75	45.56±1.77	52.38±2.04	**; $F_{(2,15)}$ 22.1
	Monsoon	30.20±1.15	43.69±0.71	45.57±2.22	***; $F_{(2,11)}$ 31.22
	Post-mon	33.12±0.75	44.35±1.27	46.14±1.57	***; $F_{(2,14)}$ 32.15
	Winter	36.12±1.75	44.5±1.79	45.96±8.52	ns; $F_{(2,14)}$ 1.11
		*; $F_{(3,18)}$ 4.85	ns; $F_{(3,18)}$ 0.28	ns; $F_{(3,18)}$ 0.5	
% Very fine sand	Summer	16.17±0.79	9.27±0.39	8.72±0.37	***; $F_{(2,15)}$ 56.73
	Monsoon	16.3±0.92	8.73±0.43	8.3±1.2	**; $F_{(2,11)}$ 24.61
	Post-mon	14.64±0.59	9.29±0.5	6.39±1.2	**; $F_{(2,14)}$ 26.03
	Winter	17.27±0.47	7.88±0.44	13.04±5.25	ns; $F_{(2,14)}$ 2.37
		ns; $F_{(3,18)}$ 2.33	ns; $F_{(3,18)}$ 2.22	ns; $F_{(3,18)}$ 1.03	
%Silt+Clay	Summer	8.32±0.31	10.39±0.18	11.31±2.51	ns; $F_{(2,15)}$ 1.10
	Monsoon	12.72±1.07	13.19±0.52	4.91±1.15	**; $F_{(2,11)}$ 23.72
	Post-mon	7.61±0.56	9.59±0.31	11.03±1.3	ns; $F_{(2,14)}$ 4.19
	Winter	7.16±0.24	8.003±1.92	5.62±1.97	ns; $F_{(2,14)}$ 0.57
		***; $F_{(3,18)}$ 16.23	*; $F_{(3,18)}$ 4.62	ns; $F_{(3,18)}$ 3.55	

Table 3.2b. Seasonal variations in pH, organic matter and inorganic non-metallic constituents of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR).

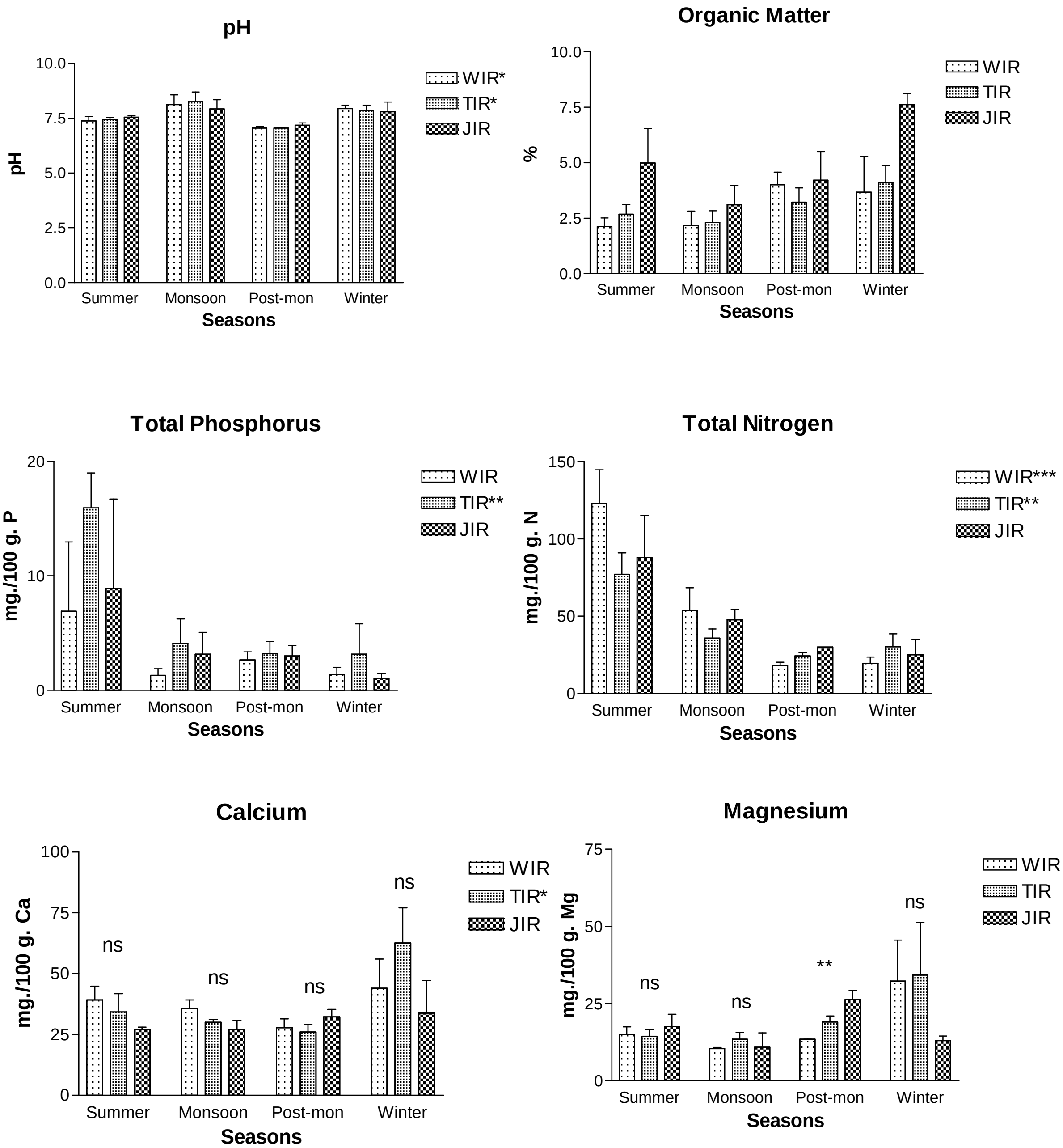
Soil parameters	Seasons	WIR	TIR	JIR	Significance among 3 sites
Soil pH	Summer	7.38±0.2	7.45±0.09	7.55±0.06	ns; $F_{(2,15)}$ 0.44
	Monsoon	8.13±0.45	8.25±0.46	7.93±0.42	ns; $F_{(2,11)}$ 0.14
	Post-mon	7.05±0.09	7.05±0.03	7.18±0.12	ns; $F_{(2,14)}$ 0.7
	Winter	7.95±0.16	7.85±0.25	7.8±0.43	ns; $F_{(2,14)}$ 0.06
		*; $F_{(3,18)}$ 3.64	*; $F_{(3,18)}$ 3.79	ns; $F_{(3,18)}$ 1.15	
Organic matter (%)	Summer	2.13±0.38	2.68±0.44	4.99±1.55	ns; $F_{(2,15)}$ 2.12
	Monsoon	2.16±0.66	2.31±0.53	3.11±0.87	ns; $F_{(2,11)}$ 0.54
	Post-mon	4.01±0.57	3.23±0.64	4.22±1.28	ns; $F_{(2,14)}$ 0.35
	Winter	3.68±1.61	4.1±0.78	7.62±0.49	ns; $F_{(2,14)}$ 4.11
		ns; $F_{(3,18)}$ 0.98	ns; $F_{(3,18)}$ 1.64	ns; $F_{(3,18)}$ 2.94	
Calcium mg/100g soil	Summer	39.15±5.69	34.18±7.55	27.03±1.009	ns; $F_{(2,15)}$ 1.23
	Monsoon	35.75±3.47	30.0±1.16	27.0±3.72	ns; $F_{(2,11)}$ 2.18
	Post-mon	27.78±3.67	26.88±3.61	32.25±3.07	ns; $F_{(2,14)}$ 0.69
	Winter	44.0±12.13	62.5±14.57	33.67±13.42	ns; $F_{(2,14)}$ 1.13
		ns; $F_{(3,18)}$ 0.91	*; $F_{(3,18)}$ 3.77	ns; $F_{(3,17)}$ 0.35	
Magnesium mg/100g soil	Summer	15.08±2.37	14.43±2.16	17.5±4.09	ns; $F_{(2,15)}$ 0.29
	Monsoon	10.43±0.34	13.53±2.17	10.9±4.65	ns; $F_{(2,11)}$ 0.32
	Post-mon	13.48±0.06	19.58±2.19	26.25±2.99	**; $F_{(2,14)}$ 8.67
	Winter	32.25±13.33	34.25±16.92	13.0±1.53	ns; $F_{(2,14)}$ 0.65
		ns; $F_{(3,18)}$ 2.1	ns; $F_{(3,18)}$ 1.22	ns; $F_{(3,17)}$ 3.41	
Total Nitrogen mg/100g soil	Summer	123.0±21.68	77.2±13.82	88.08±27.27	ns; $F_{(2,15)}$ 1.22
	Monsoon	53.5±14.93	35.75±6.005	47.63±6.71	ns; $F_{(2,11)}$ 0.81
	Post-mon	18.0±2.27	24.3±2.1	30.0±0.0	**; $F_{(2,14)}$ 11.47
	Winter	19.5±4.11	30.2±8.47	33.33±8.11	ns; $F_{(2,14)}$ 1.06
		***; $F_{(3,18)}$ 13.51	**; $F_{(3,18)}$ 7.61	ns; $F_{(3,17)}$ 3.05	
Total Phosphorus mg/100g soil	Summer	6.93±6.03	15.95±3.02	8.9±7.81	ns; F(2,15) 0.63
	Monsoon	1.3±0.58	4.13±2.12	3.15±1.92	ns; F(2,11) 0.73
	Post-mon	2.68±0.69	3.21±1.06	3.01±0.89	ns; F(2,14) 0.09
	Winter	1.4±0.63	3.18±2.63	1.07±0.42	ns; F(2,14) 0.43
		ns; F(3,18) 0.74	**; F(3,18) 7.2	ns; F(3,17) 0.6	

Fig. 3.2a. Seasonal variations in sediment texture of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



*** For ANOVA**
*** P< 0.05, **P< 0.001, *** P < 0.0001**

Fig. 3.2b. Seasonal variations in pH, organic matter and inorganic non-metallic constituents of soil at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



*** For ANOVA**
*** P< 0.05, **P< 0.001, *** P < 0.0001**

Table 3.3. Correlation of various abiotic factors of water at WIR

Parameters	Acidity	Cl	DO	Free CO2	B. alkalinity	Inorganic P	Kjeldahl N	Nitrate	Nitrite	H. alkalinity	pH	Salinity	Sulphate	Water Temperature	Total P	Water cover
Acidity	1.000															
Cl	0.125	1.000														
DO	-0.019	0.006	1.000													
Free CO2	0.294**	-0.155	-0.207*	1.000												
B. alkalinity	0.192	-0.069	-0.141	0.147	1.000											
Inorganic P	0.007	-0.291**	-0.003	0.196	0.209*	1.000										
Kjeldahl N	0.290**	-0.054	-0.047	0.169	0.172	-0.091	1.000									
Nitrate	0.083	-0.199	0.206	0.115	-0.037	0.149	0.303*	1.000								
Nitrite	0.540**	-0.013	0.068	0.051	0.185	-0.026	0.311**	-0.066	1.000							
H. alkalinity	0.191*	-0.148	0.187*	0.084	-0.137	-0.126	0.066	-0.068	0.178*	1.000						
pH	-0.180	-0.056	-0.009	-0.006	-0.331**	-0.087	-0.247*	-0.089	-0.183	0.257**	1.000					
Salinity	-0.273**	1.000**	0.184*	-0.373**	-0.134	-0.106	-0.240*	-0.115	-0.065	-0.234**	-0.088	1.000				
Sulphate	0.183	0.083	-0.113	0.297**	0.243**	-0.026	0.391**	0.216	0.079	-0.087	-0.336**	-0.158	1.000			
Water Temperature	-0.083	-0.521*	-0.152	-0.027	0.299	0.458*	-0.129	-0.168	0.218	-0.199	0.437*	-0.502*	-0.482*	1.000		
Total P	-0.237*	-0.048	-0.040	-0.093	-0.285**	-0.075	-0.122	0.133	-0.208*	-0.084	0.237*	-0.126	-0.103	-0.020	1.000	
Water cover	0.074	0.461*	0.549**	0.019	-0.150	-0.515*	0.319	0.142	-0.258	0.418	-0.111	0.208	0.351	-0.650**	0.152	1.000

** Correlation is significant at 0.01 level (2-tailed) * Correlation is significant at 0.05 level (2-tailed)

Table 3.4. Correlation of various abiotic factors of water at TIR

Parameters	Acidity	Cl	Free CO_2	DO	B. alkalinity	Inorganic P	Kjeldahl N	Nitrate	Nitrite	H. alkalinity	pH	Salinity	Sulphate	Water Temperature	Total P	Water cover
Acidity	1.000															
Cl	0.399**	1.000														
Free CO2	0.363**	0.106	1.000													
DO	0.014	0.127	-0.374**	1.000												
B. alkalinity	0.454**	0.201*	0.186	-0.258*	1.000											
Inorganic P	0.339**	0.235*	0.297**	-0.030	0.219*	1.000										
Kjeldahl N	0.279**	0.293**	0.154	0.265*	0.081	0.072	1.000									
Nitrate	0.313**	0.197	0.614**	-0.409**	0.188	0.270*	0.450**	1.000								
Nitrite	0.372**	0.258	0.142	-0.047	0.245*	0.037	0.056	0.000	1.000							
H. alkalinity	0.036	-0.089	0.053	-0.119	-0.019	-0.037	-0.088	0.011	-0.119	1.000						
pH	0.087	-0.284**	0.348**	-0.232*	-0.157	0.120	0.169	0.269*	-0.103	0.147	1.000					
Salinity	0.399**	1.000**	0.106	0.127	0.201*	0.235*	0.293**	0.197	0.258*	-0.089	-0.284**	1.000				
Sulphate	0.394**	0.225	0.301**	-0.252*	0.291*	0.349**	0.505**	0.508**	0.119	-0.007	0.282*	0.225	1.000			
Water Temperature	0.272	0.177	0.495*	-0.569**	-0.102	0.236	0.192	0.306	0.061	-0.162	0.283	0.177	0.238	1.000		
Total P	0.146	0.139	0.022	0.220*	0.323**	0.115	-0.006	-0.142	0.209*	-0.222*	-0.384**	0.139	-0.256*	-0.383	1.000	
Water cover	0.160	0.152	-0.516*	0.534**	0.148	0.015	0.216	-0.156	-0.034	-0.194	-0.306	0.152	0.360	-0.070	-0.380	1.000

** Correlation is significant at 0.01 level (2-tailed)   * Correlation is significant at 0.05 level (2-tailed)

Table 3.5. Correlation of various abiotic factors of water at JIR

Parameters	Acidity	Cl	Free CO_2	DO	B. alkalinity	Inorganic P	Kjeldahl N	Nitrate	Nitrite	H. alkalinity	pH	Salinity	Sulphate	Water Temperature	Total P	Water cover
Acidity	1.000															
Cl	-0.344**	1.000														
Free CO2	0.283*	-0.075	1.000													
DO	-0.147	0.169	-0.338**	1.000												
B. alkalinity	0.290*	0.009	0.476**	-0.153	1.000											
Inorganic P	-0.222	0.151	-0.037	0.242*	-0.019	1.000										
Kjeldahl N	0.099	0.083	-0.037	0.138	-0.119	-0.133	1.000									
Nitrate	0.055	0.055	0.037	-0.265*	0.231	-0.116	-0.101	1.000								
Nitrite	0.595**	-0.193	0.078	-0.087	0.323**	-0.095	-0.075	0.121	1.000							
H. alkalinity	0.228	-0.151	0.076	0.030	0.107	-0.033	-0.041	0.118	0.096	1.000						
pH	-0.075	0.018	-0.280*	-0.062	0.010	0.020	-0.113	-0.076	0.052	0.046	1.000					
Salinity	-0.344**	1.000**	-0.075	0.169	0.009	0.151	0.083	0.055	-0.193	-0.151	0.018	1.000				
Sulphate	0.045	0.192	0.002	0.174	0.235*	-0.055	0.028	-0.073	0.373**	0.016	0.136	0.192	1.000			
Water Temperature	0.122	-0.383	-0.107	0.239	-0.289	0.011	0.133	0.596**	0.118	0.356	-0.348	-0.383	-0.030	1.000		
Total P	-0.045	-0.133	0.007	0.314**	-0.166	-0.045	0.155	-0.333*	-0.211	-0.055	-0.162	-0.133	-0.250*	-0.417	1.000	
Water cover	-0.221	0.765**	0.308	0.015	0.683**	0.083	-0.459*	-0.256	-0.046	-0.185	0.298	0.765**	0.307	-0.234	-0.202	1.000

** Correlation is significant at 0.01 level (2-tailed)   * Correlation is significant at 0.05 level (2-tailed)

Table 3.6. Correlation of various abiotic factors of soil at WIR

Parameters	Calcium	%Coarse sand	% Fine sand	Magnesium	Organic matter	pH	%Silt+Clay	Total Nitrogen	Total phosphorus	%Very fine sand
Calcium	1.000									
% Coarse sand	-0.277	1.000								
%Fine sand	0.194	-0.469	1.000							
Magnesium	0.513*	-0.297	0.450	1.000						
Organic matter	0.092	0.071	0.048	-0.068	1.000					
pH	0.501*	-0.317	-0.350	0.295	0.361*	1.000				
%Silt+Clay	-0.124	-0.196	-0.675*	-0.344	-0.131	0.502	1.000			
Total Nitrogen	0.210	-0.348	0.058	-0.085	0.238	0.218	0.078	1.000		
Total Phosphorus	-0.027	-0.295	0.554	-0.051	-0.042	0.045	-0.116	0.305*	1.000	
%Very fine sand	0.331	-0.545	0.003	0.230	0.000	0.421	-0.004	0.385	-0.380	1.000

** Correlation is significant at 0.01 level (2-tailed)   * Correlation is significant at 0.05 level (2-tailed)

Table 3.7. Correlation of various abiotic factors of soil at TIR

Parameters	Calcium	%Coarse sand	% Fine sand	Magnesium	Organic matter	pH	%Silt+Clay	Total Nitrogen	Total phosphorus	%Very fine sand
Calcium	1.000									
% Coarse sand	0.505	1.000								
%Fine sand	0.335	-0.347	1.000							
Magnesium	0.837**	0.443	0.535	1.000						
Organic matter	0.132	0.465	-0.151	0.107	1.000					
pH	0.414	-0.437	-0.121	0.251	0.491*	1.000				
%Silt+Clay	-0.715**	-0.622*	-0.469	-0.776**	-0.347	0.586*	1.000			
Total Nitrogen	0.297	-0.183	0.230	0.215	-0.192	0.349	-0.028	1.000		
Total Phosphorus	0.007	0.007	0.260	0.111	0.221	0.218	-0.162	0.620**	1.000	
%Very fine sand	-0.475	-0.362	-0.312	-0.640	-0.030	-0.029	0.339	0.010	-0.251	1.000

** Correlation is significant at 0.01 level (2-tailed)   * Correlation is significant at 0.05 level (2-tailed)

Table 3.8. Correlation of various abiotic factors of soil at JIR

Parameters	Calcium	%Coarse sand	% Fine sand	Magnesium	Organic matter	pH	%Silt+ Clay	Total Nitrogen	Total phosphorus	%Very fine sand
Calcium	1.000									
% Coarse sand	0.169	1.000								
%Fine sand	-0.513	-0.701*	1.000							
Magnesium	0.411	-0.590*	0.285	1.000						
Organic matter	0.348	0.385	-0.587**	0.424	1.000					
pH	-0.594*	0.301	0.018	-0.487	-0.194	1.000				
%Silt+Clay	-0.254	-0.680*	0.349	0.687*	-0.167	-0.428	1.000			
Total Nitrogen	0.197	-0.538	0.239	0.231	-0.268	0.058	0.354	1.000		
Total Phosphorus	0.002	-0.495	0.082	0.291	-0.003	0.001	0.583*	0.512*	1.000	
%Very fine sand	0.597*	0.323	-0.756**	-0.246	0.450	-0.049	-0.474	-0.006	-0.141	1.000

** Correlation is significant at 0.01 level (2-tailed)   * Correlation is significant at 0.05 level (2-tailed)

Discussion

Physico-chemical properties of water

Spatial and temporal changes in habitat provide a shifting mosaic of biotic and abiotic conditions that play a major role in organizing communities (Habeeba *et al.*, 2012). Thus, the abiotic environment of an aquatic habitat directly affects the distribution, population density and diversity of the communities.

For aquatic ecosystems temperature is a factor of great importance as it not only affects the organisms but also physical and chemical characteristics of water (Delince, 1992; Abdo, 2005). The mean surface water temperature, between 22°C to about 26°C during early morning hours reflects the sub tropical location of the three reservoirs studied. This temperature is expected to accelerate the growth rate of the organisms supported in it. Although cooling and warming of water is slow compared to land and seasonal changes correspond to changes in the ambient temperature. In contrast to the reports of Deshkar, (2008), who studied the same area subsequent to Narmada inundation, during the present study (2009-11) water temperature at the three reservoirs was comparatively lower during the same period. This could be the effect of establishment of vegetation cover. The reservoirs studied are inundated with water since the turn of century, and over a decade the hydroperiod as well as water cover has increased resulting in increased vegetation cover. The vegetation cover prevents the heating of land during summer and hence comparative lower temperatures as well as seasonal differences are observed. At higher altitudinal lakes in the central Satpura range higher temperatures have also been reported during dry summer in response to ambient temperature than monsoon- the wet summer at Yashwant Lake (Ekhande, 2010) and Lotus lake (Patil, 2011).

Similarity in the pattern of fluctuations in water temperature and almost same temperature is evinced by the location of three reservoirs in the same climatic regime. The distance between the three reservoirs is less than 50 kms. hence no significant difference are observed in the influence of climatic conditions. However, the variable correlations of water temperature with other abiotic parameters at the three reservoirs may be in response to the conditions prevailing at the local level. The location of the three reservoirs is in subtropics where though the temperature fluctuates over the seasons, the overall weather is comparatively warmer. In present study, temperature correlating differently with other abiotic parameters of water at each of these reservoirs supports these assumptions. Temperature plays important role especially in wetland ecosystems by setting up daily thermal current and thermal stratification (Ramchandra *et al*., 2000). Under small temperature changes this can result into shift in food web dynamics the mechanism being independent of species (O’ Connor *et al*., 2009). The seasonal changes have been reported definitely to produce impact on plankton, mollusc and bird dynamics (Deshkar, 2008).

Several studies have reported water cover in lakes and reservoirs to be maximum during post-monsoon when streams continue to bring water (Deshkar, 2008; Ekhande, 2010; Patil, 2011). After a period of three years this remained true for the two smaller reservoirs but at WIR, the larger reservoir, the water level was found to be maximum in winter. This can be the influence of difference in cropping patterns and change in irrigation pattern as well as difference in the release of water from the reservoirs. All the reservoirs are inundated with Narmada water under same schedules hence receive water at same time but draining time depends on cropping patterns resulting in difference in the water cover. Its correlation could only be established positively with DO at WIR and TIR, and with alkalinity and salinity at JIR. Influence in relation to

Narmada inundation needs to be investigated with exact time of inundation and changes over the period.

The aquatic life is usually protected in a pH range between 4.5 and 9.6 (Dwivedi and Sonar, 2004). In a water body, this is controlled by various nutrients like phosphates and nitrites (Goldman and Horne, 1983), chemical components like CO_2, DO and various dissolved salts that regulate biological and biochemical reactions (Verma *et al.*, 2006). The waters in the semi-arid zone of India are usually alkaline. With the change in season, dilution of various components in the monsoon and concentration of the same due to evaporation of water in summer result in seasonal fluctuations in pH. Further, depending on the local geological as well as biological influences, the differences among these three are expected to occur. These differences are non-significant only in monsoon when the area is totally covered with green vegetation at the onset of rainy season diminishing the differences. Metabolism of submersed aquatic plants can also influence concentrations of dissolved inorganic carbon, which in turn impacts pH (Slavick, 2007). The differences in water cover and vegetation has probably led to highest pH during summer as well as winter at WIR and TIR while only during summer at JIR. On a hot sunny day, photosynthetic activities are also expected to cause fluctuations in pH. With reference to density of vegetation the three reservoirs studied are neither protected nor managed on planned basis. Hence, depending on prevailing circumstances differences in the acidity at three reservoirs occurred over four seasons. The composition and distribution of plant communities in lakes is influenced by water chemistry over broad geographical regions (Slavick, 2007). The vegetation composition and their distribution in the area is considered in Chapter (5). A significant and positive correlation was found between pH, and water temperature as well as total phosphorus at WIR; a significant one with free CO_2 and nitrates at TIR. A wide variety of organisms including algae, macrophyte, zooplankton, macro invertebrates, amphibians, and fishes are adversely affected by acidification (Haines, 1981; Hunter *et al*., 1986). Deshkar (2008) could not establish any common correlation of acidity in the four waterbodies of the semi-arid zone. This stands true for the present study too. Generally, waters with low levels of carbonates, bicarbonates and phosphates have low buffering capacity (Agrawal, 1999). However, the contribution of either Kjeldahl Nitrogen, nitrate or nitrites, CO_2, bicarbonate or hydroxyl alkalinity to the acidity is expressed as their correlation at 0.01 or 0.05 level at the three reservoirs *i.e.* these are the main contributors to acidity of water at the three irrigation reservoirs studied.

The total alkalinity remains higher in eutrophic waters (Craft, 1997; Osborne and Totme, 1994). Adebisi (1980) showed alkalinity to be inversely correlated with the water level. Further, dilution also plays an important role in lowering the alkalinity (Chakraborty *et al*., 1959). Though the reservoirs studied are not undergoing eutrophication, good vegetation cover present in shallow waters (WIR and TIR) or on the earthen dam (TIR and JIR) may influence the alkalinity of water. The waters with moderate to high alkalinity are towards neutral (7 to 8.3). CO_2 being utilized for photosynthesis, higher alkalinity of water is maintained. However, in a 24 hour period, during cloudy conditions with low light in monsoon, utilization of CO_2 decreases with the amount of oxygen used in respiration exceeding the amount produced by photosynthesis (Slavick, 2007) as is noted at the two smaller reservoirs, TIR and JIR. The water with alkalinity between 40 to 90 mg/l is medium productive while more than 90 mg/l is highly productive (Sugunan, 1989). Alkalinity more than 60 mg/l is considered good for production of fish (Spence, 1964). Fish is a major prey base of waders and fish culture is carried out at WIR and TIR. Alkalinity also influences the species composition, an important factor in determining plant distribution over broad geographical regions.

Daily Dissolved Oxygen changes as large as 12 mg/L occur in surrounding waters due to photosynthesis and respiration (metabolism) in dense submersed aquatic plant stands (Slavick, 2007). Oxygen enters water as a result of two processes: First through diffusion: which is accelerated when the water turbulence is increased and when there is a strong blowing wind. Additionally, oxygen also diffuses into cold water at a higher rate than into warm water and second through photosynthesis. Oxygen, a by-product of this process is released into surrounding water. Hence, the oxygen can increase during winter (Alfred and Thapa, 1996) as is also noted during present study. However, increased DO during monsoon can be due to increase in water turbulence. DO > 5 mg/l is considered favorable for growth and activity of most aquatic organisms (US EPA, 2001). Further, the oxygen deficit during summer is a characteristic feature of a productive wetland (Sreenivasan, 1970; Timms, 1970). This was observed in the present study at all the study areas. These fluctuating levels showed a positive correlation with salinity and water cover at all the reservoirs while only with total phosphates at TIR and JIR.

High chloride levels lead to higher salinity levels which were found at WIR and JIR during winter. The relative decrease in chloride concentration during the warm period especially post-monsoon may be due to dilution after rainy season. The source of chlorides in water is either weathering and leaching of sedimentary rocks or domestic and industrial waste (Goel *et al.*, 1980; Sinha, 1986). At the three reservoirs the chances of latter are low hence the possibility of weathering and leaching of rocks increases. The three reservoirs are located on extension of deccan trap rock system (Rajyagore and Tripathy, 1979) where leaching of Chlorides from rocks may be possible. Many researchers have reported that salinity/chloride contents are high in water during summer due to effects of concentration and evaporation while low in monsoon due to dilution (Walujkar, 2005; Deshkar, 2008; Ekhande, 2010; Patil, 2011). The chloride content in soil is higher at the three reservoirs during summer and its leaching increases during monsoon as well as in response to increase in water level due to Narmada inundation. Compared to Deshkar, (2008) the chlorides/salinity was found to be higher at the three reservoirs which have changed from seasonal to almost perennial water bodies receiving water at least twice in a year (WIR/TIR) probably increasing leaching. Though JIR is not receiving Narmada water directly, some Narmada water is definitely reaching JIR as it has not dried totally for the last few years. However, Rathod, (2009) has reported complete drying of the JIR during summer.

The decomposition of organic matter by microbes utilizes O_2 and produces CO_2 at the bottom of the water body. During summer decomposition increases while during winter it decreases further declining the CO_2 production. When the oxygen concentration in waters containing organic matter is reduced, the carbon dioxide concentration rises and hence high levels were found in higher temperatures at WIR and JIR. Over the ordinary temperature range (0°-30° C) the solubility of CO_2 is about 200 times that of oxygen. Carbon dioxide can also combine with Calcium and magnesium to form carbonates and bicarbonates. CO_2 in water makes it acidic hence CO_2 is positively correlated to acidity.

When nutrients are considered sulphates are also considered. Sulphate toxicity is dependent on chloride and hardness concentrations, water quality chemistry and characteristics. The high levels of sulphates during monsoon at WIR and TIR may be due to the high TDS brought with surface runoff levels in the reservoirs. The difference in sulphate concentration at different locations could be due to the fact that the sulphate discharged to the lakes is used up as a source of oxygen. Sulphates are constituents of TDS and known to form salts with sodium, potassium, magnesium and other cations (McDaniel, 2007). It is widely distributed in nature and natural waters. Though concentration of sulphate in water ranges from a few to several hundred milligrams per litre in drinking water it averages around 0.1 to 0.5 g/l (IOWA report, 2009). Sulphates being a natural salt component, the risk associated with its toxicity are low. The sulphate toxicity is dependent on water chemistry. The sulphate concentrations in the waters of the three reservoirs being low do not pose any toxicity risk. Sulphate enrichment of water has been thought to mobilize phosphates (Lamers *et al.*, 1998a 1998b; Caraco *et al.*, 1989; Roelofs, 1991) while through sulphite production to inhibit the coupled nitrification-denitrification (Joye and Hollibough, 1995) which may result in high nitrogen availability for plants. Positive correlation of sulphates at 0.01 with Kjeldahl nitrogen at WIR and TIR with free CO_2, inorganic phosphates, nitrates at 0.01; hydroxyl and bicarbonate alkalinity at 0.05 and negative with DO has been recorded at TIR; positively with hydroxyl and bicarbonate alkalinity at JIR has been noted. Sulphate toxicity is dependent on chlorides and hardness concentrations (IOWA report, 2009) which shows no relation in the present study.

The increase in nitrogen in the form of ammonia, nitrate and nitrite concentrations has been linked to the addition of agricultural fertilizers and urban sewage. The higher levels of nutrients during the wet seasons in most lakes are presumably the result of mixing events that redistribute nutrients to the surface water, and inputs from run-off. Especially, the consistently higher nitrate-nitrogen concentrations during the wet seasons are assumed to increase due to input from the drainage basin (Zinabu, 2002).

The high amounts of nitrates and nitrites as well as Kjeldahl nitrogen during summer and monsoon at the three reservoirs, may be attributed to the above fact. The higher values of nitrates are indicative of the oxidation of ammonia by nitrifying bacteria and biological nitrification (Seike *et. al.*, 1990; Abdo, 2005) and the lower values to the denitrification of nitrate-nitrogen by denitrifying bacteria (Abdo, 2005).

Nitrite (NO^{2-}), an intermediate in oxidation or reduction process of ammonia and nitrates, is not ordinarily found in high concentrations in surface waters. Its occurrence indicates the efficiency of biological processes such as nitrification, denitrification or biological nutrient removal (Patra *et al.*, 2010). The difference in the nitrate and nitrite levels in the waters of three reservoirs indicates that these biological processes take place depending on the available microclimatic conditions influenced by overall climatic conditions.

The second nutrient, Nitrogen, occurs naturally in the soil in organic forms as decaying plant and animal residues as well as in fertilizers. In soil, bacteria convert various forms of nitrogen to Nitrates (NO_3-), the desirable form used by majority of plants. It is also highly leachable and readily moves with water through the soil profile (Addiscott *et al.*, 1991). This is reflected in the present study also as nitrate content in water were high at the three reservoirs during summer and monsoon. In summer, when water levels go down, exposed vegetation decays, releasing nitrate in water while during monsoon the levels are maintained due to input via rainwater runoff. Total nitrogen was also found to be high in soils of the three reservoirs during summer and monsoon (Table 2).

The higher Kjeldahl nitrogen that includes both organic nitrogen and ammonia nitrogen may be correlated to the contamination of JIR water with excrement and its decomposition as the anthropogenic pressure is high here. At the other two reservoirs, the levels were high only during summer when dead organic matter accumulates and degradation takes place. Exposure to sunlight causes dissolved organic matter to release nitrogen rich compounds that are biologically available and enhances degradation of humic acid by bacteria. In a water body, in addition to ammonia, nitrogen also occurs in the form of nitrates (NO_3^-) that are also linked with fertilizer runoff and sewage (Addiscott *et al.*, 1991).

Further, the high amounts of phosphate in water are thought to be mainly a result of their use leaching from detergents. Phosphorus is also removed from the sediment and water via plant roots and incorporated into plant biomass (Slavick, 2007). Though phosphorus, the second to nitrogen as a growth limiting nutrient, is an essential element for plant growth and primary productivity its excess in water can lead to eutrophication. It makes about 0-2% of plant dry weight. According to US EPA (2001), no more than 0.25 mg/l of total phosphorus is recommended for reservoirs. At the three reservoirs total phosphates were present below permissible limits. However, they were higher during post-monsoon when the water level was maximum and plant growth had accelerated after clearing of clouds of monsoon. It was highest in the soil during summer (Table 3.2) which may have entered into water when rains started and reached to maximum level in water in post-monsoon. However, Deshkar, (2008) has reported maximum phosphates during monsoon. The onset of monsoon needs to be considered in agricultural runoff adding phosphates to the reservoirs. Nevertheless, the three reservoirs studied are under least threat of eutrophication at present. Highest amount of total phosphates (both Inorganic and Total) were found during summer due to pits of water formed in the reservoirs. The rapid growing vegetation when reaches maxima, it dies and decays. This process uses up oxygen. In the present study, positive correlation of total phosphorus with oxygen at JIR (0.01) and TIR (0.05) indicates comparatively low level of decay or balanced growth of vegetation while at WIR no such correlation could be established. Of course, drying occurs in summer in absence of rains and inundations, while growth starts on the onset of monsoon, increases in post-monsoon and stabilizes by winter.

Extremely active phosphate anions (PO_4^{3-}) are mobilized through precipitation of cations of Ca^{2+}, Mg^{2+}, Fe^{3+} and Al^{3+} depending on the properties of soil. These are forms of phosphorus that are highly insoluble and not available to plants (Sharma *et al.*, 2011).

Physico-chemical properties of soil

During last century, many wetlands have been lost as a result of anthropogenic activities while those that still exist are subjected to increasing pressures due to agricultural practices land drainage, pollution and urban development (Williams, 1997; Brown, 1998; Wood *et al.*, 2003). In addition to hydrodynamic conditions (Sanz, 1986; Davoult, 1990), theories on trophic distribution along environmental gradients are based on factors such as sediment composition (O’ Connor, 1972; Probert, 1984; Gaston, 1987) which are intimately associated.

The texture of soil of the three reservoirs comprised mainly of sand. According to the Government of Gujarat State Agricultural Marketing Board and Vadodara district Gazetteer, the western part of Vadodara district where the two reservoirs are located has alluvial sandy loam to sandy clay loam. Percentage of coarse sand is maximum at reservoir (WIR) in central part of the district while fine sand in the eastern and northern part of district i.e. at TIR and JIR respectively with latter having still higher percentage of fine sand. The region lying in Doab of Narmada, in South and Mahi in North has more loamy soil in south and sandy in north (Gazzetteer- Vadodara district). A seasonal river Orsang, a tributary of Narmada, flows 4 kms east of WIR while a major river of Gujarat, Mahi, flows 5 kms north of JIR. The differences in soil texture could be the influence of the rivers in geological times. Percentage of clay, though lower among the four categories considered, increases during monsoon with simultaneous decrease in fine sand at WIR and TIR. At JIR the scrub vegetation in the catchment area probably prevents soil erosion, preventing silt and clay to enter the reservoir. However, rain washes away the same in monsoon and exposes the sand increasing significantly the percentage of coarse sand in the sediments.

The differences in the percentage of coarse sand are significant at 0.01 in summer and monsoon showing effects of strong winds as well as rains on top soil. Significant at 0.05 in post-monsoon when conditions start settling down and nil in winter when overall climatic conditions are stable and land is covered with vegetation or water.

According to Mau, (2001) the amount of runoff from a watershed can be an important factor in explaining site-to-site variability in chemical or sediment loading characteristics. The silt- and clay-sized particles have large surface areas relative to their mass and, therefore, settle out of the water column much slower than sand-sized or larger material (Morris and Fan, 1998). These small particles are transported farther into the reservoir and settle out from the water column into bottom sediment in calm-water areas where the reservoir hydrodynamics are minimal. Xu *et al.,* (2003) have reported that with the increase in lake sediment size and diameter, concentration of TN and TP declined which supported a positive relation of fine sand and nutrients as the availability of nutrients for growth is high in sediments with intermediate density. Total phosphorus concentrations are correlated with silt- and clay-sized particles too (Mau, 2001). A significant and positive correlation of silt and clay was noted with total phosphates in present study. In addition, in an estuary in China, Gao *et al*., (2008) have noted linear correlations of total nitrogen and carbon with mean grain size and thus “grain size effect” is an important factor that influences the distribution of nutrients - a positive correlation of percent organic matter with percent coarse sand and total nitrogen was observed at the three reservoirs.

Soil pH is known to affect cation and anion exchange by altering surface change of colloids. A higher concentration of H^+ (lower pH) neutralizes the negative charge of a colloid. Because the colloid is negatively charged cations dominate the exchange sites (Brady and Weil, 2002) thereby decreasing cation exchange and increasing anion exchange and vice versa. Soil pH was highest in monsoon which may be due to leaching of alkalinity contributing elements in water as reflected in significant correlation in pH of water at 0.01 at all the three reservoirs. Further, WIR is receiving Narmada water under the same schedule and mainly during winter when the Rabi crop is in developing stage.

The amount of chlorides in water is determined by the types of rocks and soils it has contacted. The element chlorine exists in nature as chloride salts of calcium, magnesium, potassium and sodium. Its average soil concentration is estimated at 100 ppm. Chlorine is required by plants for certain photo-chemical reaction in photosynthesis and it is important for hydration and balancing of positively charged ions in cation transport (Schulte, 2004). It is one of the first elements removed from minerals by weathering process as soils are formed. Atmospheric chloride inputs often increase near heavily industrialized areas where large quantities of coal are burned (Fixen, 1993). This may stand true for JIR where high levels of chloride content during monsoon were noted. Among the three reservoirs this reservoir is in closer proximity to the refinery area near Ranoli. High concentration of chlorides in soils of the three reservoirs noted in summer may be due to the low water levels which lead to concentration of elements. Chlorides are not strongly associated with either soil minerals or organic matter and therefore exist primarily in dissolved form in the soil solution (Schulte, 2004) but a positive correlation of chlorides is noted with organic matter, nitrogen and phosphorus in soils.

The decaying aquatic plants add organic matter to the sediments. When and how much organic matter is added to the sediment influences dissolved oxygen concentrations. If large amounts of dead organic matter are added to the lake under warm, still conditions, oxygen depletion and its associated negative impacts on aquatic organisms can occur (Slavick, 2007). Hence, the higher organic matter content in the soil may be due to the higher sedimentation rates (due to decomposition of foliage and detritus). The maximum abundance of decomposers settle organic matter and macrophytes at the bottom of water body while increased water temperature, activate the process of decomposition of these organic sediments (Malhotra *et al.,* 1996).

As sediment type greatly affects plant establishment and the growth and the structure of community depending on it, small change in its type and depth can affect the plant life in a number of ways. Sediment movement and accumulation in aquatic system follow standard laws of physics: Higher energy waters have greater sediment load than lower energy water as large item settle quickly than small item with decreases water energy. Hence, sediment accumulation frequently increases when aquatic plants become established. The overall higher organic matter in JIR soil reflects the comparatively greater vegetation cover in the surrounding area. This does not allow silt and clay runoff and hence in monsoon compared to the other seasons organic matter is low in soil but slowly builts up over post-monsoon and winter and decreases in summer. At the other two reservoirs also the non-significant built up of organic matter is seen over post-monsoon and winter. In the semi-arid zone of Gujarat, the overall weather is dry and vegetation cover starts growing on the onset of monsoon, builds up during post-monsoon, accumulates in winter and drops in summer. Organic matter is correlated positively with pH at WIR and TIR only. Freshwater ecosystems are the most productive ecosystems as they possess one of the earth's largest actively cycled reservoirs for organic matter (Hedges, 1992). The bulk of this dissolved organic matter *i.e.* the larger biologically refractory molecules, include humic substances which on exposure to sunlight releases nitrogen rich compounds (Bushaw *et al.,* 1996) enhancing bacterial degradation of humic substances. A hypothesis states that by stabilizing sediments, aquatic plants reduce the resumption of nutrients available for suspended algae (Slavick, 2007). Stabilizing sediment also reduces the resumption of dead organic matter and clay particles. As said earlier the presence of more vegetation in JIR is reflected with high concentration of organic matter among the three reservoirs during all seasons with increase in the same during winter. However, the differences among the three reservoirs are not significant.

Calcium (Ca) is an important constituent of most soils and its minerals mostly are found bound with other substances (Gibb, 2007). It is relatively abundant in soils and rarely limits crop production as it is predominantly positively held on soil clay and organic matter particles. As it has relatively strong attraction to the surface of clay, its leaching normally does not occur at any appreciable extent (Kelling and Schulte, 2004). It is held more tightly than magnesium (Mg^{++}), potassium (K^{+}), and other exchangeable cations. Parent material from which soils are usually formed also contain more calcium than magnesium or potassium (Kelling and Schulte, 2004). Soil calcium is important for lowering the pH level and hence associated with acidity (Gibb, 2007). Highest calcium levels found during winter at all the study areas can be due to its accumulation because of non utilization. Mollusc which depend on Calcium to produce shell reproduce in monsoon and grow in post-monsoon. Large numbers of mollusc are found in the reservoir studied which enters dormancy during winter when temperature goes down probably leading to accumulation of calcium in soil. Ondina *et al.,* (2004), have shown gastropods preferring high calcium soil in their study. Calcium bound to CO_2 in soil increase the pH (McCauley, 2009) hence soils low in calcium often have low pH. A positive correlation of pH and calcium at WIR and TIR explains the fact that calcium occurs in highly buffered soils.

Magnesium is also an essential micronutrient because of its role in phosphate energy transfer and because it is a structural molecule in chlorophyll. Acidic soils, especially sands, often contain relatively low levels of magnesium while neutral soils or those with high pH usually contain more than 500 ppm of exchangeable magnesium (Schulte, 2004). During winter magnesium levels were found to be high in soils of WIR and TIR *i.e.* when they were more basic. JIR soils were low in magnesium content in winter. Magnesium ions are also held on the surface of clay and organic matter particles. While this exchangeable form is available to plants, like calcium, it also does not leach easily from the soil (Schulte, 2004). A positive correlation of magnesium with organic matter at TIR and JIR and a significant one with silt and clay at JIR prove the above observation. Soils with calcite limestone, acid that is sandy soils and organic soils containing free calcium carbonate are likely to be magnesium deficient. A positive correlation of calcium and magnesium was noted at all the three reservoirs (a significant one at WIR and TIR).

Nitrogen exists in the soil system in many forms and changes (transforms) very easily from one form to another. Atmospheric N is the major reservoir for N in the N cycle (air is 79% N_2 gas). When the plant material is decomposed, N is released. In addition small amounts of N are added to soil from precipitation**.** Soil organic matter is also a major source of N used by crops. High total nitrogen in sediment during summer may be correlated to the oxidation of dead plant forming organic matter. Nitrogen is probably lost from agricultural lands through soil erosion and runoff (O'Leary *et al.*, 2002) as is reflected with the lower value of total nitrogen during monsoon which washes of organic matter exposing sand content in soil. Consequently with respect to N, it is known that its mineralization increases after drainage and subsequent aeration of wet soils (Bridgham *et al.*, 1998; Cabrera, 1993; Updegraff *et al.*, 1995) whereas denitrification decreases as the consequence of decrease of anoxic regions (Groffman and Tiedje, 1988; Seitzinger, 1994).

Both the effects of drainage lead to increased N availability. Although a negative correlation of nitrogen content was found with percent coarse sand at all the three reservoirs, according to Davidsson *et al.*, (1997), the total N concentration decreases in sandy soil, *i.e.* from the outflow of the longest cores, about 40% of the inflowing nitrogen may be removed. A positive correlation of fine sand particles with total nitrogen has been observed in the study at all the reservoirs.

Phosphorus availability for wetland plants is largely controlled by chemical equilibria in soil (Richardson and Marshall, 1986). Phosphorus (P) is an essential element classified as a macronutrient because of the relatively large amounts required by plants. In natural systems like soil and water, P exists as phosphate, a chemical form in which each P atom is surrounded by 4 oxygen (O) atoms forming orthophosphate, the simplest phosphate. Phosphate is taken up by plants from soils, transferred to animals that consume them, and returned to soils as decaying organic residues in soils. According to, Sarvanakumar *et al.*, (2008), the capacity of sediment to retain or release phosphorus is one of the important factors, which influence the concentration of inorganic/organic phosphorus in the overlying waters. Much of the phosphate used by living organisms becomes incorporated into organic compounds. When plant materials are returned to the soil, this organic phosphate is slowly released as inorganic phosphate or be reincorporated into more stable organic materials and become part of the soil organic matter. The release of inorganic phosphate from organic phosphates, called mineralization, is caused by microorganisms breaking down organic compounds. The activity of these microorganisms is highly influenced by soil temperature and soil moisture. The process is most rapid when soils are warm and moist but well drained. Phosphate can potentially be lost through soil erosion and to a lesser extent to water running over or through the soil (Busman *et al.,* 2002) which was observed during monsoon at TIR and JIR. Total phosphorus concentration in soil was found to be highest in summer at all the three reservoirs because of higher temperatures. According to Mucha and Costa, (1999), the sediment organic load is an important disturbance factor. Associated with this parameter, they found high fine fraction percentage, reducing conditions and the predominance of reduced forms of nitrogen (NH_4), phosphorus (PO_4) and sulphur (H_2S) in interstitial water of an estuary. Total phosphorus in present study also showed a positive correlation with percent fine sand, chlorides, pH and total nitrogen at all the three irrigation reservoirs.

Conclusion

The physical and chemical properties of freshwater body are characteristic of the climatic, geochemical, geomorphological and pollution conditions as well as anthropogenic activities. The physico-chemical properties of water as well as soil affect the biota present therein.

These parameters are affected due to seasonal fluctuations in the climatic conditions, water level, inundation from Narmada, anthropogenic pressure *etc*. At the three reservoirs in subtropics although overall weather is comparatively warmer, fluctuation in temperature and humidity (rain) are observed. The inundation from Narmada River during the study influenced the water level probably changing the chemistry of water and soil. As WIR was almost dry during the summer of first year of the study, high fluctuations were noted in the physico-chemical properties of its water and soil whereas the anthropogenic disturbances at TIR influenced the nutrient levels. However at JIR presence of emergent vegetation all throughout the year showed the impacts on the chemistry of water and soil. The high sandy composition at the three reservoirs may have adverse effects on the biotic communities in the area.

MACROPHYTES AT THE THREE RESERVOIRS

Introduction

Vegetation is one of the important factors influencing invertebrate communities in shallow lentic systems such as ponds and wetlands. Abundance of invertebrates influences the wetland ecosystem as they themselves are the food for higher taxa such as fish and waterfowl (Euliss and Grodhaus, 1987). They are also important for composition and abundance of bottom fauna, as well as for epiphytic and mining organisms. They provide not only food and protection against predators but also protection from excessive water movements (Poznanska *et al.,* 2009). These aquatic plants are mostly referred as Macrophytes. They are predominantly vascular plants and are divided usually on the basis of their habit and location in ponds or lakes. They may be 1) the marginal emergent plants, 2) the rooted submerged hydrophytes, 3) the rooted hydrophytes with floating leaves and 4) the free surface floating hydrophyte (Odum, 1996). They also provide protection from predation (Mittelbach, 1988; Schriver *et al*., 1995).

In India, almost all the water resources are occupied with various types of macrophytes *viz*. rooted, free-floating, submerged, *etc*, forming an integral part of the ecosystem and acting as bio-filters (Dhote and Dixit, 2007). Human activities such as wetland reclamation and construction of buildings on wetland have adverse effect on the macrophytes. Further harvesting of the aquatic vegetation for various purposes produce greatest impact on the distribution of these vegetation and also the entire aquatic ecosystems (Zhao, 2013).

In Gujarat, studies on freshwater macrophytes have been carried out by Mukherjee *et al.*, (2002). Few studies deal with the effect of water level fluctuations on macrophytes bottom fauna and of near-shore zones of these water bodies (Hynes, 1961; Richardson *et al.,* 2002). A study carried out in two Florida lakes suggests higher density of invertebrate taxa in vegetated water as compared to open waters (Schramm and Jirka, 1989). The importance of macrophytes as a substrate for benthos when the mud is unfavorable is also studied in the back waters of the Amazon. Here, the floating mats of *Paspalidium sp*. and other macrophytes serve as a potential habitat for benthic fauna (Fittkau, 1971;Junk, 1973). Macrophytic vegetation plays an important role in maintaining the ecosystem of a lake. Depending on a water body's intended use, aquatic plants can be looked upon either as beneficial parts of the aquatic ecosystem or as nuisance.

All the four types of macrophytes are important for the wetland ecosystem. The abundance of littoral macroinvertebrates is closely related to the presence of soft vegetation. Submerged macrophytes change the physical and chemical conditions of their surroundings, providing a better habitat for both phytophilous and bottom fauna (Vermaat *et al*., 2000; Madsen *et al*. 2001; Cheruvelil *et al.,* 2002; Pinowska, 2002; Tessier *et al*., 2004) while the free-floating ones act as substrates for attachment of the invertebrates. Macrophytes affect, and in turn get affected by, their surroundings but are relatively slow in responding to changes (Naturvårdsverket, 2007). They show differences in preference to nitrogen, phosphorus, pH and alkalinity (Marklund, 2008). Overabundant plant growth is usually caused by excessive nutrients (nitrogen and phosphorus). Phosphorus along with sediment may enter the pond through runoff from the catchment area. The Phosphorus increases the nutrient level in wetland and the sediments cause siltation, further decreasing the depth of wetland (Rizzo *et al.,* 2009).

The purpose of this investigation is to determine the quality and preferences of macrophytes and to assess how they differ within the three irrigation reservoirs through which one can determine their effects on birds and macroinvertebrates.

Materials and methods

The study was carried out from March 2009 to February 2011. The study area was sampled for macrophytes by quadrat sampling. Six quadrats of 30 cms. X 30 cms. were selected randomly for collection of macrophytes per visit. The samples were collected, sorted, washed, dried, and preserved between blotting papers. The macrophytes were mainly identified at least up to genus level with the help of standard keys.

The macrophytes are analysed by diversity indices like Species richness for each visit. Total number of species observed per visit is considered as species richness. Only Jaccard's similarity index (J) was carried out to understand the similarity in species between the study areas. Percentage of occurrence was calculated using the following formula:

Number of times a species was observed / total number of species (for both annual and seasonal).

The macrophytes observed in the study were given abundance scale according to the rate of their encounter during the study period. The species observed during >35 visits were rated as Abundant, that observed between 26-35 visits as Common, those observed 11-25 times as Frequent, for 5-10 visits as Uncommon and those that were observed <5 times as Rare.

For the statistical analysis the data for species richness of 3 months is pooled according to the seasons as Summer: March, April, May; Monsoon: June, July, August; Post-monsoon: September, October, November and Winter: December, January, February. Further the Mean and standard error of mean (SEM) were calculated and One-way ANOVA performed as described by Fowler and Cohen, (1995) with No post test for various parameters for four seasons using GraphPad Prism version 3.00 for Windows, (GraphPad Software, San Diego California USA). The p value for ANOVA is non significant if $P > 0.05$ (ns), significant if $P < 0.05$ (*), significantly significant (**) if P is < 0.001 and highly significant (***) if $p < 0.0001$.

Results

A total of 24 species (Annexure 3; Plate 8) of macrophytes were accounted for during the whole study periods at all the three irrigation reservoirs. Of these 22 species each were observed at WIR and TIR and 12 at JIR (Annexure 3). According to the classification by Whittaker (1972), all these species belonged to 11 orders namely Solanales, Nymphaeales, Alismatales, Poales, Gentianales, Fabales, Caryophyllales, Lamiales, Ranunculales and Malpighiales. These orders included altogether 14 families namely Convolvulaceae, Gentianaceae, Nymphaeaceae, Nelumbonaceae, Hydrocharitaceae, Poaceae, Cyperaceae, Najadaceae, Gramineae, Amaranthaceae, Verbenaceae, Papaveraceae, Typhaceae and Euphorbiaceae. Of these, Nympheaceae, Hydrocharitaceae, Najadaceae, Gentianaceae, Amaranthaceae, Verbenaceae, Papaveraceae and Euphorbiaceae were not sampled at JIR.

Mean species richness (Table 5.1, Fig. 5.1)

Annual

The annual mean species richness was highest 5.97±0.27 species at TIR, 5.63±0.27 at species WIR and 4.05±0.22 species at JIR with highly significant differences when comparison among the reservoirs were made (P<0.0001; $F_{(2,116)}$ 16.01.)

Seasonal

When seasonal comparison for each reservoir was carried out at WIR highest species richness per quadrate was observed during monsoon (7.3±0.56 species). During summer it was 5.83±0.4 species, during post-monsoon 5.1±0.48 and during winter it was 5.17±0.34. Significantly significant seasonal variations were noted (P<0.001; $F_{(3,34)}$ 5.25). At TIR also, highly significant seasonal variations were noted (P<0.0001; $F_{(3,39)}$ 17.34) with highest species richness during monsoon (8.4±0.37 species) which declined during post-monsoon (5.4±0.34 species) and winter (4.91±0.37 species) and increased during summer (5.5±0.36 species). A different trend was observed at JIR, with maximum 5.63±0.46 species during monsoon, 4.29±0.29 species during post-monsoon, 3.64±0.31 species during winter and 3.25±0.3 species during summer. Here also the seasonal variations were highly significant (P<0.0001; $F_{(3,34)}$ 9.75).

Comparisons among the reservoirs

When species richness among the reservoirs were compared (Table 1), highest species richness per quadrat was recorded during summer at WIR and TIR followed by JIR (P<0.0001; $F_{(2,27)}$ 16.07). During monsoon high species richness was observed at TIR followed by WIR and JIR with significantly significant differences (P<0.001; $F_{(2,25)}$ 7.69) while no differences were noted during post-monsoon (P>0.05; $F_{(2,24)}$ 1.82). During winter also a similar trend was observed but with significantly significant differences ($P<0.001$; $F_{(2,31)}$ 5.7).

Jaccard's similarity index (Table 5.2; Fig. 5.2, 5.3)

The annual Jaccard's similarity index was maximum between WIR + TIR with 87% common species, followed by 48% between TIR + JIR and minimum between JIR + WIR with 43%.

During monsoon the Jaccard's similarity index was maximum between WIR + TIR with 63% similarity, followed by 46% between JIR + WIR and minimum 38% between TIR + JIR. However, during post-monsoon the similarity was maximum between WIR + TIR with 64%, followed by between TIR + JIR with 36% and minimum between JIR + WIR with 33%. In winter it was 40% each between WIR + TIR and between JIR + WIR while 35% between TIR +JIR. During summer it was 63%; 38% and 46% respectively between WIR + TIR, TIR + JIR and JIR+ WIR.

Percentage occurrence of Macrophytes

Annual (Table 5.3)

When percentage occurrence for each species is calculated, the species that occurred most at WIR was *Limnanthemum indicum* and *Ipomoea aquatica* with 15% and 14% respectively. At TIR and JIR *Ipomoea aquatica* dominated with 16% and 24% respectively while *Limnanthemum indicum* was absent at both the reservoirs. *Najas graminea* also occurred with higher percentage 10% and 14% respectively at WIR and TIR while this species was absent at JIR. *Nymphaea nouchali* occurred throughout the year at TIR but only with 1% while it was not found at WIR and JIR. Same was the case with *Nelumbo nucifera* which dominated throughout the year with 24% occurrence only at JIR but was not found at WIR or TIR. *Hydrilla verticillata* was encountered most at WIR (8%) and TIR (9%) only. *Ipomoea carnea* occurred most at TIR with 10% occurrence but at WIR only with 1% and was absent at JIR. *Cynodon dactylon* occurred at three reservoirs with 5%, 5% and 8% respectively. While *Cyperus rotundus* occurred with 6%, 6% and 7% occurrence at WIR, TIR and JIR respectively. *Eragrostis sp.* occurred at 3%, 1% and 2%, respectively while sedges for example *Bulbostylis barbata* occurred at 0.94% at WIR, 1% at TIR and was absent at JIR. *Typha sp.* occurred most at JIR with 13% followed by 4% at TIR and only 1% at WIR. One more member of Gramineae family was noted at WIR, TIR and JIR was *Dactyloctenium aegyptiacum* with 0.47%, 1% and 2% occurrence and *Euphorbia hirta* was recorded at all the three reservoirs with 2 % each at WIR and TIR and 0.65% at JIR. Other species found at three reservoirs were *Echinocloa colonum* with 8 % at WIR, 6 % at TIR and 7% at JIR, *Chloris barbata* with 3%, at WIR 2% at TIR and 1% at JIR, *Eleusine indica* with 5% at WIR, 3% at TIR and 4% at JIR and *Tephrosia sp.* with 3% at WIR, 1% at TIR and 1% at JIR. *Andropogon gerardii* was encountered at 0.94% at WIR and, 1% at TIR. *Vetiveria zizanioides* also occurred with 1% each at WIR and TIR respectively. *Desmostachya bipinnata* occurred seldom and only at WIR (2%) and TIR (3%). Shrubs like *Alternanthera axillaris* and *Lippia nodiflora* occurred only at WIR (0.94% and 1%) and TIR (2% and 3%). Also a small thorny species called *Argemone mexicana* occurred at WIR (0.47%) and TIR (0.78%).

<u>Seasonal</u> (Table 5.4)

WIR

Summer: During summer, the highest occurrence at WIR was noted for submergent species *Najas graminea* with 16% followed by *Cyperus rotundus, Echinocloa colonum* and *Limnanthemum indicum* a rooted free-floating hydrophyte with 11% occurrence each. *Ipomoea aquatica* and *Hydrilla verticillata* occurred at the same value of 8% during this season. Grasses such as *Cynodon dactylon, Eragrostis sp., Chloris barbata* and *Eleusine indica* occurred at 5% in the reservoir. *Ipomoea carnea, Tephrosia sp., Euphorbia hirta* and *Typha sp.* occurred at 2% during high temperatures of summer.

Monsoon: During the rainy season, as the water level increased, highest occurrence of *Echinocloa colonum* was noted at 10%. *Limnanthemum indicum* and *Ipomoea aquatica* were noted at 9% while *Cynodon dactylon* occurred at 7%. *Cyperus rotundus, Eragrostis sp., Tephrosia sp., Euphorbia hirta* and *Desmostachya bipinnata* each at 6%. *Ipomoea carnea, Chloris barbata, Eleusine indica* and *Lippia nodiflora* occurred at 4% while *Andropogon gerardii, Vetiveria zizanioides, Bulbostylis chordata and Alternanthera axillaris* occurred at 3% during monsoon. *Argemone mexicana* and *Typha sp.* occurred at 1% at the reservoir.

Post-monsoon: During post-monsoon also *Limnanthemum indicum* and *Ipomoea aquatica* dominated the reservoir at 20% occurrence. *Hydrilla verticillata* and *Najas graminea* occurred at 16% and 14% respectively. *Cyperus rotundus* and *Echinocloa colonum* occurred at 6 % while, *Cynodon dactylon, Eragrostis sp.* and *Eleusine indica* occurred at 4% and *Typha sp., Tephrosia sp.* and *Chloris barbata* at 2%.

Winter: *Limnanthemum indicum* and *Ipomoea aquatica* dominated the reservoir at 20% and 19% occurrence. This was followed by *Najas graminea* with 16% and *Hydrilla verticillata* with 11% occurrence, *Eleusine indica* with 8% and the most common weed *Echinocloa colonum* with 6%. *Cyperus rotundus* and *Cynodon dactylon* occurred at 5% and was of *Eragrostis sp., Vetiveria zizanioides, Tephrosia sp., Desmostachya bipinnata* and *Chloris barbata* with minimum occurrence at 1% at the reservoir.

TIR

Summer: At TIR, highest occurrence was noted for *Ipomoea aquatica* with 18% dominance. This was followed by *Hydrilla verticillata* (13%), *Najas graminea* (15%) and *Ipomoea carnea* (10%). *Cyperus rotundus* occurred in the area at 7%,. *Typha sp.* and *Echinocloa colonum* occurred at 4% each while *Nymphaea nouchali, Eleusine indica, Euphorbia hirta* and *Desmostachya bipinnata* occurred at the reservoir with 3% occurrence. At 1% occurrence each *Dactyloctenium aegyptiacum, Bulbostylis barbata, Chloris barbata, Tephrosia sp., Alternanthera axillaris* and *Lippia nodiflora* were noted least during the studies.

Monsoon: During rainy season, *Ipomoea aquatica* dominated with 12% occurrence followed by *Ipomoea carnea* with 10%, *Najas graminea* and *Echinocloa colonum* with 9% and 8% respectively. *Cyperus rotundus* and *Lippia nodiflora* occurred at 6% each. While *Cynodon dactylon Chloris barbata*, *Eleusine indica, Desmostachya bipinnata* and *Typha sp.* all occurred at 4% during the season. However, submergent species *Hydrilla verticillata,* and other shrubs like *Alternanthera axillaris* and *Euphorbia hirta* occurred at 3% during monsoon at this reservoir. *Bulbostylis chordata*, *Tephrosia sp.* and *Vetiveria* *zizanioides* occurred at 2% while *Eragrostis sp., Dactyloctenium aegyptiacum, Argemone mexicana* and *Andropogon gerardii* occurred at minimum 1% at the reservoir.

Post-monsoon: During post-monsoon also *Ipomoea aquatica* dominated with 18% followed by *Najas graminea* with 16% occurrence, *Ipomoea carnea* with 11%. *Cynodon dactylon* with 7% followed by *Hydrilla verticillata, Typha sp., Echinocloa colonum* and *Lippia nodiflora* each with at 5% while *Cyperus rotundus, Eleusine indica* and *Andropogon gerardii* with 3% each. *Nymphaea nouchali, Eragrostis sp., Dactyloctenium aegyptiacum, Tephrosia sp., Chloris barbata, Desmostachya bipinnata* and *Vetiveria zizanioides* occurred at 1% with least occurrence at the reservoir.

Winter: At TIR also *Ipomoea aquatica* dominated with 20% occurrence during winter. *Najas graminea* and *Hydrilla verticillata* followed with 16% occurrence each while *Ipomoea carnea* and *Cyperus rotundus* dominated at 7% and 9% occurrence respectively. *Cynodon dactylon* and *Echinocloa colonum* occurred at 5% while 1% occurrence was noted for the free floating species *Nymphaea nouchali* and Poaceae family member *Eragrostis sp., Eleusine indica, Tephrosia sp., Chloris barbata, Desmostachya bipinnata, Eragrostis sp., Dactyloctenium aegyptiacum, Vetiveria zizanioides* and other species like *Argemone mexicana, Lippia nodiflora, Euphorbia hirta* and *Typha sp.* at the reservoir.

JIR

Summer: During the dry season at JIR, the decreasing water levels lead to the occurrence of emergent species such as *Ipomoea aquatica* and *Nelumbo nucifera* which are free floating rooted hydrophyte. Both the species were noted at 30% occurrence each. These were followed by the common species of grass *Echinocloa colonum* with 7% occurrence, *Typha* the invasive species at 10% while *Cyperus rotundus, Eleusine indica* and *Cynodon dactylon* at 5% and *Eragrostis sp., Dactyloctenium aegyptiacum, Tephrosia sp., Chloris barbata* and *Euphorbia hirta* at 2%.

Monsoon: During this season too *Ipomoea aquatica* and *Nelumbo nucifera* (17%) dominated the reservoir. *Typha sp.* and *Echinocloa colonum* followed with 11% and 13% respectively. *Cynodon dactylon* and *Cyperus rotundus* at 8% each occurrence while *Eleusine indica* occurred at 6% and *Dactyloctenium aegyptiacum, Tephrosia sp.* had 4% occurrence . *Eragrostis sp., Chloris barbata* and *Euphorbia hirta* each occurred at 2%.

Post-monsoon: The dominating species at JIR was *Ipomoea aquatica* with 24% occurrence in post-monsoon. *Nelumbo nucifera* and *Typha sp.* occurred at 20% and 17% respectively while *Cynodon dactylon* and *Cyperus rotundus* occurred at 10%. *Echinocloa colonum* occurred at 6% while all other macrophytes such as *Eragrostis sp., Dactyloctenium aegyptiacum, Chloris barbata, Eleusine indica* and *Euphorbia hirta* occurred at 3%.

Winter: During winter, *Ipomoea aquatica* and *Nelumbo nucifera* occurred with a percentage of 25% and 30% respectively at the reservoir. *Cynodon dactylon* and *Typha sp.* occurred at 10% and 12% respectively while *Cyperus rotundus* was noted at 7% occurrence. *Echinocloa colonum* and *Eleusine indica* occurred at 5% during this season. *Eragrostis sp.* and *Dactyloctenium aegyptiacum* occurred at 2%.

Table 5.1. Species Richness of macrophytes at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Species Richness	**WIR**	**TIR**	**JIR**
Annual (***) $\mathbf{F_{(2,116)}}$ **16.01**	5.63 ± 0.27	5.97 ± 0.27	4.05 ± 0.22
Seasonal	**(**)$\mathbf{F_{(3,34)}}$ 5.25**	**(***)$\mathbf{F_{(3,39)}}$ 17.34**	**(***)$\mathbf{F_{(3,34)}}$ 9.75**
Summer (***) $\mathbf{F_{(2,27)}}$ **16.07**	5.83 ±0.4	5.5 ± 0.36	3.25 ± 0.3
Monsoon (**) $\mathbf{F_{(2,25)}}$ **7.69**	7.3 ±0.56	8.3 ± 0.37	5.63 ± 0.46
Post-monsoon (ns) $\mathbf{F_{(2,24)}}$ **1.82**	5.1 ±0.48	5.4 ± 0.34	4.29 ± 0.29
Winter (**) $\mathbf{F_{(2,31)}}$ **5.7**	5.17 ± 0.34	4.91 ± 0.37	3.64 ± 0.31

Table 5.2. Annual and seasonal Jaccard's similarity index (J) at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Jaccard's similarity index (J)	**WIR+TIR**	**TIR+JIR**	**JIR+WIR**
Annual	87%	48%	43%
Seasonal Jaccard's similarity index			
Summer	63%	38%	46%
Monsoon	73%	52%	50%
Post-monsoon	64%	36%	33%
Winter	40%	35%	40%

Table 5.3. Annual percentage occurrence of macrophytes found at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Species	WIR	TIR	JIR
Ipomoea aquatica	14.55	16.80	24.18
Ipomoea carnea	1.88	10.16	-
Limnanthemum indicum	15.02	-	-
Nymphaea nouchali	-	1.17	-
Nelumbo nucifera	-	-	24.84
Hydrilla verticillata	8.45	9.38	-
Najas graminea	10.8	14.06	-
Bulbostylis barbata	0.94	1.17	-
Cyperus rotundus	6.57	6.64	7.84
Cynodon dactylon	5.63	5.08	8.5
Eragrostis sp.	3.29	1.56	2.61
Tephrosia sp.	3.29	1.56	1.96
Chloris barbata	3.76	2.34	1.31
Eleusine indica	5.63	3.13	4.58
Desmostachya bipinnata	2.35	3.13	-
Echinocloa colonum	8.45	6.25	7.84
Andropogon gerardii	0.94	1.17	-
Vetiveria zizanioides	1.41	1.56	-
Alternanthera axillaris	0.94	2.34	-
Lippia nodiflora	1.41	3.91	-
Argemone mexicana	0.47	0.78	-
Euphorbia hirta	2.35	2.34	0.65
Typha sp.	1.41	4.30	13.07
Dactyloctenium aegyptiacum	0.47	1.17	2.61

Table 5.4. Seasonal Percentage occurrence of macrophytes found at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

Species	Sites	Summer	Monsoon	Post-monsoon	Winter
Ipomoea aquatica	WIR	8.33	9.09	20.83	19.35
	TIR	18.46	12.20	18.52	20.00
	JIR	30.77	17.78	24.14	25.00
Ipomoea carnea	WIR	2.78	4.55	-	-
	TIR	10.77	10.98	11.11	7.27
	JIR	-	-	-	-
Limnanthemum indicum	WIR	11.11	9.09	20.83	20.00
	TIR	-	-	-	-
	JIR	-	-	-	-
Nymphaea nouchali	WIR	-	-	-	-
	TIR	3.08	-	-	1.82
	JIR	-	-	-	-
Nelumbo nucifera	WIR	-	-	-	-
	TIR	-	-	-	-
	JIR	30.77	17.78	20.69	30.00
Hydrilla verticillata	WIR	8.33	-	16.67	11.67
	TIR	13.85	3.66	5.56	16.36
	JIR	-	-	-	-
Najas graminea	WIR	16.67	-	14.58	16.67
	TIR	15.38	9.76	16.67	16.36
	JIR	-	-	-	-
Cynodon dactylon	WIR	5.56	7.58	4.17	5.00
	TIR	3.08	4.88	7.41	5.45
	JIR	5.13	8.89	10.34	10.00
Cyperus rotundus	WIR	11.11	6.06	6.25	5.00
	TIR	7.69	6.10	3.70	9.09
	JIR	5.13	8.89	10.34	7.50
Bulbostylis barbata	WIR	-	3.03	-	-
	TIR	1.54	2.44	-	-
	JIR	-	-	-	-
Erogrostis sp.	WIR	5.56	6.06	-	1.67
	TIR	-	1.22	1.85	1.82
	JIR	2.56	2.22	3.45	2.50
Tephrosia sp.	WIR	2.78	6.06	2.08	1.67
	TIR	1.54	2.44	1.85	1.82
	JIR	2.56	4.44	-	-
Chloris barbata	WIR	5.56	4.55	2.08	1.67
	TIR	1.54	4.88	-	1.82
	JIR	-	2.22	3.45	-
Eleusine indica	WIR	5.56	4.55	4.17	8.33
	TIR	3.08	4.88	3.70	-
	JIR	5.13	6.67	-	5.00

Desmostachya bipinnata	**WIR**	-	6.06	-	1.67
	TIR	3.08	4.88	1.85	1.82
	JIR	-	-	-	-
Echinocloa colonum	**WIR**	11.11	10.61	6.25	6.67
	TIR	4.62	8.54	5.56	5.45
	JIR	7.14	10.42	6.45	4.88
Andropogon gerardii	**WIR**	-	3.03	-	-
	TIR	-	1.22	3.70	-
	JIR	-	-	-	-
Vetiveria zizanioides	**WIR**	-	3.03	-	1.67
	TIR	-	2.44	1.85	1.82
	JIR	-	-	-	2.44
Alternanthera axillaris	**WIR**	-	3.03	-	-
	TIR	1.54	3.66	-	-
	JIR	-	-	-	-
Lippia nodiflora	**WIR**	-	4.55	-	-
	TIR	1.54	6.10	5.56	1.82
	JIR	-	-	-	-
Argemone mexicana	**WIR**	-	1.52	-	-
	TIR	-	1.22	-	1.82
	JIR	-	-	-	-
Euphorbia hirta	**WIR**	2.78	6.06	0.00	
	TIR	3.08	3.66	3.70	1.82
	JIR	-	2.22	-	-
Typha sp.	**WIR**	2.78	1.52	2.08	-
	TIR	4.62	4.88	5.56	1.82
	JIR	10.26	13.33	17.24	12.50
Dactyloctenium aegyptiacum	**WIR**	-	-	-	1.67
	TIR	1.54	-	1.85	1.82
	JIR	0.00	4.44	3.45	2.50

Figure 5.1. Annual and seasonal species richness of macrophytes at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

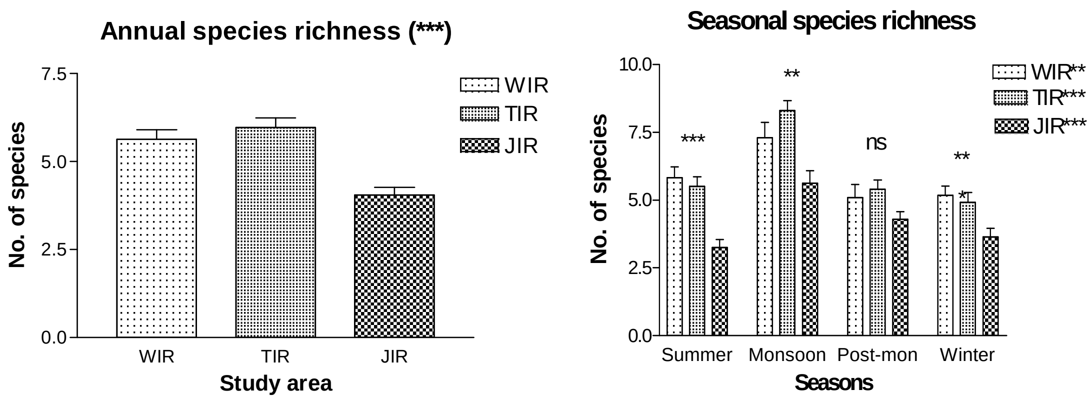


Figure 5.2. Annual Jaccard's similarity index (J) at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)

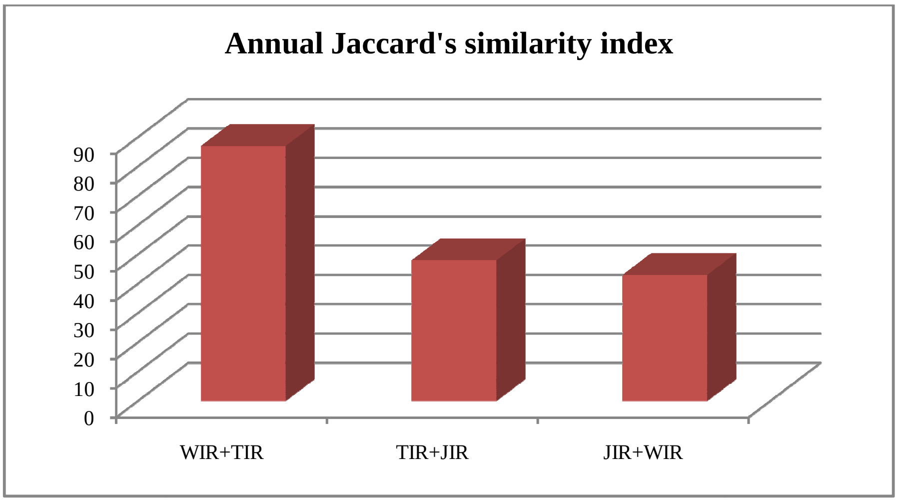
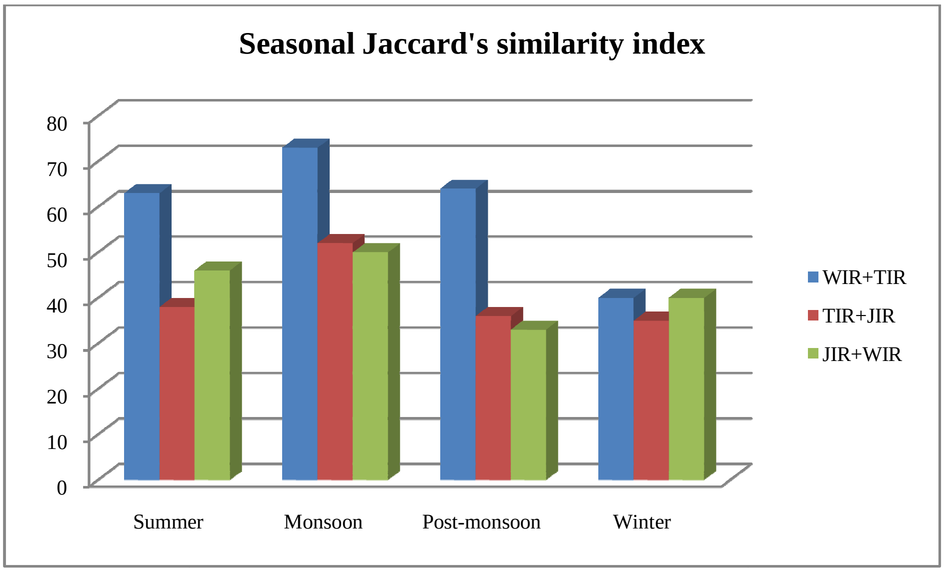


Figure 5.3. Seasonal Jaccard's similarity index (J) at Wadhwana Irrigation Reservoir (WIR), Timbi Irrigation Reservoir (TIR) and Jawla Irrigation Reservoir (JIR)



Discussion

Changes in water level and temperature in the study areas were the main variables determining the condition of investigated sites with reference to different macrophyte stands over the seasons. The depth at the sites primarily depended on the water inflow from the Narmada river which resulted in prolonged shallowness of the study sites.

Species richness

While it appears that relationships between species richness and whole-lake area are not always significant, stronger interactions may be found in cases where only the actual vegetated area is used as a predictor (Vestergaard and Sand-Jensen, 2000). In a review of world-wide data for 139 lakes, Duarte *et al.,* (1986) found that the cover of hydrophytes is relatively smaller in larger water bodies, rather than being a constant proportion of the lake area.

The species richness was highest when calculated annually at TIR as the whole earthen dam is heavily covered with different species of plants. At WIR, although the species were similar to TIR, because of the construction of a concrete dam (Plate 6) at both the reservoirs replacing the earthen one, sandy soil was added. This changed the composition of vegetation. Personal observations lead to a conclusion that TIR recovered faster as compared to WIR in terms of loss of the plant species. Although, JIR had a dense vegetation of *Calotropis sp.* and other shrubs on its dam, the edges of the reservoir from where the samples were collected were covered with *Ipomoea aquatica* and some members of Poaceae family throughout the study. Hence, least annual species richness was noted at JIR during the whole study. The high species diversity of macrophytes in the reservoirs studied is also a consequence of the diversity of habitats on the banks of the reservoir, mainly morphometric characteristics of the shoreline, its slope, water depth, and pollution by nutrients (Heegaard *et al.,* 2001; Irfanullah and Moss, 2004).

The high richness noted during summer at TIR and WIR are probably the result of extended hydroperiod due to Narmada inundation. The areas sampled at TIR were covered with vegetation for almost whole study period while the points at which the quadrats were sampled at WIR had more dry vegetation. The area at the backside of the WIR has very shallow damp areas where little vegetation could survive except when completely submerged. Hence the occurrence of macrophyte species decreased at WIR in comparison to TIR. At JIR however, the earthen dam was densely covered with vegetation, but at the sampling points on the northern side of the reservoir, the dam was covered with dense reeds of *Typha sp.* Also known as Cattails, these reeds are reported to dominate the marsh wetlands that have seasonal standing water along the margins (Robb, 1989). They have been discovered to be highly invasive (Davis and Ogden, 1994). Hence because of the domination of the edges of this reservoir by emergent vegetation like *Typha sp.* and *Ipomoea aquatica* the richness is low in comparison to the other two reservoirs studied.

Aquatic plant coverage is expected to continue to fluctuate based on natural conditions, predominantly due to rainfall. Rainfall leads to proliferation of seeds that become dormant due to dry weather of summer. Thus rainfall leads to a visible lush green cover. . Rainfall also increases the water level in the reservoirs. These two factors lead to an increase in the species richness as higher water level also submerges the other terrestrial vegetation grown on the earthen dam and hence higher numbers of species were recorded per sample. The species richness during monsoon was also high at TIR and WIR but a lesser effect of rainfall was found at JIR. At WIR and TIR inundation of Narmada water also led to high water levels in the reservoir in winter. As JIR lacks direct Narmada Inundation, water level fluctuations were low in comparison to the other two reservoirs where seasonal species dry but other survive throughout the year. Richness of macrophytes in Post-monsoon showed similar responses and followed the same trend with high richness at the three reservoirs. After monsoon, although the water levels stabilize gradually, the proliferation of terrestrial as well as aquatic vegetation continues maintaining the richness.

Winter showed a different trend with highest species richness at both TIR and WIR due to prolonged hydroperiod and hydrospread and least at JIR. As summer nears a different kind of mosaic of microhabitats is formed at WIR and TIR. The survival strategies of macrophytes to fluctuations of environmental conditions involve resistant spores, seeds, dormant vegetative parts and flexibility of life cycles (Grillas, 2004, Bella *et al*., 2010). Hence, early winter showed a good diversity at both the reservoirs but as the reservoir started drying up due to high temperature, the richness gradually decreased during late winters. Species like *Limnanthemum indicum*, two species of *Ipomoea*, *Hydrilla verticillata* and *Najas graminea* led to good species richness in the area.

When richness among the reservoirs was compared, TIR showed highest richness in summer in comparison to other reservoirs as it never dried up completely during the study period and hence contained more species. Same was the case in monsoon and post-monsoon as TIR had the most diverse flora which leads to its dominance among the three reservoirs studied. But during winters due to low temperatures the growth in plants declined and hence lowest species richness was recorded in this season with WIR and TIR observing very similar richness quotient.

Jaccard's similarity index (J)

The distance between the three reservoirs surveyed is about 25-50 kms. and hence the similarity between the three reservoirs would be evident. The seed dispersal due to natural conditions as well as biotic components cannot be ruled out. Seeds of *Typha sp.* are dispersed by wind and those of *Nelumbo sp.* by animals. Others species are may be dispersed through Narmada canal as among the three reservoirs the highest similarity index was noted between WIR and TIR and lowest at WIR and JIR. Thus the distance being longer in this said reservoir dispersal through wind can be minimum. Similarity between WIR and TIR may be because of the role of abundant emergent species like *Ipomoea aquatica*, submerged hydrophytes like *Hydrilla verticillata* and *Najas graminea.* These submerged hydrophytes were absent at JIR. Also grasses like *Cynodon dactylon* and sedges like *Cyperus rotundus* were very common in the area. However, according to Gee *et al.*, (1997), it is likely that two small ponds would together support more species than a single large pond. This was evident during the study period. Not surprisingly, the proximity of other waterbodies has an influence on the local species richness and composition of macrophyte communities (Van den Brink *et al.*, 1991; Bornette *et al.*, 1998).

Seasonal similarities in the study areas were more evident as less than 50% similar species between the three reservoirs in summer and winter when dry conditions are created because of extreme temperatures in the region. However, in monsoon and post-monsoon the similarities were higher because monsoon is the season when productivity increases with favourable atmospheric conditions and also other abiotic environmental variables. This indicates that when macroclimatic conditions in the area are moderate various plant species are distributed in wider area. The similarity index during the cold season was almost similar at all the three irrigation reservoirs as only those macrophytes proliferate which were resistant to colder temperatures in the area.

Percentage occurrence

<u>Annual</u>

The annual percentage occurrence was highest for emergent vegetation of *Ipomoea aquatica* at all the three reservoirs. This genera has been documented as largely invasive species in any freshwater ecosystem dominating most freshwaters and have been known to cause ecological problems too (Lacoul and Freedman, 2006). Though *Limnanthemum indicum* was also an abundant species it was found only at WIR while *Nymphaea nouchali* only at TIR. As both WIR and TIR are becoming perennial due to Narmada inundation, their original feature was seasonal (Deshkar, 2008). The free-floating macrophytes survived and hence were sampled for the whole study period. Even *Hydrilla verticillata* and *Najas graminea* both submergent species were found during the whole study period at WIR and TIR. The decreased water clarity due to inundation of water from Narmada may decrease the presence of these submergent species. Similar results were noted by Zhao *et al.*, (2013) in a lake in China. This species was entirely absent at JIR as the edges of this water body are predominantly covered with *Ipomoea aquatica*. The central portion of JIR is completely occupied with *Nelumbo nucifera* known as Indian Lotus. This species was present all throughout year but was observed at JIR only. According to Meerhoff, (2003) direct competition by phytoplankton for nutrients minimize the free floating species in freshwater habitats. This may stand true in the present study. The levels of phytoplankton recorded by Rathod (2009) for JIR are comparatively lower than those reported at WIR and TIR by Deshkar (2008) indicating lower nutrient competition for the macrophytes.

Duarte *et al.*, (1987) suggested that emergent macrophytes typically colonize a relatively constant proportion of the lake area, regardless of the absolute size of the water body. Also, low-light conditions in the shallow littoral zone promote dominance by emergent species and they do not grow deeper than 3 mts. As samples of macrophytes were taken from shallow waters the occurrence by emergent species of vegetation, most members of family: Poaceae like grasses and weeds of family Cyperaceae was common (See annexure 3). All Gramineae members were noted to be at very low occurrence values at TIR and JIR and *Typha sp.* at JIR which are again invasive weeds.

Other than the above mentioned aquatic species, some terrestrial species were also noted during the study while sampling. One of them is *Lippia nodiflora*, which is a herb. It prefers well drained sandy soils and often encountered near bordering waterways. This species was common at TIR, rare at WIR and absent at JIR. At TIR it was found in water when water levels were high. Also considered as an invasive weed, *Alternanthera axillaris* was not very common during the study but occurred frequently at TIR. As the earthen dam at TIR was more steep and deeper at the edges terrestrial vegetation were also commonly noted when water levels were high. An extremely hardy pioneer plant, *Argemone mexicana* tolerant of drought and poor soil, was a rare species occurring in the samples. Similarly, *Euphorbia hirta* was noted rarely only at WIR. Being common in open grasslands, this species was frequently sighted during the study period but rarely occurred in samples. These indicate that at the two larger reservoirs because of fluctuating water level occasionally terrestrial species present at the edge are also submerged.

Seasonal

The seasonal changes in the percentage occurrence of plants (aquatic or terrestrial) are dependent on many factors such as biogeography, dispersal, climatic factors, hydrology, *etc*. (Lacoul and Freedman, 2006). The seasonal occurrence of *Ipomoea aquaticaimum* was maximum at all the three reservoirs, although it was less abundant during monsoon at WIR where water levels were very high. As mentioned earlier, this is an invasive species found in moist soils and hence common in freshwater ecosystems. *Ipomoea carnea*, rare in its occurrence near shore was found on the opposite side of the earthen dam at WIR where dampness in soil was prevalent. It was noted only during summer and monsoon at the reservoir as during summer small patches of water led to its proliferation which survived in water during monsoon too. Also known as aquatic weed, the same species was more frequent at TIR. *Limnanthemum indicum* frequently occurred at WIR during post-monsoon and winter mainly as this species prefers overall warm climate of the tropics. At the other two reservoirs the dominance of other aquatic emergent species of macrophytes may have lead to the absence of this species. Next was the submergent vegetation species *Hydrilla verticillata* and *Najas graminiea* at WIR and TIR with frequent occurrences during post-monsoon and winter and rare occurrences during summer because of fluctuating water levels during the above mentioned seasons and drier conditions during summer at WIR. Its higher occurrence during all seasons except monsoon at TIR was noted because of lower water level fluctuations as the reservoir did not dry up during summer as noted for WIR.

In any aquatic ecosystem, monocots (grasses) dominate the vegetation having more species diversity in contrast to terrestrial habitats (Sukumaran and Jeeva, 2011). In present study also, the members of the family Gramineae and Cyperaceae occurred frequently during sampling at the reservoirs. Most of them were emergent. They are mainly invasive weeds of agriculture crops and generally prefer warm and moist climates of the tropics with a very wide range of distribution. They were equally distributed throughout the four seasons. *Cynodon dactylon* was a very common species found at the three irrigation reservoir in all the seasons whose growth and development are promoted by warm moist conditions. *Cyperus rotundus* is also another common species but rare in occurrence in the present study. As it prevails in hot and moist areas it was mostly found during summer and monsoon. *Eleusine indica* also tolerates dry conditions well. Due to its tolerance to drought, it occurred throughout the year at all the three irrigation reservoirs. *Echinocloa colonum* normally growing under dryland conditions; does not thrive flooded soils. Its seed has little or no dormancy and germinates throughout the year when moisture is available and hence it occurred during monsoon at WIR. Although sampling limitations must have led to its rarity in samples at TIR and it did not occur at JIR. Sedges also normally occur near aquatic habitats. Widely distributed over the warmer parts of the world, *Bulbostylis barbata*, was rare in samples but very abundant at all the three irrigation reservoirs throughout the year. *Chloris barbata* present in waste places and rotation crops has very wide distribution in tropics and hence it probably occurred at all the study sites but observed only during summer and monsoon showing its preference for warmer climates. *Typha sp.* is also an invasive genus mostly found dominating near water bodies. Commonly found at the edges of the reservoirs it is emergent in nature and does not allow any other species to proliferate in its vicinity. This species occurred throughout the year at all the three irrigation reservoirs.

Conclusion

In conclusion, it can be said that more diverse plant species occurred at two larger reservoirs WIR and TIR as fluctuating levels of water due to monsoon and Narmada inundation with effect of seasonal changes created varied microclimatic conditions where several plant species fluctuated in their occurrence all throughout the year. At the smaller reservoir JIR, the climatic conditions had pronounced effect and mainly tolerant species occurred throughout the year.

PLATE 8

PHYLUM: TRACHEOPHYTA

ORDER: NYMPHAEALES

FAMILY: NYMPHAEACEAE

Nymphaea nouchali

ORDER: RANUNCULALES

FAMILY: PAPAVERACEAE

Argemone mexicana

ORDER: FABALES

FAMILY: FABACEAE

Tephrosia sp.

ORDER: GENTIANALES

FAMILY: GENTIANACEAE

Limnanthemum indicum

ORDER: SOLANALES

FAMILY: CONVOLVULACEAE

Ipomoea aquatica

Ipomoea carnea

ORDER: PROTEALES

FAMILY: NELUMBONACEAE

Nelumbo nucifera

ORDER: LAMIALES

FAMILY: VERBENACEAE

Lippia nodiflora

ORDER: CARYOPHYLLALES

FAMILY: AMARANTHACEAE

Alternanthera axillaris

ORDER: MALPHIGIALES

FAMILY: EUPHORBIACEAE

Euphorbia hirta

ORDER: ALISMATALES

FAMILY: HYDROCHARITACEAE

Hydrilla verticillata

ORDER: NAJADACEAE

Najas graminea

ORDER: POALES

FAMILY: CYPERACEAE

Cyperus rotundus

FAMILY: GRAMINEAE

Cynodon dactylon

FAMILY: GRAMINEAE (Contd.)

Eragrostis sp.

Chloris barbata

Dactyloctenium aegypticum`

Echinocloa colonum

FAMILY: GRAMINEAE (Contd.)

Andropogon gerardii

Vetiveria zizanioides

Desmostachya bipinnata

SUMMARY

Wetlands are among the most important and productive ecosystems of the world and are important bird habitats. In the semi-arid zone of Central Gujarat irrigation reservoirs provide varied microhabitats to birds. Migratory as well as resident shorebirds utilize these wetlands in huge numbers. They use very different habitats, great distances apart, during breeding and non-breeding (wintering) seasons. On the wintering grounds their primary concern is fuelling up in recovery from, and preparation for, long distance migration. The macroinvertebrates form the prey base for the birds. Out of the diverse forms of invertebrates the molluscs form a major component as they are the source of calcium. In recent years, there is a greater emphasis given on the studies for understanding benthic environment, its communities and productivity and this has led to increased exploitation of many inland water bodies. However, conservation strategies for wetland invertebrates are still poorly developed, and, in general, there are few case studies on the conservation of this large, diverse and important group. The occurrence and the distribution of these invertebrates is influenced by the water quality. The interacting physical and chemical factors influence the level of primary productivity in aquatic ecosystems and thus influence the aquatic food web. Vegetation in these ecosystems has also been known to have a profound effect on the distribution of birds and benthic communities. Hence, a thorough understanding is needed for conservation and management of these ecosystems. The present study deals with wader density and diversity at three irrigation reservoirs and role of benthic fauna, physico-chemical properties of water and soil and vegetation on the same with seasonal changes.

Chapter 1

Birds have higher dispersal rate and are the first to abandon any of the unfavourable condition and thus are considered to be the important component of a habitat. This chapter deals with the wading birds. They respond by moving to local concentrations of food availability and move away from unsuitable areas. Hence their presence and absence is also used to assess the transient conditions of wetlands. Research on waterbird communities in India has mainly involved habitat diversity, population structure and the importance of migratory species visiting from other continents, essentially in the western, eastern and southern parts of the country. In Gujarat, Vadodara district boasts of a number of natural and man-made wetlands with varied habitats. Of the three irrigation reservoirs studied, one is less disturbed and the other two are under anthropogenic pressures due to closer human settlements. All three are surrounded by agricultural matrices.

The study conducted for migratory as well as resident and resident-migratory waders include total of 25 species, of small and large waders, preferring to feed on the infauna (in substratum) and epifauna (on substratum) of the reservoirs. Of these, 13 were migratory, 11 resident and 1 resident-migratory. When the mean density of small waders was considered, it was highest at WIR in comparison to the other reservoirs with seasonal fluctuations, as the migratory populations swarm the area increasing the density and species richness in winter. Among the three, WIR is the most preferred site for resident as well as the as migratory species with late migrants utilizing the wetland till early summer. WIR and TIR also provided habitats for the early migrants and resident species during post-monsoon. However, at JIR, the low density all throughout the year may be attributed to the absence of shallow water in the reservoir alongwith the dense vegetation on the earthen dam as well as in catchment area. This wetland is mainly preferred by large resident species of waders which could feed on epifauna amongst vegetation and simultaneously keep a watch on approaching predator if any. The lowest density and the species richness of the waders were observed during monsoon at all the three reservoirs because of the absence of migratory species in the area. However, populations of egrets and Glossy Ibis at the three study areas mainly affected the densities of large waders in the area. They were also noted to be least in monsoon as during this period these species are busy in their nesting activities and as water is everywhere with abundant supply of food, their visits to water bodies are infrequent.

It is known that when the species diversity (H') is high the birds are less evenly distributed (E is low). However, in the present study H' and E for small waders are low at the larger wetland with high density and species richness while high at smaller wetland with few species and low density of birds.

Family Scolopacidae which includes Ruffs, Godwits and Sandpipers were maximum at WIR in comparison to TIR and JIR as the highest migratory populations of this family members were noted at WIR especially during winter. The recurvirostrids that include single species of Black-winged Stilt was noted to be high at TIR which indicates their preference for the water with higher nutrient content. Charadriids on the other hand were high at JIR because of higher number of Red wattled lapwing in agriculture fields in the immediate vicinity of reservoir. Although the Charadriids also include plovers that were common at WIR, plovers did not make up a significant population influencing the density of this family at WIR. Glareolids (pratincoles and coursers) were noted to be maximum at WIR as Oriental pratincoles could acquire their preferred habitat at this reservoir. Rostratulids (Greater painted snipe) were rare in the study. Of the large waders, family Threskiornithidae *i.e.* mainly Glossy Ibis preferred the backside of WIR where shallow water levels increase food availability. The Ardeids *i.e.* egrets preferred the agricultural matrices around JIR and hence their higher population around it.

Thus, TIR and WIR support both migratory (mainly small waders) and resident (Large waders) species of birds while JIR due to its vegetation composition supports large resident species of birds.

Chapter 2

This chapter includes studies on benthic fauna other than Molluscs. 79 species belonging to 38 families of 11 orders noted at the three reservoirs indicates presence of good diversity in benthos. Seasonally, highest species richness of benthos noted in winter at WIR and TIR supports the huge number of migratory species of birds. In summer due to dry conditions, many benthoses undergo aestivation while many die in unsuitable conditions hence are inaccessible. Breeding rate is also low hence the density as well as diversity declined. However, during monsoon because of the high water levels at the reservoir which led to their dispersal from the area few benthos were recorded. As water levels stabilised the richness started developing in post-monsoon due to their successful breeding in presence of moderate climate with reference to temperature and humidity. The highest density of benthos was noted at WIR which has larger area followed by TIR and JIR. Due to the prevailing circumstances at local levels *i.e.* submerged vegetation at WIR and TIR while more emergent vegetation at JIR, the status of macrobenthic fauna was different with the former two supporting more infauna while later one epifauna.

The diverse vegetation at JIR provided spatial heterogeneity and protection from severe competition and predation to carabids. Hence, not much fluctuation was observed in their density at the reservoir. The high occurrence of coleopterans and hemipterans in the study sites is attributed to their preference for varied microhabitats for their survival in the area. The carabids mainly dominating in moist soil had very high occurrences in WIR and TIR. Trombidiforms were the second dominant group at WIR because of their preference for open waters which was not available at the other two reservoirs. However, at JIR, hemipterans dominated as the hebrid (low DO tolerant species) were abundant. The occurrence of oligochaetes can be indicative of their preferences to moist soil. The hymenopterans made their presence felt all throughout the year and hence had moderate occurrence. Ground spiders were sampled more at JIR because of the presence of vegetation on the earthen dam and the dipterans because of the larvae of *Culex sp.* that were encountered frequently. All other orders such as orthopterans, ephemeropterans, trichopterans and odonates had very low occurrence in the present study as majority of them are aquatic in nature.

The similarity in the macrobenthos was overall high between WIR and TIR because of the similarities in the habitats due to extended but fluctuating water cover and hydro-period. The physico-chemical properties of water and soil correlated variably with benthic fauna. Narmada inundation and different agricultural practices lead to the mixing of water further changing the soil and water chemistry. Under such circumstances benthos undergoing aestivation/hibernation can survive for longer duration. The conditions are more pronounced at WIR and TIR.

Chapter 3

Molluscs are one of the major prey base for several species of birds especially water birds as they are major source of calcium for egg shell production. In the present study of the semi arid zone only six species of mollusc belonging to five families were noted.

Bellamya bengalensis was the most widely distributed species that was dominant at three wetlands (WIR, TIR and JIR) but with different status. *Lamellae consobrinus* were sighted occasionally at WIR and TIR. The Narmada water inundation takes place at both the irrigation reservoirs influencing water levels. *Indoplanorbis exustus* is the dominant species at JIR and TIR which is under anthropogenic pressure. This species is known to sustain in the water with high nutrient content. Sightings of *Thiara granifera* was very rare at the three reservoirs studied.

The variations in density of mollusc are different during all the seasons and indicate that the water cover and not the water level affect the density of the molluscs. Further, other factors affecting the mollusc were the lower temperature that forces the mollusc to move to deeper parts of the soil. Hence the density of the birds like Glossy ibis, Godwits, and Ruffs that have longer beak were higher in numbers at these wetlands as their long beak helped them to catch the mollusc from the deeper soils. All the reservoirs studied showed different abiotic factors correlated with molluscan density. Correlation regarding the soil physico-chemical parameters and the mollusc density indicated a significant relationship of molluscan density to calcium content needed for their growth and development and with soil pH as they need alkaline environment for survival.

Chapter 4

This chapter deals with the study of physical and chemical properties of water and soil of three reservoirs. The physical and chemical properties of freshwater body are characteristic of the climatic, geochemical, geomorphological and pollution conditions as well as anthropogenic activities. The physico-chemical properties of water as well as soil affect the biota present therein.

The parameters for the physico-chemical properties of water studied include water temperature, pH, Acidity, Bicarbonate Alkalinity (HCO_3^-), Hydroxyl Alkalinity (OH^-), Salinity, Dissolved Oxygen (DO) and Carbon dioxide (CO_2), Chloride (Cl^-), Kjeldahl nitrogen, Nitrate (NO_3^-), Nitrite (NO_2^-), Inorganic and Total Phosphates (PO_4^{-3}) and Sulphates (SO_4). While the physical and other aggregate properties of soil studied are soil texture, pH and Organic matter, while, inorganic non-metallic constituents includes Chloride (Cl^-), Total Nitrogen, Total Phosphorus, Calcium and Magnesium.

These parameters are affected due to seasonal fluctuations in the climatic conditions, water level, inundation from Narmada, anthropogenic pressure *etc*. At the three reservoirs in subtropics although overall weather is comparatively warmer, fluctuation in temperature and humidity (rain) are observed. The inundation from Narmada River during the study influenced the water level probably changing the chemistry of water and soil. As WIR was almost dry during the summer of first year of the study, high fluctuations were noted in the physico-chemical properties of its water and soil whereas the anthropogenic disturbances at TIR influenced the nutrient levels. However at JIR presence of emergent vegetation all throughout the year showed the impacts on the chemistry of water and soil. The high sandy composition at the three reservoirs may have adverse effects on the biotic communities in the area. For example, the construction of a concrete dam during the study period led to increase in the sand content which increased due to its addition in WIR while mowing of vegetation and reconstruction of the existing dam at TIR effecting on the biotic communities. The high organic matter content at JIR is a symptom of eutrophication in the reservoir decreasing the faunal use of the reservoir.

Chapter 5

This chapter deals with study of macrophytes in the study areas. Macrophytes are large plants, mostly referred to as aquatic plants. Changes in water level and temperature in the study areas were the main variables determining the location of investigated sites with different macrophyte stands and the periods of sampling over two years. In addition to rainwater the depth at the sites primarily depended on the water inflow from the Narmada river which resulted in extended shallowness of the study sites.

All together 24 species of macrophytes were accounted during the whole study periods at all the three irrigation reservoirs. Of these 22 species were observed at WIR and TIR each while only 12 at JIR. The richness was highest when calculated at TIR as the whole earthen dam is heavily covered with different species of plants while at WIR the construction of a concrete dam brought changes in the vegetation cover. Earthen dams at WIR and TIR were repaired and parts we replaced by concrete which lead to losses in natural vegetation at the irrigation reservoirs. The least species richness noted at JIR during the whole study was due to invasive species. At JIR the sampling points on the northern side of the reservoir are covered with dense reeds of *Typha sp.*

The seasonal changes in the percentage occurrence of plants (aquatic or terrestrial) are dependent on many factors such as biogeography, dispersal, climatic factors, hydrology, etc. *Ipomoea aquatica* had highest occurence at all the three reservoirs, although it was less abundant during monsoon at WIR because of very high water levels in the reservoir. *Ipomoea carnea*, rare in occurrence, was present on the opposite side of the earthen dam at WIR where dampness in soil was prevalent. It was noted only during summer and monsoon at the reservoir. A higher occurrence of the submerged macrophytes during all seasons except monsoon was noted at TIR because of the lower water level fluctuations as the reservoir did not dry up during summer as seen at WIR. Members of family Gramineae and Cyperaceae occurred frequently during sampling at the reservoirs. Most of them were emergent. They are mainly invasive weeds of agriculture crops and generally prefer warm and moist climates of the tropics with a very wide range of distribution.

Hence the present study summarizes the dependence of fauna on the flora of the three reservoirs studied. The presence of submerged and emergent vegetation in the study areas ultimately affected the distribution of benthos on which the waders were dependent. These interlinking characteristics of a food chain will help us in understanding the ecosystems near wetlands.

GENERAL CONSIDERATIONS

Wetlands are one of the crucial natural resources. Wetlands are areas of land that are either temporarily or permanently covered by water. This means that a wetland is neither truly aquatic nor terrestrial. The wetlands exhibit enormous diversity according to their genesis, geographical location, water regime and chemistry, plants and soil or sediment characteristics. Because of their transitional nature, the boundaries of wetlands are often difficult to define. Wetlands do, however, share a few attributes common to all forms. Of these, hydrological structure (the dynamics of water supply, storage and loss) is most fundamental to the nature of a wetland system.

The three study areas selected in the present study are man-made irrigation reservoirs with difference in hydroperiod, geography and anthropogenic pressures. Of the three selected reservoirs two are regularly inundated with Narmada water (WIR and TIR). The third one, JIR without Narmada inundation does get Narmada water through seepage from canal that is passing nearby. Further it also has river tributaries in its catchment area which might be responsible for the input of water in the wetland. The human disturbances as well as the land matrix around the three reservoirs are also different influencing the flora and fauna present differently. These reservoirs support good density and diversity of waterfowls since there is increase in hydroperiod after the Narmada inundation. The results of studies by Deshkar, (2008) led to the identification of WIR as a potential IBA and one more candidate of Ramsar sites in Gujarat. As the density and diversity of birds depend on food availability, shelter, physico-chemical properties of water and soil, a smaller portion of wader diversity with its associated characteristics of soil, water, benthos and vegetation is considered in the present study. Deshkar, (2008) has stressed the need for evaluation of its potential to supports other organisms.

The present study is thus important in understanding occurrence of huge diversity and density of wader population in the reservoirs of Central Gujarat. This study is expected to make us understand the importance and dependence of macrobenthos that link the producers and consumers in an aquatic ecosystem like wetlands and its surrounding areas. With Ramsar convention, together with the Convention on Biodiversity, other species have also started receiving importance. The objectives of the present study were to determine the influence of water chemistry, sediment characteristics and availability of different prey categories on the wading bird use of the irrigation reservoirs and to evaluate the impacts of Narmada inundation on the same.

Birds are the prominent species inhabiting wetlands and form an important link in the food chain. Due to their ability to occur in varied conditions, they are considered as important indicators of health of an ecosystem. Study on wading bird populations was carried out at three irrigation reservoirs in a time span of two years from 2009 to 2011 (Chapter I). As these birds are dependent on other organisms especially benthic macroinvertebrates like insects and mollusc, the density and species richness of benthic fauna were studied (Chapter II and III). The primary productivity of a wetland depends on the water and soil chemistry which includes the physical, chemical parameters and inorganic non-metallic constituents. Hence, the fluctuations in water and soil chemistry are also considered (Chapter IV). Also, any fauna is ultimately dependent on the primary producers in an ecosystem. Thus a study on the vegetational composition at the three study sites has also been carried out in the present study (Chapter V).

The role of food abundance on water bird densities has been well established hence in a study of waders it becomes necessary to evaluate the factors affecting the abundance of macroinvertebrates.

The early migrants and resident species led to a moderate to higher density of waders at the reservoirs with less seasonal fluctuations (WIR and TIR). While during the non migratory seasons the density of birds was influenced by the microhabitats available at the wetlands. Extended hydroperiod and the availability of suitable habitat during different seasons were the two important factors affecting the species richness.

When the relation between waders and the physico-chemical properties of water is considered, variable significant as well as non-significant correlations were noted between wader density and physico-chemical properties of soil and water at the three reservoirs. This indicated the influence of Narmada inundation which keeps on changing chemistry of water and soil. Hence no single factor could be correlated with wader density.

Benthic macroinvertebrates have been intriguing targets of biological monitoring efforts because they are a diverse group of long-lived, sedentary species that react strongly and often, predictably to human influence on aquatic ecosystems. This group plays an important role as indicators of aquatic pollution. Benthos being rich in proteins, form an important component that influence habitat selection by waterbirds especially waders. Significant seasonal changes found in species richness and density of many species of the macrozoobenthic at the three irrigation reservoirs indicate their dependency on environmental factors. These changes are highly pronounced at the reservoirs under prominent Narmada inundation compared to non-inundated reservoir, JIR supporting the influence of Narmada water on fauna. Another factor influencing the species richness is anthropogenic pressures. WIR is mainly undisturbed large habitat hence the number of species present therein may be positively influenced whereas TIR facing moderate human disturbances and urban expansion is expected to support urban adaptors too influencing species richness. At JIR, the reservoir with moderate size and low human impact such conditions do not prevail and hence supports moderate species richness. Further, a decline in the density of benthic fauna from post-monsoon to winter and there after increase till February, stresses the influence of climatic conditions on the benthic invertebrates. The heterogeneity in habitat is provided by emergent vegetation at JIR.

In general, percent occurrence was high for coleopterans and hemipterans while in addition at WIR, trombidiforms also occurred with high occurrence. Many ground dwelling coleopterans prefer moist/wet soils while aquatic and semi-aquatic hemipterans prefer burrowing as well as swimming in water. All other orders had moderate to low occurrence at the three reservoirs depending on the preference of varied microhabitats.

When correlations are considered between benthos and the water quality, a significant but negative correlation was noted with salinity and sulphate at WIR, a positive one with nitrite and water temperature at TIR while no correlations were obtained for JIR. On the other hand, the correlations with soil noted a positive and significant correlation with coarse sand at WIR while with very fine sand at TIR.

The high productivity of the silty-sand and loose sandy sediment make the benthic invertebrates easily accessible for waders which was also noted in the present study as percent silt+clay correlated positively at all the three irrigation reservoirs. On the basis of the correlation of the benthic fauna with the abiotic factors also it can be said that the wetland ecosystems are maintained by the interdependency of various factors changing due to Narmada inundation.

The other component of benthic fauna, the molluscs had high density at WIR and TIR while at JIR it was low. This supports the idea that the characteristics of a wetland with Narmada inundation and without it are different. *Bellamya bengalensis,* was the most widely distributed and hence abundant at WIR. As WIR changed from seasonal to almost perennial, this species was abundant but it was frequent at TIR and JIR. *Indoplanorbis exustus* was frequent at WIR and TIR while abundant at JIR. The high organic input because of use of reservoir by locals may have led to its abundance as this species is tolerant to polluted water. *Thiara granifera* was a rare occurrence at all the three reservoirs while *Lymnaea auricularia* was noted only at WIR. The bivalve, *Lamallae consobrinus* was occasional at TIR, rare at WIR and altogether absent at JIR. Also, their breeding activities and the high levels of water in the reservoirs made their sampling difficult.

The correlation between physico-chemical properties of water and molluscs, indicated influence of fluctuating levels of water due to Narmada inundation leading to frequent change in its chemistry. However, molluscs being shelled animals can entrap their body mass in shell and protect it and emerge when the conditions are favorable in the seasonal change in their density and no single common best predictor could be defined which can be the sole factor responsible for the density of the molluscs. Further, the assumption that the presence of emergent vegetation (JIR) influences the diversity of dependent fauna stands true as at JIR status of various species of mollusc was quite different with differences in seasonal cycle.

All organisms and the communities are directly or indirectly affected by the physical characteristics of their environment. Thus, the study of interactions between biotic and abiotic factors becomes essential to understand the community structure of an ecosystem. The interrelated correlation of different parameters of water and soil chemistry suggests the physicochemical characteristic of the wetland. Hence, the quality of water and soil is also considered in the present study. The differences in these abiotic variables are mainly expected because of the climatic changes, the geographic locations (the distance from the city area), the anthropogenic pressures and the hydrology of a wetland. The seasonal differences in soil and water chemistry with differences among the three reservoirs supports the assumption that due to fluctuations resulted in water levels in response to Narmada inundations common correlations between various physico-chemical parameters could not be found.

On the basis of the present study it can be concluded that because of large size as well as Narmada inundation, WIR ahs good diversity of submergent and emergent vegetation. This provides shelter to migratory as well as resident species of waders but huge density and diversity of their prey base. Though fluctuations in parameter of water chemistry do not support a single species, the diverse species available with their own life cycle do provide prey base in different seasons.

Similarly, TIR also supports good diversity and density of waders which get almost similar conditions available at WIR. As it is a smaller reservoir density and diversity supported by it is comparatively lower.

Lastly, the vegetation studied at three reservoirs also showed differences in relation to Narmada inundation. In India, almost all the water resources are occupied with various types of macrophytes viz. rooted at shoreline, free-floating, submerged, etc, forming an integral part of the ecosystem and acting as bio-filters.

The similarity in the species composition at TIR and WIR further supports the assumption of effect of Narmada inundation. These two reservoirs are nearer to each other and receive Narmada water under the same schedule. At JIR, the earthen dam was mainly occupied by *Ipomoea aquatica* and some Poaceae family members. Hence least annual species richness was noted. The differences in vegetation may be related to the closer vicinity of TIR to urban conditions. At TIR, *Typha sp.* and *Ipomoea aquatica* contributed to the richness. Monsoon serves as a medium through which nutrients and other solutes move in the plants. Also, the water levels have increased in the reservoirs. These two factors lead to an increase in the species richness. In addition as higher water level also submerges some terrestrial vegetation grown on the earthen dam. The annual percentage occurrence was highest for emergent vegetation of *Ipomoea aquatica* at all the three reservoirs. The species provides shelter as well as nesting site for many species of birds. However, *Nymphaea nouchali* found at the edge of TIR and *Nelumbo nucifera* in the middle of JIR also provide encourage to prey base of birds. This species was present all round the but was observed at JIR only.

The differences in the occurrence of plants (aquatic or terrestrial) are dependent on many factors such as biogeography, dispersal, climatic factors, hydrology, etc. The distance between the three reservoirs surveyed is about 25-50 kms. and hence the similarity between the three reservoirs would be evident. Here, the movements of seeds due to natural conditions or human involvement cannot be ruled out.

The present study proves to be a useful source of information regarding the wetlands of the semi arid zone of Central Gujarat, India, and help in preparing the conservation and management strategies.

ANNEXURES

Annexure 1

List of the Waders observed at the three reservoirs with their migratory pattern

Sr. No.	Common Name	Scientific Name	WIR	TIR	JIR	Resident/ Migratory
	Phylum: Chordata; Super-class: Tetrapoda; Class: Aves; Sub-class: Neornithes					
A	**Order: Charadriiformes**					
I	**Family: Charadriidae**					
1	White tailed lapwing	*Vanellus leucurus*	*	-	-	**M**
2	Little ringed Plover	*Charadrius dubius*	*	*	-	**M**
3	Kentish Plover	*Charadrius alexandrinus*	*	*	-	**M**
4	Red-wattled Lapwing	*Vanellus indicus*	*	*	*	**R**
II	**Family: Scolopacidae**					
5	Eurasian Curlew	*Numenius arquata*	*	*	-	**M**
6	Black-tailed Godwit	*Limosa limosa*	*	*	-	**M**
7	Common Redshank	*Tringa acteal*	*	-	-	**M**
8	Little Stint	*Calidris minuta*	*	*	-	**M**
9	Ruff	*Philomachus pugnax*	*	*	*	**M**
10	Marsh Sandpiper	*Tringa stagnatilis*	*	*	*	**M**
11	Common Greenshank	*Tringa nebularia*	*	-	-	**M**
12	Spotted Sandpiper	*Tringa glareola*	*	*	*	**M**
13	Common Sandpiper	*Actitis hypoleucos*	*	*	*	**M**
III	**Family: Rostratulidae**					
14	Greater Painted Snipe	*Rostratula bengalensis*	*	*	-	**R**
IV	**Family: Recurvirostridae**					
15	Black-winged Stilt	*Himantopus himantopus*	*	*	*	**R**
V	**Family: Glareolidae**					
16	Indian Courser	*Cursorius coromandelicus*	*	*	-	**R**
17	Oriental Pratincole	*Glareola maldivarum*	*	-	-	**M**
B	**Order: Ardeiformes**					
VI	**Family: Ardeidae**					
18	Grey heron	*Ardea cinerea*	*	*	*	**R**
19	Large Egret	*Casmerodius albus*	*	*	*	**R**
20	Intermediate Egret	*Mesophoyx intermedia*	*	*	*	**R**
21	Little Egret	*Egretta garzetta*	*	*	*	**R**
22	Indian Pond Heron	*Ardeola grayii*	*	*	*	**R**
VII	**Family: Threskiornithidae**					
23	Black-headed Ibis	*Threskiornis melanocephalus*	*	*	*	**R**
24	Black Ibis	*Pseudibis papillosa*	*	*	*	**R**
25	Glossy Ibis	*Plegadis falcinellus*	*	*	*	**RM**

Annexure 2

List of the Benthic fauna alongwith abundance scale of families observed at the three reservoirs

Sr. No.	Scientific Name	WIR	TIR	JIR
α	**Phylum: Arthropoda**			
▲	**Class: Insecta**			
A	**Order: Coleoptera**			
I	**Family: Carabidae**	**F**	**F**	**UC**
1	*Apotomus sp.*	*	*	*
2	*Tachys luxus*	*	*	-
3	*Bembidion sp.*	*	*	-
4	*Casnoidea indica*	-	*	-
II	**Family: Staphylinidae**	**F**	**F**	**R**
5	*Paederus fucipes*	*	*	*
6	*Paederus sp.*	*	*	*
7	*Bledius sp.*	*	-	-
III	**Family: Cleridae**	**R**	-	-
8	Unidentified sp.	*	-	-
IV	**Family: Chrysomelidae**	**R**	**UC**	**UC**
9	*Aphthona sp.*	*	*	-
10	*Cryptocephalus sp.*	-	*	-
11	*Chaetocnema basalis*	-	*	-
12	Unidentified sp. 1	-	-	*
13	Unidentified sp. 2	-	*	-
14	Unidentified sp. 3	-	-	*
V	**Family: Coccinellidae**	**R**	-	-
15	*Stethorus sp.*	*	-	-
VI	**Super family: Hydrophiloidea**	* **(R)**	-	-
VII	**Family: Hydrophilidae**	**R**	**UC**	**R**
16	*Hydrophilus sp.*	-	*	-
17	Unidentified sp. 1	*	*	-
18	Unidentified sp. 2	-	*	-
VIII	**Family: Noteridae**	**R**	**R**	**R**
19	*Canthydrus sp.*	*	*	*
20	Unidentified sp.	*	*	*
IX	**Family: Dytiscidae**	-	**R**	**R**
21	*Hydaticus sp.*	-	*	-
22	*Laccophilus sp.*	-	*	-
23	Unidentified sp. 1	-	-	*
24	Unidentified sp. 2	-	*	-
X	**Family: Limnichidae**	-	**R**	-
25	*Byrrhinus sp.*	-	*	-
26	Unidentified sp.	-	*	-

XI	**Family: Curculionidae**	**-**	**R**	**R**
27	*Lissorhptrus sp.*	-	*	*
B	**Order: Hemiptera**			
XII	**Family: Hebridae**	**R**	**R**	**F**
28	*Hebrus sp.*	*	*	*
29	Unidentified sp.	-	-	*
XIII	**Family: Cercopidae**	**R**	-	-
30	*Bofylus sp.*	*	-	-
XIV	**Family: Mesovellidae**	**R**	-	-
31	*Mesovelia sp.*	*	-	-
XV	**Family: Pleidae**	**R**	**R**	**R**
32	*Paraplea sp.*	*	-	-
33	Unidentified nymph	-	*	-
34	Unidentified sp. 1	*	-	-
35	Unidentified sp. 2	-	-	*
XVI	**Family: Gerridae**	**R**	**R**	**R**
36	*Gerris sp.*	*	*	*
XVII	**Family: Gelastocoridae**	**R**	**R**	-
37	*Nerthra sp.*	*	*	-
XVIII	**Family: Ochteridae**	**R**	-	-
38	*Ochterus sp.*	*	*	-
XIX	**Family: Nepidae**	**R**	**R**	-
39	*Nepa sp.*	*	*	-
XX	**Family: Corixidae**	**R**	**R**	-
40	*Micronecta sp.*	*	*	-
XXI	**Family: Notonectidae**	**R**	**R**	-
41	Unidentified sp.	*	*	-
XXII	**Family: Lygaeidae**	-	-	**R**
42	Unidentified sp.	-	-	*
C	**Order: Diptera**			
XXIII	**Family: Culicidae**	**R**	**UC**	**UC**
43	*Culex sp.*	*	*	*
XXIV	**Family: Chironomidae**	**R**	**R**	-
44	*Chironomous sp.*	*	*	-
D	**Order: Orthoptera**			
XXV	**Family: Gryllotalpidae**	**R**	**R**	**R**
45	*Gryllotalpa africana*	*	*	*
XXVI	**Family: Tridactylidae**	**R**	**R**	-
46	*Xya sp.*	*	*	-
E	**Order: Odonata**			
47	Sub-family: Lestinae	* (**R**)	*(**R**)	-
48	Unidentified sp. 1	*	-	-
49	Unidentified sp. 2	-	-	*
50	Unidentified sp. 3	-	*	-
F	**Order: Hymenoptera**			

XXVII	**Family: Formicidae**	**UC**	**UC**	**UC**
51	*Camponotus compressus*	*	*	*
52	*Camponotus radiatus*	*	-	-
53	*Camponotus sericeus*	*	*	*
54	*Camponotus sp.1*	*	*	*
55	*Camponotus sp. 2*	-	-	*
56	*Camponotus sp.3*	-	*	-
57	*Oecophylla smaragdina*	*	*	*
58	*Monomorium minimum*	*	*	*
59	*Solenopsis invicta*	*	*	*
XXVIII	**Family: Aphidiidae**	-	**R**	-
60	*Aphis sp.*	-	*	-
G	**Order: Ephemeroptera**			
62	Unidentified sp.	* (**R**)	-	*(**R**)
H	**Order: Trichoptera**			
XXIX	**Family: Hydropsychidae**	**R**	**R**	-
63	Unidentified sp.	-	*	-
▲	**Class: Arachnida**			
I	**Order: Araneae**			
XXX	**Family: Araneidae**	**R**	**UC**	**R**
64	*Argiope sp.*	*	*	*
XXXI	**Family: Salticidae**	**R**	**R**	**R**
65	*Plexippus sp.*	*	*	*
XXXII	**Family: Lycosidae**	**R**	**R**	**R**
66	*Paradosa sp.*	*	*	-
XXXIII	**Family: Tetragnathidae**	-	-	**R**
67	*Tetragnatha sp.*	-	-	*
XXXIV	**Unidentified Spiders**	**R**	**R**	**R**
68	Unidentified sp. 1	*	-	-
69	Unidentified sp. 2	-	*	-
70	Unidentified sp. 3	-	-	*
J	**Order: Trombidiformes**			
XXXV	**Family: Hydrachnidae**	**UC**	**UC**	**R**
71	*Hydrachna sp.*	*	*	*
72	Unidentified sp. 1	*	*	*
β	**Phylum: Annelida**			
▲	**Sub-Class: Oligochaeta**			
J	**Order: Megadrilacea**			
XXXVI	**Family: Naididae**	**R**	**UC**	**UC**
73	*Dero sp.*	*	-	-
74	*Branchiura sowerbyi*	*	*	-
75	*Stylaria fossularis*	-	*	*
76	*Tubifex tubifex*	*	*	*
XXXVII	**Family: Megascolecidae**	**R**	**R**	-

77	*Perionyx sp.*	*	*	-
XXXVIII	**Unidentified Annelids**	**R**	**R**	-
78	Unidentified sp. 1	*	-	-
79	Unidentified sp. 2	-	*	-

Annexure 3

List of the Macrophytic vegetation alongwith abundance scale observed at the three reservoirs

Sr. No.	Scientific name	WIR	TIR	JIR	Type of vegetation
	Kingdom: Plantae; Phylum: Tracheophyta				
A	**Order: Nymphaeales**				
I	**Family: Nymphaeaceae**				
1	*Nymphaea nouchali*	**-**	*** R**	**-**	Rooted free floating
B	**Order: Ranunculales**				
II	**Family: Papaveraceae**				
2	*Argemone mexicana*	*** R**	*** R**	**-**	Terrestrial
C	**Order: Fabales**				
III	**Family: Fabaceae (Papilionaceae)**				
3	*Tephrosia sp.*	*** UC**	***R**	***R**	Terrestrial
D	**Order: Gentianales**				
IV	**Family: Gentianaceae**				
4	*Limnanthemum indicum*	*** C**	**-**	**-**	Rooted free floating
E	**Order: Solanales**				
V	**Family: Convolvulaceae**				
5	*Ipomoea aquatica*	*** C**	*** A**	*** A**	Emergent
6	*Ipomoea carnea*	*** R**	*** C**	**-**	Emergent
F	**Order: Proteales**				
VI	**Family: Nelumbonaceae**				
7	*Nelumbo nucifera*	**-**	**-**	***A**	Rooted free floating
G	**Order: Lamiales**				
VII	**Family: Verbenaceae**				
8	*Lippia nodiflora*	*** R**	*** F**	**-**	Terrestrial
H	**Order: Caryophyllales**				
VIII	**Family: Amaranthaceae**				
9	*Alternanthera axillaris*	*** R**	*** UC**	**-**	Terrestrial
I	**Order: Malphigiales**				
IX	**Family: Euphorbiaceae**				
10	*Euphorbia hirta*	*** R**	*** UC**	*** R**	Terrestrial
J	**Order: Alismatales**				
X	**Family: Hydrocharitaceae**				
11	*Hydrilla verticillata*	*** F**	*** F**	**-**	Submergent
XI	**Family: Najadaceae**				
12	*Najas graminea*	*** F**	*** A**	**-**	Submergent
K	**Order: Poales**				
XII	**Family:Cyperaceae**				

13	*Cyperus rotundus*	*** F**	*** F**	***F**	Terrestrial
14	*Bulbostylis barbata*	*** R**	*** R**	**-**	Terrestrial
XIII	**Family: Gramineae**				
15	*Cynodon dactylon*	*** F**	*** F**	***F**	Terrestrial
16	*Eragrostis sp.*	*** UC**	*** R**	*** R**	Terrestrial
17	*Chloris barbata*	*** UC**	*** UC**	***R**	Terrestrial
18	*Eleusine indica*	*** F**	*** UC**	*** UC**	Terrestrial
19	*Echinocloa colonum*	*** F**	*** F**	*** F**	Terrestrial
20	*Andropogon gerardii*	*** R**	*** R**	*** R**	Terrestrial
21	*Vetiveria zizanioides*	*** R**	*** R**	*** R**	Terrestrial
22	*Desmostachya bipinnata*	*** R**	*** UC**	**-**	Terrestrial
23	*Dactyloctenium aegypticum*	*** R**	*** R**	*** R**	Terrestrial
XIV	**Family: Typhaceae**				
24	*Typha sp.*	*** R**	*** F**	*** F**	Emergent

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