CHAPTER 3

ODONATE DIVERSITY AROUND WETLANDS

Introduction

Odonata is the order consisting of the Dragonflies (Anisoptera) and Damselflies (Zygoptera), which is a small but well-known order of insects with wide distribution. Adult dragonflies and damselflies are the most easily recognizable insect taxa (Maiolini and Carolli, 2009), due to their comparatively larger size amongst the insects, bright colours and diurnal nature with interesting behavioural patterns.

All the Odonates have aquatic nymphs that are active predators preying on almost any kind of ingestible organisms they can perceive. The adults are highly adapted for an active aerial life and most of their behaviour takes place on the wings. They are generalized, obligate carnivores (Corbet, 1962) predating on small insects predominantly during flight (Mitra, 2007). Anisopteran larvae leave the water shortly before dawn while the zygopteran larvae during the day (Miller, 2007). Their adult life is mainly composed of two behavioural patterns, Feeding and Reproduction. The first half after the emergence as adult is utilized for dispersal and feeding so that the young imago can develop into mature adults while the second half, after getting itself established in a habitat, is utilized mainly for the purpose of reproduction.

Odonata is a relatively well-known order of insects whose members breed in a wide variety of aquatic habitats. Some species are specialists that use discrete habitats and others are generalists that are able to survive in different types of environments (Cannings et al., 2007). For several reasons, odonates are given priority in inventory of biodiversity of a habitat (Scudder, 1996). Unlike most invertebrates, they can be relatively easily identified, even in field in many cases. They are upper level predators in the invertebrate food chain and have often been identified as indicators of ecosystem health (Walker and Corbet, 1975; Carle,
1979; Takamura et al., 1991; Clark and Samways, 1996; Trevino, 1997; Corbet, 1999; Cannings et al., 2007). Many species are habitat specific, and their presence has been used to characterize health of wetlands of all sorts. Odonates are also considered among the most popular ‘flagship’ groups of insects (Oertli et al., 2002), and parallel the role for aquatic environments that the butterflies play for terrestrial ones (Hawking and New, 2002) and are well suited for long-term monitoring programs (Cannings et al., 2007). Their amphibious life history, relatively short generation time, high trophic position, and diversity (Corbet, 1993; Clark and Samways, 1996) are the characteristics that make them indicator species useful in providing an early warning system for subtle (and not so subtle) shifts in water quality, biotic community composition, and trophic dynamics due to human activities in and around wetlands.

As Anisopteran species have excellent flying capacities, they are not expected to meet great difficulties in extending their range. However, Zygopterans are weak fliers and hence face greater difficulties in extending their range (Beukema, 2007). Compared to dragonflies, damselflies are adapted to a larger variety of habitats, indicating the greater ecological diversity of this taxon (Steytler and Samways, 1995).

Being primarily aquatic, their life history is closely linked to the specific aquatic habitats. It is possible to detect a community of this group around ponds or streams. The diversity of dragonfly species is considered as an emergent property of such ecological category (Begon et al., 1996; Perez et al., 2007). However, the Odonates show low correlations with environmental variables in microhabitat scale; while, strong correlation at biotope scale, and hence are postulated as good indicators of particular habitats (Samways et al., 1996).

As their life cycle depends on the suitability of both aquatic and terrestrial habitats along with abundant and diversified prey (Maiolini and Carolli, 2009), the presence of the
optimum conditions in the habitat regulate their population. Hence diversity of the local odonato-fauna is determined by the overall ecological quality of water bodies and related land-water ecotones (Chovanec and Waringer, 2001; Schindler et al., 2003; Chovanec et al., 2004; Smith et al., 2006). In other words, they show strong relationship with the structure and ecological integrity of their habitats (Chovanec, 1994; Steytler and Samways, 1995; Sahlén and Ekestubbe, 2001; Hawking and New, 2002). They have been used as the bio-indicator of the wetland quality and are a flagship species for certain tourism attractions in Europe, Australia, USA and Japan (Clausnitzer and Jödicke, 2004). In Japan, Europe and South Africa, study of dragonflies have been recommended at many instances for the conservation of the ecosystem (Bried, 2005).

Studies on Odonata includes relationships with water quality (Azrina et al., 2006), biotope quality (Clark and Samways, 1996; Clausnitzer, 2003) and general species richness (Sahlen and Ekestubbe, 2001; Briers and Biggs, 2003), and their use as indicators for wetland conservation (Bried et al., 2007), riparian management needs (Samways and Steytler, 1996), wetland buffer width requirements (Bried and Ervin, 2006) and shallow lake restoration (D’Amico et al., 2004). As a group of species that are especially sensitive to changes in their habitat, Odonate populations can also be indicative of the richness of other invertebrates and macrophytes (Corbet, 1999; Bried and Ervin, 2005) and is also considered to act as umbrella species, facilitating the protection of habitat that is crucial for the survival of other species (Bried and Ervin, 2005). Dragonflies are known to be very sensitive to structural habitat quality and thus can provide a valuable tool to evaluate landscape degradation (Rith-Najarian, 1998; Sahlén, 1999; Clausnitzer, 2003). Considering these facts, in the present study around wetlands in semi arid zone of Central Gujarat, the Odonate fauna was documented.
Results

Most of the Odonates prefer environment near water bodies, hence good diversity and density of odonates were recorded in the present study conducted in the area surrounding three reservoirs in Central Gujarat.

Number of species (Table 3.1, Figure 3.1, Annexure 2)

Total 45 species of Odonates present around the three reservoirs included 18 species of 4 families (Coenagrionidae, Lestidae, Protoneuridae and Platycnemididae) of sub-order Zygoptera (Damselflies) and 27 species of 4 families (Aeshnidae, Gomphidae, Cordulegasteridae and Libellulidae) of sub-order Anisoptera (Dragonflies). Of the Zygopteran families, 3 families each were present at the three reservoirs, TIR, JIR and WIR represented by 12, 14 and 13 species respectively while of Anisopteran families, 23 species representing all 4 families were present at TIR while 23 species belonging to only 2 families were observed at JIR and 22 species belonging to 3 families at WIR.

Among the Zygopteran families, Coenagrionidae was the richest family with 9, 12 and 10 species recorded around TIR, JIR and WIR respectively. Lestidae was represented by only 2 species each at TIR and WIR while a single species at JIR. Protoneuridae was represented by a single species only at WIR. Platycnemididae was also represented by a single species at TIR and JIR. Sub-order Anisoptera had higher species richness than Zygoptera at all the three reservoirs. Libellulidae of this sub order was the richest Anisopteran family with 19 species each at TIR and WIR, and 21 species at JIR. Other Anisopteran families include Aeshnidae with a single species at TIR, Cordulegasteridae with a single species at both TIR and WIR and Gomphidae with 2 species at all the three reservoirs.
Abundance Rating (Table 3.2, Figure 3.2, Table 3.8)

Three species *Trithemis pallidinervis, Brachythemis contaminata* and *Crocothemis servilia* of family Libellulidae were abundant at WIR. Of these first two were common at TIR and last two at JIR. Five species were rated as Common at TIR and WIR each while 4 at JIR. Besides the above mentioned two species, common species at TIR include *Ischnura senegalensis, Ictinogomphus rapax and Pantala flavescens* which were also common at WIR. In addition two species *Diplacodes trivialis* and *Crocothemis erythraea* were common at WIR while frequent at the other two reservoirs. *Diplacodes lefebvrei* and *Rhyothemis variegate* were rated as common at JIR. Four species of Anisopterans were rated as frequent at TIR while 2 species each of Zygopterans and Anisopterans at WIR while JIR showed presence of 9 frequent species. These include *Bradinopyga geminata* at TIR and WIR, *Crocothemis servilia, Diplacodes trivialis and Crocothemis erythraea* at TIR while *Pseudagrion microcephalum, Onychargia sp.* and *Trithemis aurora* at WIR. The frequent species at JIR include two species of *Ischnura, I. aurora* and *I. senegalensis, Onychargia sp.*, *Ceriagrion coromandelium, Pantala flavescens, Sympetrum vulgatum, Trithemis pallidinervis Diplacodes trivialis and Crocothemis erythraea*.

Ten, eight and eleven species were uncommon at TIR, JIR and WIR respectively. Rare species amounted to the largest number with 16 species at both TIR and JIR while 12 species at WIR. Species representing families Lestidae, Protoneuridae, Platycnemididae, Aeshnidae and Cordulegasteridae were observed once or twice and hence all were rated rare in addition to some species of family Coenagrionidae and Libellulidae.

Jaccard's Similarity Index (J) (Table 3.3)

The annual Jaccard's similarity index for odonates was maximum 0.71 for TIR and JIR while 0.63 and 0.64 for TIR and WIR and JIR and WIR respectively (Figure 3.3). The
seasonal Jaccard's similarity index (Figure 3.4) showed variations without any specific trend in all the seasons. The highest 0.68 similarity occurred between JIR and WIR during monsoon when the similarity between TIR and JIR was 0.52 and that for TIR and WIR 0.54. In post-monsoon, the highest similarity of 0.65 was observed between JIR and TIR while for TIR and WIR and JIR and WIR it was 0.49 and 0.59 respectively. The similarity in winter at the three reservoirs varied with 0.46, 0.47 and 0.56 for TIR and JIR, JIR and WIR and TIR and WIR respectively. In summer the similarity index between TIR and JIR was found to be 0.51, JIR and WIR 0.59 and WIR and TIR 0.5.

Annual Mean Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) (Table 3.4, Figure 3.5)

Species Richness – The annual mean Species richness of Odonates was found to be highest 8.71 ± 0.64 species at JIR and lowest 6.09 ± 0.53 species at TIR. At WIR it was 8.44 ± 0.56 species with moderately significant differences among the three reservoirs (p < 0.01, F(2, 125) 6.48).

Density – The annual mean density of Odonates was found to be highest 0.61 ± 0.13 individuals/10m²/min at WIR while lowest 0.32 ± 0.1 individuals/10m²/min at TIR. Density at JIR was moderate with 0.36 ± 0.08 individuals/10m²/min. The differences among the three reservoirs were non-significant (p > 0.05, F(2, 125) 2.22).

Shannon Weiner Diversity Index (H') – The annual mean H' for Odonates was maximum 1.51 ± 0.08 at WIR while minimum 1.21 ± 0.09 at TIR. For JIR it was 1.46 ± 0.09. The differences among the three reservoirs showed significant differences (p < 0.05, F(2, 125) 3.37).
Evenness (E) – The mean annual evenness for Odonates was more or less same for TIR and WIR with 0.73 ± 0.05 and 0.72 ± 0.04 respectively while 0.68 ± 0.05 for JIR and hence differences among the three habitats were non-significant (p > 0.05, F (2, 125) 0.28).

Seasonal Variations in mean Species Richness, Density, Shannon Weiner Diversity Index (H’) and Evenness (E) (Table 3.5, Figure 3.6)

Species Richness

Around the three reservoirs same seasonal trend in the species richness of Odonates was observed with higher mean species richness during summer and post-monsoon and lowest in winter.

Seasonal variations around Each Reservoir

TIR- The mean species richness showed variation in different seasons of the year at TIR with highest 8.46 ± 1.12 species in post-monsoon which decreased to lowest 3 ± 0.39 species in winter. The mean seasonal species richness in summer was 7 ± 0.88 species while in monsoon it was 6.1 ± 1.07 species. The seasonal variations varied highly significantly (p < 0.001) with F (3,41) 7.03).

JIR – At JIR, the mean seasonal species richness of Odonates was 9 ± 0.85 species in summer which increased in monsoon to 9.5 ± 0.91 species and reached to maximum 11.57 ± 1.11 species during post-monsoon and was lowest 6 ± 1.45 in winter. The seasonal differences showed significant variations (p < 0.05, F (3,34) 3.84).

WIR – The mean seasonal species richness at WIR oscillated over the year with 9.58 ± 1.05 species in summer which decreased in monsoon to 7.91 ± 0.95 species and increased to highest 10.9 ± 1.21 species in post-monsoon and decreased again to lowest 5.75 ± 0.79 species in winter with p < 0.01 (F (3,41) 4.97).

Differences among the reservoirs
The differences in mean seasonal species richness among the three habitats in all the seasons were non-significant (p > 0.05). In monsoon, post-monsoon and winter higher mean species richness was recorded at JIR while lower at TIR with F(2,26) 2.73, F(2, 25) 2.01 and F(2,32) 3.13 respectively. In summer maximum mean species richness was observed at WIR while minimum at TIR (F(2,33) 2.12).

Density

As recorded for the species richness the density was also found to be highest during post-monsoon while lowest in winter.

Seasonal variations around Each Reservoir

TIR - The mean density of Odonates was 0.28 ± 0.15 individuals/10m²/min in summer which was maintained at 0.24 ± 0.09 individuals/10m²/min in monsoon and was found to be highest 0.74 ± 0.32 individuals/10m²/min in post-monsoon. It decreased to the minimum 0.05 ± 0.04 individuals/10m²/min in winter. The seasonal variations were non-significant (p > 0.05, F(3,41) 2.58).

JIR - The mean density showed the same trend as recorded for TIR but with higher density 0.39 ± 0.11 individuals/10m²/min in summer which was almost maintained at 0.31 ± 0.12 individuals/10m²/min in monsoon but was found to be highest 0.63 ± 0.18 individuals/10m²/min in post-monsoon and decreased to the lowest 0.20 ± 0.19 individuals/10m²/min in winter. The seasonal variations were non-significant (p > 0.05, F(3,34) 1.16).

WIR - Subtle different trend was observed at WIR compared to other two reservoirs where the density was 0.27 ± 0.14 individuals/10m²/min in summer which increased to 0.74 ± 0.36 individuals/10m²/min in monsoon and further to 1.36 ± 0.25 individuals/10m²/min in post-monsoon and dropped significantly to 0.21 ± 0.12 individuals/10m²/min in winter. The seasonal variations were moderately significant (p < 0.01, F(3,41) 5.16).
**Differences among the reservoirs**

The differences in the mean density of odonates among the three reservoirs were non-significant \((p > 0.05)\) in all seasons of the year. The mean density of Odonates in summer was recorded to be highest at JIR while it was almost same at TIR and WIR \((F_{(2, 33)} 0.25)\). In monsoon the highest mean density of Odonates was recorded at WIR while lowest at TIR with \(F_{(2, 26)} 1.25\), during post-monsoon also highest mean density was recorded at WIR while lowest at JIR with non significant differences \((F_{(2, 26)} 1.92)\). Although the lowest densities were recorded in winter at all the three reservoirs, among the three it was lowest at TIR and almost same at the other two reservoirs \((F_{(2, 32)} 0.51)\).

**Shannon Weiner Species Diversity Index \((H')\)**

Mean Shannon weiner diversity index for odonates also showed non-significant differences for seasonal variations at all the three reservoirs. \(H'\) was found to be highest in post-monsoon while lowest in winter.

**Seasonal variations around Each Reservoir**

**TIR** – The mean diversity index of Odonates at TIR was same \(1.35 \pm 0.19\) and \(1.35 \pm 0.17\) in summer and post-monsoon respectively while lowest \(0.94 \pm 0.15\) in winter and moderate \(1.23 \pm 0.2\) in monsoon \((p > 0.05, F_{(3,41)} 1.27)\).

**JIR** – At JIR, mean \(H'\) was \(1.48 \pm 0.13\) in summer which increased marginally to \(1.65 \pm 0.16\) in monsoon and was maintained at \(1.69 \pm 0.18\) in post-monsoon while was found to be lowest \(1.14 \pm 0.22\) in winter indicating no significant seasonal variations \((p > 0.05, F_{(3,34)} 1.94)\).

**WIR** – At WIR same trend as that of JIR was noted with \(1.42 \pm 0.17\) \(H'\) in summer increasing to \(1.57 \pm 0.08\) in monsoon and further to \(1.83 \pm 0.14\) in post-monsoon and was
lowest 1.27 ± 0.19 in winter. The seasonal differences varied non-significantly (p > 0.05, F (3,41) 2.25).

**Differences among the reservoirs**

In summer, the diversity index was noted to be highest for JIR and lowest for TIR. The differences among the three reservoirs in summer showed non-significant differences (p > 0.05, F (2,33) 0.15). In monsoon too, it was highest for JIR while lowest for TIR (p > 0.05, F (2,26) 2.19). However, in post-monsoon, mean H’ was highest for WIR while lowest for TIR. The differences among the reservoirs were non-significant (p > 0.05, F (2,25) 2.5) in this season. In winter too, same trend as that of post-monsoon was observed with maximum H’ for WIR and minimum for TIR with non-significant (p > 0.05, F (2,32) 0.82) differences.

**Evenness (E)**

Minor variations were observed in the seasonal mean Evenness and hence the differences varied non-significantly (p > 0.05) amongst the reservoirs during all seasons. It ranged between 0.6 to 0.8.

**Seasonal variations around Each Reservoir**

TIR – Highest mean evenness 0.81 ± 0.11 was noted in winter while during rest of the seasons the mean evenness was comparatively low, with 0.7 ± 0.09 in summer, 0.71 ± 0.1 in monsoon and 0.69 ± 0.06 in post-monsoon (p > 0.05, F (3,41) 0.35).

JIR – At JIR, mean evenness was highest 0.75 ± 0.07 in monsoon and lowest 0.59 ± 0.12 in winter, while it was 0.72 ± 0.07 and 0.7 ± 0.07 in summer and post-monsoon respectively (p > 0.05, F (3,34) 0.59).

WIR – Mean seasonal evenness was 0.61 ± 0.07 in summer at WIR which increased non-significantly to 0.79 ± 0.04 in monsoon and further to 0.81 ± 0.05 in post-monsoon but decreased to 0.68 ± 0.1 in winter (p > 0.05, F (3,41) 1.66).
Differences among the reservoirs

In summer maximum mean evenness was recorded for JIR closely followed by TIR and minimum at WIR (p > 0.05, F_{(2,33)} 0.51) while during following season monsoon, maximum mean E was recorded for WIR while minimum for TIR (p > 0.05, F_{(2,26)} 0.31). In post-monsoon too maximum mean Evenness was noted at WIR while at TIR and JIR it was almost same (p > 0.05, F_{(2,25)} 1.48). During winter highest mean evenness was recorded for TIR while lowest for JIR (p > 0.05, F_{(2,32)} 0.94).

Annual Percentage Occurrence (Table 3.6, Figure 3.7)

As mentioned earlier of the total 8 families recorded in the study, 7 families were present at TIR while family Protoneuridae was absent. At JIR only 5 families were present and families Aeshnidae and Cordulegasteridae along with Protoneuridae were absent. While at WIR 6 families were present and the families Aeshnidae of Anisoptera and Platycnemididae of Zygoptera were not represented.

TIR – When the percentage occurrence is compared on annual scale it is observed that Libellulidae (Anisoptera) is the most dominant family with highest 66.06 % of the species followed by Coenagrionidae (Zygoptera) with 20.07%, Gomphidae (Anisoptera) 8.76%, Platycnemididae (Zygoptera) 2.55% Lestidae (Zygoptera) 1.46%; Cordulegasteridae (Anisoptera) 0.73% and Aeshnidae (Anisoptera) 0.36%.

JIR – At JIR only 5 families were represented with Libellulidae being the most dominant family with 70.28% while Coenagrionidae followed with 25.08% occurrence, Gomphidae had 3.72% and Lestidae and Platycnemididae with very low percentages of 0.62% and 0.31% respectively.
WIR – Six families were represented around WIR again with Libellulidae dominating with 63.95% of the total odonates while Coenagrionidae constituted 26.32% followed by Gomphidae 8.16%, Lestidae 1.05% and Protoneuridae and Cordulegasteridae 0.26% each.

Differences among the reservoirs

When the comparison is made among three habitats, Libellulidae was the most dominant family with maximum percentage occurrence at JIR. Coenagrionidae followed Libellulidae but had highest percentage occurrence around WIR while Lestidae had the highest percentage occurrence around TIR. Family Protoneuridae was absent around TIR and JIR, and Platycnemididae around WIR. Aeshnidae was absent at JIR and WIR. Gomphidae had more or less same percentage of occurrence at TIR and WIR while lower percentage at JIR and Cordulegasteridae had higher percentage at TIR while it was absent at JIR.

Seasonal Percentage Occurrence (Table 3.7, Figure 3.8)

As was evident in the annual scenario, the seasonal percentage occurrence also clearly indicated highest percentage of Family Libellulidae (Dragonflies - Anisoptera) in all the seasons at the three reservoirs. When considered in hierarchal orders family Libellulidae with families Coenagrionidae and Gomphidae were the three families represented all throughout the year at all the three reservoirs. During monsoon Lestidae (Damselflies) was absent around all the reservoirs while it was present only around TIR in post-monsoon and at JIR in winter with low presence at all the reservoirs during summer. Protoneuridae (Damselflies) was present only at WIR that too only during summer while over rest of the year it was absent. Platycnemididae (Damselflies) was totally absent at WIR while it was present only during winter around JIR and in all seasons except winter around TIR. Aeshnidae (Dragonflies) was observed only at TIR that too only during summer while
Cordulegasteridae (Dragonflies) occurred in summer at WIR while during monsoon and post-monsoon at TIR.

*Seasonal differences around reservoirs*

When seasonal difference in percentage occurrence of odonates around each reservoir are considered, different families in a particular season at each reservoir are taken into consideration.

**Summer**

*TIR* – Libellulidae accounted for 73.81% of the total odonates followed by Coenagrionidae with 13.1%, Gomphidae 7.14% and Lestidae 3.57%. Platycnemididae and Aeshnidae each constituted 1.19% of total Odonates in this season.

*JIR* – At JIR, 82% of the Odonates were contributed by family Libellulidae while only 14% by family Coenagrionidae. The percentage contributed by other families was very low with family Gomphidae contributing 3% while Lestidae just 1%.

*WIR* – Around WIR also family Libellulidae constituted nearly 73% of the total Odonates in summer while Coenagrionidae constituted 12.17% and Gomphidae 9.57%. Family Lestidae constituted 3.48% while families Protoneuridae and Cordulegasteridae constituted 0.87% each.

**Monsoon**

*TIR* - In monsoon also family Libellulidae contributed maximum 67.21% of the total Odonates, while Coenagrionidae contributed 16.39%, closely followed by Gomphidae with 9.84% and Platycnemididae 4.92%. Cordulegasteridae had low percentage occurrence of 1.64.

*JIR* – In monsoon only 3 families were represented around JIR with highest 73.68% of Libellulidae, 21.05% Coenagrionidae and 5.26% Gomphidae.
CHAPTER 3

WIR – Around WIR also only these 3 families were represented during monsoon with
63.22% Libellulidae, 29.89% Coenagrionidae and 6.9% Gomphidae.

Post-monsoon

TIR – Family Libellulidae constituted 58.06%, and family Coenagrionidae 25.81% of the
total odonates with 10.75% of family Gomphidae. Family Platycnemididae, Lestidae and
Cordulegasteridae had low percentage occurrence of 3.23%, 1.08% and 1.08% respectively.

JIR – As in monsoon, during post-monsoon too JIR had presence of only three families
Libellulidae 70.37%, Coenagrionidae with 25.93% and Gomphidae with 3.7%.

WIR – WIR also showed presence of these three families i.e. Libellulidae with maximum
55.05%, Coenagrionidae 33.03% and Gomphidae 11.93%.

Winter

TIR – Only three major families were represented around TIR in winter with 66.67% of total
Odonates contributed by Libellulidae, 27.78% by Coenagrionidae and 5.56% by
Gomphidae.

JIR – At JIR, all five families reported were present in winter with 48.48% of Libellulidae,
45.45% Coenagrionidae while Gomphidae along with Platycnemididae and Lestidae had
minor representation of 3.03% for the former and 1.52% each for the later two.

WIR – At WIR again only three major families were represented with 63.77% Libellulidae,
34.78% Coenagrionidae and 1.45% Gomphidae.

Differences among the habitats

Coenagrionidae had comparatively higher representation at JIR during summer and winter
while at WIR it was more prevalent in monsoon and post-monsoon. Amongst the three
reservoirs, Lestidae though not common, was observed more frequently at TIR in summer
and post-monsoon, at WIR only in summer and at JIR in summer as well as winter.
Protoneuridae was present only during summer that also only at WIR. Platycnemididae was observed around TIR in three seasons as compared to single appearance in the fourth season winter at JIR. Aeshnidae was also observed only at TIR during summer. Gomphidae had overall low occurrence at JIR among the three reservoirs where its percentage never increased beyond 5%. This family was more common during post-monsoon at TIR and WIR. Cordulegasteridae appeared at TIR in monsoon and post-monsoon while during summer at WIR. JIR had the highest percentage of Libellulidae among the three reservoirs in all seasons except winter when the percentage was lower than that at TIR and WIR.

**Variations along Seasons in three major families at each reservoir**

**Libellulidae** – At JIR decrease in the percentage occurrence was observed from summer to winter, while at TIR and WIR the decrease was up to post-monsoon while increase was noted in winter.

**Coenagrionidae** – A trend of increase in the percentage occurrence from summer up to winter was observed for this family at all the three reservoirs.

**Gomphidae** – At TIR, the percentage occurrence of this family increased from summer through monsoon to post-monsoon and declined significantly to minimum in winter. At JIR, more or less same percentage occurrence was observed in all the seasons except monsoon when it was higher, while at WIR, it oscillated with higher percentage in summer which decreased in monsoon, increased to maximum percentage in post-monsoon and declined again to minimum in winter.
### Table 3.1: Number of species belonging to different families of order Odonata at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

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<th>Pla (1)</th>
<th>Aes (1)</th>
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### Table 3.2: Abundance rating of Odonate species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

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<td>12</td>
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</tbody>
</table>

### Table 3.3: Annual and Seasonal Jaccard’s similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

<table>
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<th>Summer</th>
<th>Monsoon</th>
<th>Post monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>JIR</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WIR</td>
<td>0.63</td>
<td>0.64</td>
<td>0.5</td>
<td>0.54</td>
<td>0.68</td>
</tr>
<tr>
<td>JIR</td>
<td>0.71</td>
<td>-</td>
<td>0.51</td>
<td>0.52</td>
<td>0.65</td>
</tr>
</tbody>
</table>

### Table 3.4: Annual Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

<table>
<thead>
<tr>
<th></th>
<th>Species Richness (**)</th>
<th>Density (ns)</th>
<th>Shannon Weiner index (*)</th>
<th>Evenness (ns)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR</td>
<td>$F_{0.015}$ 6.48</td>
<td>$F_{0.015}$ 2.22</td>
<td>$F_{0.015}$ 3.37</td>
<td>$F_{0.015}$ 0.28</td>
</tr>
<tr>
<td>JIR</td>
<td>6.09 ± 0.53</td>
<td>0.32 ± 0.1</td>
<td>1.21 ± 0.09</td>
<td>0.73 ± 0.05</td>
</tr>
<tr>
<td>WIR</td>
<td>8.71 ± 0.64</td>
<td>0.36 ± 0.08</td>
<td>1.46 ± 0.09</td>
<td>0.68 ± 0.05</td>
</tr>
</tbody>
</table>
### Table 3.5: Seasonal variations in the Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

<table>
<thead>
<tr>
<th>Species Richness</th>
<th>Among Reservoirs Within Reservoirs</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR (***) F(3,6) 7.03</td>
<td>(ns) F(0,0) 2.12</td>
<td>7 ± 0.88</td>
<td>6.1 ± 1.07</td>
<td>8.46 ± 1.12</td>
<td>3 ± 0.39</td>
</tr>
<tr>
<td>JIR (*) F(3,6) 3.84</td>
<td>(ns) F(2,0) 2.73</td>
<td>9 ± 0.85</td>
<td>9.5 ± 0.91</td>
<td>11.57 ± 1.11</td>
<td>6 ± 1.45</td>
</tr>
<tr>
<td>WIR (**) F(3,6) 4.97</td>
<td>(ns) F(2,0) 2.01</td>
<td>9.58 ± 1.05</td>
<td>7.91 ± 0.95</td>
<td>10.9 ± 1.21</td>
<td>5.75 ± 0.79</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Density</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR (ns) F(3,2) 2.58</td>
<td>0.28 ± 0.15</td>
<td>0.24 ± 0.09</td>
<td>0.74 ± 0.32</td>
<td>0.05 ± 0.04</td>
</tr>
<tr>
<td>JIR (ns) F(2,2) 1.16</td>
<td>0.39 ± 0.11</td>
<td>0.31 ± 0.12</td>
<td>0.63 ± 0.18</td>
<td>0.20 ± 0.19</td>
</tr>
<tr>
<td>WIR (**) F(2,2) 3.51</td>
<td>0.27 ± 0.14</td>
<td>0.74 ± 0.36</td>
<td>1.36 ± 0.25</td>
<td>0.21 ± 0.12</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Shannon Weiner index (H')</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR (ns) F(3,2) 1.27</td>
<td>1.35 ± 0.19</td>
<td>1.23 ± 0.17</td>
<td>1.35 ± 0.17</td>
<td>0.94 ± 0.15</td>
</tr>
<tr>
<td>JIR (ns) F(2,2) 1.94</td>
<td>1.48 ± 0.13</td>
<td>1.65 ± 0.16</td>
<td>1.69 ± 0.18</td>
<td>1.14 ± 0.22</td>
</tr>
<tr>
<td>WIR (**) F(2,2) 2.25</td>
<td>1.42 ± 0.17</td>
<td>1.57 ± 0.08</td>
<td>1.83 ± 0.14</td>
<td>1.27 ± 0.19</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Evenness (E)</th>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR (ns) F(2,2) 0.35</td>
<td>0.7 ± 0.09</td>
<td>0.71 ± 0.1</td>
<td>0.69 ± 0.06</td>
<td>0.81 ± 0.11</td>
</tr>
<tr>
<td>JIR (ns) F(2,2) 0.59</td>
<td>0.72 ± 0.07</td>
<td>0.75 ± 0.07</td>
<td>0.7 ± 0.07</td>
<td>0.59 ± 0.12</td>
</tr>
<tr>
<td>WIR (ns) F(2,2) 1.66</td>
<td>0.61 ± 0.07</td>
<td>0.79 ± 0.04</td>
<td>0.81 ± 0.05</td>
<td>0.68 ± 0.1</td>
</tr>
</tbody>
</table>

### Table 3.6: Annual Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

<table>
<thead>
<tr>
<th>Coenagrionidae</th>
<th>Lestidae</th>
<th>Protoneuridae</th>
<th>Platycnemididae</th>
<th>Aeshnidae</th>
<th>Gomphidae</th>
<th>Cordulegasteridae</th>
<th>Libellulidae</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR 20.07%</td>
<td>4.16%</td>
<td>0.6%</td>
<td>2.55%</td>
<td>0.8%</td>
<td>8.76%</td>
<td>0.25%</td>
<td>66.06%</td>
</tr>
<tr>
<td>JIR 25.08%</td>
<td>1.46%</td>
<td>0.6%</td>
<td>0.31%</td>
<td>0%</td>
<td>7.82%</td>
<td>0%</td>
<td>70.28%</td>
</tr>
<tr>
<td>WIR 26.32%</td>
<td>2.05%</td>
<td>0.26%</td>
<td>0%</td>
<td>0%</td>
<td>8.16%</td>
<td>0.26%</td>
<td>63.95%</td>
</tr>
</tbody>
</table>

Coe - Coenagrionidae, Les - Lestidae, Pro - Protoneuridae, Pla - Platycnemididae, Aes - Aeshnidae, Gom - Gomphidae, Cor - Cordulegasteridae, Lib- Libellulidae

### TABLE 3.7: Seasonal Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

<table>
<thead>
<tr>
<th>Summer</th>
<th>Monsoon</th>
<th>Post-monsoon</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>TIR</td>
<td>JIR</td>
<td>WIR</td>
<td>TIR</td>
</tr>
<tr>
<td>Coenagrionidae</td>
<td>13.1</td>
<td>4</td>
<td>12.17</td>
</tr>
<tr>
<td>Lestidae</td>
<td>3.57</td>
<td>1</td>
<td>3.48</td>
</tr>
<tr>
<td>Protoneuridae</td>
<td>0</td>
<td>0</td>
<td>0.87</td>
</tr>
<tr>
<td>Platycnemididae</td>
<td>1.19</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Aeshnidae</td>
<td>1.19</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Gomphidae</td>
<td>7.14</td>
<td>3</td>
<td>9.57</td>
</tr>
<tr>
<td>Cordulegasteridae</td>
<td>0</td>
<td>0</td>
<td>0.87</td>
</tr>
<tr>
<td>Libellulidae</td>
<td>73.81</td>
<td>82</td>
<td>73.04</td>
</tr>
<tr>
<td>Sr. No.</td>
<td>Common Name</td>
<td>Scientific Name</td>
<td>TIR</td>
</tr>
<tr>
<td>---------</td>
<td>-----------------------</td>
<td>----------------------------------------</td>
<td>-----</td>
</tr>
<tr>
<td>1</td>
<td>Coromandel Marsh Dart</td>
<td>Ceriagrion coromandelianum</td>
<td>U</td>
</tr>
<tr>
<td>2</td>
<td>Blue Grass Dartlet, Blue Sprite</td>
<td>Pseudagrion microcephalum</td>
<td>U</td>
</tr>
<tr>
<td>3</td>
<td>Golden Dartlet</td>
<td>Ischnura aurora</td>
<td>R</td>
</tr>
<tr>
<td>4</td>
<td>Senegal Golden Dartlet</td>
<td>Ischnura senegalesis</td>
<td>C</td>
</tr>
<tr>
<td>5</td>
<td>Pigmy Dartlet</td>
<td>Agriocnemis pygmaea</td>
<td>U</td>
</tr>
<tr>
<td>6</td>
<td>Black marsh dart</td>
<td>Onychargia sp.</td>
<td>R</td>
</tr>
<tr>
<td>7</td>
<td>Rusty Marsh Dart</td>
<td>Ceriagrion olivaceum</td>
<td>R</td>
</tr>
<tr>
<td>8</td>
<td>Common orange</td>
<td>Ceriagrion sp.</td>
<td>R</td>
</tr>
<tr>
<td>9</td>
<td>Painted Sprite Damselfly</td>
<td>Pseudagrion sp.</td>
<td>R</td>
</tr>
<tr>
<td>10</td>
<td>Common blue damselfly</td>
<td>Enallagma sp.</td>
<td>R</td>
</tr>
<tr>
<td>11</td>
<td>Ischnura sp.</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>12</td>
<td>Agriocnemis sp</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>13</td>
<td>Green Emerald</td>
<td>Lestes virdis</td>
<td>R</td>
</tr>
<tr>
<td>14</td>
<td>Emerald spreadwing</td>
<td>Lestes dryas</td>
<td>R</td>
</tr>
<tr>
<td>15</td>
<td>Common Spreadwing</td>
<td>Lestes sponsa</td>
<td>R</td>
</tr>
<tr>
<td>16</td>
<td>Blue Bambootail</td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>17</td>
<td>Yellow Bush Dart</td>
<td>Copera marginipes</td>
<td>U</td>
</tr>
<tr>
<td>18</td>
<td>Hawker Dragonfly</td>
<td>Aeshna sp.</td>
<td>R</td>
</tr>
<tr>
<td>19</td>
<td>Common clubtail</td>
<td>Jetinagomphus rapax</td>
<td>C</td>
</tr>
<tr>
<td>20</td>
<td>Snaketail</td>
<td>Ophiogomphus sp.</td>
<td>R</td>
</tr>
<tr>
<td>21</td>
<td>Spiketail</td>
<td>Cordulegaster sp.</td>
<td>R</td>
</tr>
<tr>
<td>22</td>
<td>Wandering Glider</td>
<td>Pantala flavescens</td>
<td>C</td>
</tr>
<tr>
<td>23</td>
<td>Ditch Jewel</td>
<td>Brachythemis contaminata</td>
<td>C</td>
</tr>
<tr>
<td>24</td>
<td>Long - legged Marsh Glider</td>
<td>Trithemis pallidinervis</td>
<td>C</td>
</tr>
<tr>
<td>25</td>
<td>Ruddy marsh skimmer</td>
<td>Crocothemis servilia</td>
<td>F</td>
</tr>
<tr>
<td>26</td>
<td>Common Scarlet Darter</td>
<td>Crocothemis erythraea</td>
<td>F</td>
</tr>
<tr>
<td>27</td>
<td>Ground skimmer</td>
<td>Diplacodes trivialis</td>
<td>F</td>
</tr>
<tr>
<td>28</td>
<td>Black Percher</td>
<td>Diplacodes lefebvrei</td>
<td>U</td>
</tr>
<tr>
<td>29</td>
<td>Black-tipped Percher</td>
<td>Diplacodes nebulosa</td>
<td>R</td>
</tr>
<tr>
<td>30</td>
<td>Pygmy Skimmer</td>
<td>Tetrathemis platyperta</td>
<td>R</td>
</tr>
<tr>
<td>31</td>
<td>Common Picture Wing</td>
<td>Rhyothemis variegata</td>
<td>U</td>
</tr>
<tr>
<td>32</td>
<td>Yellow-tailed Ashy Skimmer</td>
<td>Potamarcha congener</td>
<td>R</td>
</tr>
<tr>
<td>33</td>
<td>Crimson marsh glider</td>
<td>Trithemis aurora</td>
<td>U</td>
</tr>
<tr>
<td>34</td>
<td>Orange winged Dropwing</td>
<td>Trithemis kirby</td>
<td>U</td>
</tr>
<tr>
<td>35</td>
<td>Granite Ghost</td>
<td>Bradingopygga geminata</td>
<td>F</td>
</tr>
<tr>
<td>36</td>
<td>Blue Marsh Hawk</td>
<td>Orthetrum glaucaum</td>
<td>U</td>
</tr>
<tr>
<td>37</td>
<td>Black-tailed Skimmer</td>
<td>Orthetrum cancellatum</td>
<td>U</td>
</tr>
<tr>
<td>38</td>
<td>Blue-tailed Forest Hawk</td>
<td>Orthetrum triangulare</td>
<td>R</td>
</tr>
<tr>
<td>39</td>
<td>Slender skimmer</td>
<td>Orthetrum sabina</td>
<td>R</td>
</tr>
<tr>
<td>40</td>
<td>Black Pennant</td>
<td>Selysthesmus sp.</td>
<td>R</td>
</tr>
<tr>
<td>41</td>
<td>Vagrant Darter</td>
<td>Sympetrum vulgatum</td>
<td>U</td>
</tr>
<tr>
<td>42</td>
<td>Meadow hawk Dragonfly</td>
<td>Sympetrum commistum</td>
<td>R</td>
</tr>
<tr>
<td>43</td>
<td>Meadow hawk Dragonfly</td>
<td>Sympetrum sp.</td>
<td>R</td>
</tr>
<tr>
<td>44</td>
<td>Demon Dragonfly</td>
<td>Indothemis sp.</td>
<td>R</td>
</tr>
</tbody>
</table>

**Table 3.8- Abundance rating of the Odonates observed around three reservoirs**
CHAPTER 3

**Figure 3.1:** Number of species belonging to different families of order Odonata at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

![Number of Species](image1)

**Figure 3.2:** Abundance rating of the Odonate species encountered at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

![Abundance rating of Odonates](image2)

**Figure 3.3:** Annual Jaccard's similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

![Annual Jaccard's Similarity Index (J)](image3)
Figure 3.4: Seasonal Jaccard’s similarity Index for odonates between Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

Figure 3.5: Annual Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *** (P < 0.001)
Figure 3.6: Seasonal variations in the Species Richness, Density, Shannon Weiner Diversity Index (H') and Evenness (E) of Odonates at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR).

For ANNOVA ns (P > 0.05), * (P < 0.05), ** (P < 0.01), *** (P < 0.001)
Figure 3.7: Annual Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

![Annual Percentage Occurrence](image)

Figure 3.8: Seasonal Percentage Occurrence of the Odonate families at Timbi Irrigation Reservoir (TIR), Jawla Irrigation Reservoir (JIR) and Wadhwana Irrigation Reservoir (WIR)

![Seasonal Percentage Occurrence](image)
PLATE 8: SOME OF THE ODONATES OBSERVED IN THE STUDY

Dragonflies

*Brachythemis contaminata* (Ditch Jewel)

*Trithemis pallidinervis* (Long legged Marsh Skimmer)

*Diplocodes trivialis* (Ground Skimmer)
Dragonflies

*Crocothemis servilia* (Ruddy marsh skimmer)

*Rhyothemis variegate* (Common Picture wing)  *Ictinogomphus rapax* (Common Clubtail)

*Crocothemis erythaea* (Common Scarlet Darter)  *Pantala flavescens* (Wandering glider)
DAMSELFIES

*Ischnura senegalensis* (Senegal Golden Dartlet)  
*Pseudagrion microcephalum* (Blue Grass Dartlet)

*Ceriagrion coromandelianum* (Coromandel Marsh Dart)  
*Copera marginipes* (Yellow marsh Dart)

*Ischnura aurora* (Golden Dartlet)  
*Enallagma* sp. (Common blue damselfly)
Discussion

Odonates being one of the most diverse groups of insects with well evolved flight mechanism have recently engrossed the attention of large group of entomologists leading to the initiation of several studies giving their description, distribution and habitat preference. Many of the Odonate families are known to prefer the flowing water for breeding while there are others that use stagnant water. However, as the Odonate larvae are aquatic, water forms an important component in their life cycle. Odonata is a comparatively smaller order of Class Insecta with only 5680 described species worldwide (Kalkman et al. 2008) with the majority occurring in tropics (Miller, 2007). However, India has an exceptionally rich and interesting odonate fauna with over 10% (about 600 species) of the world’s species (Fraser, 1933; 1934; 1936; Tyagi, 1997). India’s Odonate fauna being poorly known there is a great need for basic information on their occurrence, distribution and seasonality (Miller, 2007).

Majority of species of both suborders of Odonates, the Zygopterans and Anisopterans, mainly prefer sunny biotopes with exposed macrophytes (Clausnitzer, 2003) and hence good number of Odonates were observed around three open irrigation reservoirs in sub-tropical semi arid zone which has good sunlight and almost no tall vegetation in immediate vicinity — the favourable conditions for this insect group.

Habitat diversity and connectivity along with the hydrological dynamics are important for the dragonflies (Clausnitzer, 2006). The irrigation reservoirs of the present study where variety of micro-habitats are present together with the presence of the alternate scrubland habitat in the surroundings support the prey base for this group. Hence, good diversity of Odonates was observed in the area. Different ecological requirements are linked to different dispersal capacities. Species with narrow niches disperse poorly, while the species with broad niche become pioneers of temporal habitats (often created by disturbance) and are
excellent colonizers (Clausnitzer, 2006). Odonates are the top predators in many of naturally fishless habitats (McPeek, 1998), and produce cascading effects due to their assemblages. These assemblages also influence overall richness and diversity of ecosystems (Reece and Mcintyre, 2009). Hence, the presence of Odonates in any habitat can act as the indication of the higher species richness supported by that ecosystem.

Reports on Indian Odonates are contradicting. According to the study conducted by Prasad (1999), Indian Odonate fauna comprises 499 species representing 17 families and 3 sub-orders. However, after a decade Subramaniam (2009) reported the presence of 470 species belonging to 139 genera 19 families and 3 sub-orders. 2 new families reported by the latter were not reported by Prasad (1999). Over a span of 10 years nearly 30 species either were not identified due to lack of proper identification keys or have become extinct. Though a good knowledge of their ecological requirements, distribution and seasonality is available (Maiolini and Carolli, 2009) there is an immediate need to document and conserve the habitats for these beautiful insects.

Of the total 470 species of Odonates recorded from India (Subramaniam, 2009) 45 species were recorded in the smaller areas of present study. Subramaniam (2009) reported nearly 267 species of Anisoptera belonging to 7 families and 195 species of Zygoptera belonging to 11 families, of which nearly 28 Anisopteran species belonging to 4 families and 17 Zygopteran species belonging to 4 families were recorded from the present study. In this area, the number of Anisopterans was higher as compared to Zygopterans. This scenario has also been recorded in the study conducted by Arulprakash and Gunathilagaraj (2008) in temporary pools of Coimbatore and Salem. The differences in number could be due to the high dispersal ability of Anisopterans (Batzier and Wissinger, 1996; Williams, 1997; Lawler, 2001; Kadoya et al., 2004) and their adaptability to the wide range of habitats (Hodgkin and
Watson, 1958; Suhling et al., 2004, 2005). Damselflies have limited dispersal ability (Weir 1974) and less preference to not only environment offered by the temporary water bodies (Williams, 1997; Kadoya et al., 2004) but also to partial or absence of shade cover as well (Clark and Samways, 1996). Shade and aquatic vegetation favour Zygoptera more than Anisoptera (Subramaniam, 2005).

The two largest families Coenagrionidae of damselflies and Libellulidae of dragonflies (Kalkman et al., 2008) were dominant in present study too. These two families are considered to be of recent origin (Rehn, 2003). Almost all ubiquitous odonate species belonging to these two families dominate in unshaded habitats with stagnant water (both artificial and natural). Both families include species with the greatest migratory capacity, including those with distributions spanning more than one continent and almost all species found on isolated islands (Kalkman et al., 2008).

In majority of the studies conducted in the Indian sub-continent, these two families have been rated as the most species rich families (Gunathilagaraj et al., 1999; Asaithambi and Manickavasagam, 2002; Kandibane et al., 2003; Emiliyamma, 2005; Miller, 2007; Sharma and Joshi, 2007; Sharma et al., 2007; Subramaniam, 2007; Sharma et al., 2009; Rangnekar et al., 2010). Nearly same numbers of species (35 each at TIR and WIR and 37 species at JIR) were recorded from the three habitats which are only about 25 to 50 kms away from each other. However their occurrence and seasonality varied probably because of the microhabitat characteristic of each. Urbanization does not affect the dragonfly diversity (Lubertazzi and Ginsberg, 2010) and hence no major effect of the human activities was found in the present study as the number of Odonates was almost same at the reservoir (TIR) nearer to Vadodara city. However, the human presence has been reported to disturb Odonates (Bried, 2005; Maiolini and Carolli, 2009) and lead to their frequent appearance.
and disappearance in the area. Further, though the size of the water bodies are known to
determine the species richness and diversity of Odonata (Lounibos *et al*. 1990; Clark and
Samways, 1996; Stewart and Samways, 1998; Schindler *et al*., 2003; Kadoya *et al*., 2004;
Carchini *et al*., 2005; Suh and Samways, 2005) no major difference in the Odonata diversity
was recorded amongst the three reservoirs.

In the present study, the habitats selected are the reservoirs, basically the lentic ecosystems.
According to Subramaniam *et al*., (2008) and Subramaniam, (2009) lentic habitats are
believed to increase the species richness of an area, but can also potentially encourage
colonization of widespread generalist species such as Libellulids. Among Anisoptera,
Libellulidae with more than 1000 species is the most dominant family and is justified as the
largest dragonfly family in the world. It has 85 species reported in India. Members of
families Aeshnidae, Cordulegasteridae and Gomphidae that prefer breeding in running water
of streams and rivers for breeding (Miller, 2007) were not well represented in the present
study.

Though Coenagrionidae is the largest zygopteran family with more than 1000 species
recorded over the world only 58 species are recorded from India (Subramaniam, 2009) and
only 12 species in the present study. Coenagrionidae is generally referred as the Narrow
winged damselflies or Pond damselflies restricted to stagnant water. Hence, they were found
to be more common around the reservoirs where the water flow is slow. Another family that
prefers ponds and swamps is Lestidae a small family of the Spread wings. Though their
distribution is cosmopolitan their presence around the reservoirs was rare as they might
prefer smaller water bodies. Similarly, Platycnemididae and Protoneuridae though having
considerable numbers of species in India were represented by single species each as they are
very sensitive to habitat modifications. They disappear completely in the absence of the
suitable conditions (Subramaniam et al., 2008). The fluctuating water levels over the season with parallel changes in the hydro period and water spread in the monsoon dependent reservoirs probably do not provide suitable stable habitat for these families. Hence they were among the rare families in the present study. Of the two, Protoneuridae is generally known to prefer the slow flowing streams in the forests where the disturbances are less whereas the habitats selected in the present study are open and away from forests. This family was completely absent at TIR and JIR while observed just once at WIR which is comparatively undisturbed area only at 25 Kms. distance from the forest of the Jambughoda wildlife Sanctuary. All Protoneurids breed in running waters and most of them are restricted to forested landscapes, and hence are common in the Western Ghats of Peninsular India (Subramaniam, 2005). Family Platycnemididae is also known to be more common in the habitats with running waters of rivers and streams. It is known to prefer breeding in the mountainous stream (Subramaniam, 2005), hence was not so common around the reservoirs in the flat land of Central Gujarat.

**Abundance Rating**

The number of species that are accidental in appearance and rare is always higher as compared to the abundant species (Krebs, 1985). In the present study too, 40-50% of the odonates were rated as rare. Species with specific habitat requirements can become rarer due to environmental degradation (Moore, 1982) as they have to explore newer habitats for colonization. They may be accidental in the areas to which they are not adapted. For these rare odonates survival through emergence is particularly worthy as it is the period of substantial mortality (Crowley et al., 1987). Hence, abundance of species is spatially and temporally variable. Some species are abundant, some are rare, and the rest are in between (Rageai and Allam, 1978). Presence of 3 species abundant at WIR and none at TIR and JIR
indicate the differences at regional level. These three species *Brachythemis contaminate*, *Trithemis pallidinervis* and *Crocothemis servilia* of family Libellulidae are the most common species in India preferring lentic habitat.

*Brachythemis contaminate* is found in any kind of water body may that be polluted or unpolluted. This species prefers perching on the low vegetation or ground in the vicinity of water, sometimes on water surface making occasional short flights (Miller, 2007) to capture flying insects like Diptera, Ephemeroptera and Plecoptera (Mitra, 2007). However, it also feeds on other smaller insects like ants, aphids, etc. which were abundant in the area (Chapters 4 and 6). This species was found all throughout the year but their number was maximum during summer and post-monsoon.

*Trithemis pallidinervis*, a widely distributed species of India was commonly found at WIR especially during winter when other species were not observed. It perches on prominent places of vegetation about 1m above the ground, facing wind and close to water edge (Miller, 2007) as was also observed in summer and post-monsoon in the present study.

*Crocothemis servilia* is another widespread dragonfly species in India, seen frequently perching on the low vegetation at temporary lakes and permanent ponds. This species also feeds only on the live and predominantly flying insects like adults of Diptera, Ephemeroptera, Neuroptera with smaller Lepidopterans as well as damselflies (Mitra, 2007). It showed two peaks one during May-July and second during October to January as is also observed by Miller (2007) and Mitra (2007).

*Ischnura senegalensis* – Prefers stagnant or slow moving water and is absent in the intact forests (Clausnitzer 2006). The canal systems of the reservoirs produce slow moving water system increasing the abundance of this species. At the two reservoirs, TIR and WIR, where
because of Narmada inundation the slow moving water system prevails for longer duration, probably this species is quite common.

*Ictinogomphus rapax* — A Gomphid known to be present all over the Oriental region with flight period all year round was the common species at TIR and WIR that have longer hydro period compared to JIR where it was uncommon. Although most of the Gomphids are known to breed in running water this species prefers stagnant water for breeding (Subramaniam, 2005).

*Pantala flavescens* — This migratory species is one of the best known and most-widely distributed libellulid, occurring in all the tropical and some temperate regions of the world (Askew, 1988; Silsby, 2001). They are found in large flocks swarming around the place where food is abundant. Sharma and Joshi (2007) found them to be the most dominant species at Dholbaha dam in Shivalik Punjab. This species breed in marshes and ponds and fly all throughout the year, but huge swarms can be seen just before and after monsoon (Subramaniam, 2005). The rating of this species as frequent at JIR may be attributed to the presence of *Rhyothemis variegate* a common species at JIR that exhibits similar flying behavior to that of *P. flavescens*, probably obstructing and pushing away the latter species.

*Diplacodes trivialis* - is another common species in India. It perches on low vegetation or on the ground and rarely flies over 1 m height and hence is called as the Ground skimmer (Miller, 2007). It breeds in the muddy puddles at the pond edges. It is observed all throughout the year as it has no specific flight period (Subramaniam, 2005). The differences in the rating of this species among the reservoirs can be mainly due to the availability of more muddy puddles around the larger WIR which are preferred by this species.

*Crocothemis erythraea* — is the species that perches on vegetation or ground in the vicinity of the water body. It is a low-land species preferring lower altitudes where the water is
stagnant (Ott, 2007). In the lentic water bodies of the study, this species was rated as common at WIR while Frequent at TIR and JIR.

*Diplacodes lefebvreii* - The Black percher is a widespread species with range extending from Africa to Eurasia and is common in the Indian subcontinent. It prefers well vegetated temporary or seasonal freshwater habitats (Clausnitzer, 2005). JIR, though not temporary has comparatively shorter hydro period and water spread in the absence of Narmada inundation hence probably this species was common at JIR while was uncommon at other two reservoirs.

*Rhyothemis variegate* - a prominent dragonfly of marshes, paddy fields and ponds is easily mistaken for a butterfly (Subramaniam, 2005). This species reported from many parts of India (Miller, 2007) is a weak flier and frequently perches on aquatic weeds. It is rarely seen away from water and flies all throughout the year near the perennial marshes (Subramaniam, 2005). It was common at JIR where emergent aquatic weeds are present towards dam side and uncommon at TIR and WIR where water is deeper towards dam side with less emergent vegetation for perching.

*Bradinopyga geminate* - This species was common at reservoirs with Narmada inundation. It usually perches on compound stone walls, boulders, etc. and easily amalgamates with surroundings because of its extremely varied colouration making it quite inconspicuous. The species is commonly found near rock pools and other similar small water collections (Subramaniam, 2005) which occurred due to seepage of water around the two reservoirs. It flies throughout the year and prefers sunlit time of the day (Miller, 2007).

*Pseudagrion microcephalum* - a species of both lentic as well as lotic habitats is generally found resting on the bushes in the water bodies or at the edges of the water body. Vegetation is very important for this species (Subramaniam, 2005) and the absence of vegetation for
perching reduces its numbers. June to November is considered as its flight period when it is most active (Subramaniam, 2005). This species was frequent at WIR the larger reservoir with extensive canal system while uncommon at the other two reservoirs.

*Onychargia sp.* — Though a very widely distributed species, it is probably under-recorded in many areas. Where it occurs, it is common and is capable of surviving in secondary and disturbed habitats. It breeds in ponds and marshes with trees, and swamp forest (IUCN, 2009). However, it was observed frequently at JIR and WIR while was rare at TIR.

*Trithemis aurora* — A frequent species at WIR while uncommon at TIR and JIR, is one of the common dragonflies of wetlands of India. The males usually perch on dry twigs, aquatic plants and over head cables. It breeds in streams, rivers, canals, ponds and tanks and flies all throughout the year (Subramaniam, 2005). In the present study it was mainly observed during September to December as is also reported by Kumar (1972).

*Jschnura aurora* — It is a widespread species found in plains as well as altitudes, and common among vegetation along the banks of ponds, rivers, canals and estuaries (Subramaniam, 2005). It preys on both the flying as well as settled prey like the Diptera and Epmeroptera (Mitra, 2007). In the present study its occurrence was low and varied at the three reservoirs as rare, common and uncommon.

*Ceriagrion coromandelium* — rated as frequent at JIR, the reservoir with reeds while uncommon at other two is reported to be common along the banks of ponds, rivers and canals and also found frequently far away from water bodies. It breeds in shallow water bodies with profuse growth of grass and other aquatic plants (Subramaniam, 2005). It perches on low vegetation (Miller, 2007) and makes periodic swift flights to prey on the small flying insects (Mitra, 2007). This species was reported to be one of the dominant species in the study by Sharma and Joshi (2007) at Dholbaha dam of Shivalik Punjab.
**Sympetrum vulgatum** - rated as frequent at JIR while uncommon at TIR and WIR, is basically a European species that has expanded its range in Asia. It breeds in standing water and hence probably was observed around the reservoirs.

**Agriocnemis pygmaea** - Though a common Indian species during October-January (Subramaniam, 2005), it was uncommon around all the three reservoirs. It is known to be present in diverse natural and manmade habitats. Its larvae commonly occur among the aquatic weeds and algae (IUCN, 2011) while adults perch among the vegetation and flies very close to the ground.

**Trithemis kirbyi** – Though this species has wide distribution and prefers freshwater like Streams, rivers and pools, woodland or bushes (IUCN, 2011), it was uncommon at all the three reservoirs.

**Coptera marginipes** – The species with varied status as absent at WIR, rare at JIR and uncommon at TIR is known to inhabit ponds, puddles, canals and streams. It also flies very close to the ground and breeds in shallow water collections, such as rainwater puddles and backwaters of streams. August-November is considered as its flight period (Subramaniam, 2005). In present study also it was observed from September to November.

In a habitat the core species show fewer variations in flight period as compared to the edge species. The climatic variations are also more pronounced at the edge of habitats (Purse and Thompson, 2003). Distribution of different species of Odonates is not recorded for Gujarat hence which species is core species and which species is edge species cannot be decided for the semi arid zone of Gujarat with reference to varied flight period. The common species are usually found in larger numbers as compared to the rare species (Shelton and Edward, 1983; Kandibane et al., 2005). The common species have the ability to survive in the existing environmental conditions and are observed all through the year. This was found to be true in
the present study too, where the rare species disappeared with the change in the season but common did not.

**Jaccard's Similarity Index (J)**

The higher annual Jaccard's similarity index suggests the overall resemblance of the habitats around the three reservoirs in the semi arid zone of Gujarat which are hardly 25 to 50 Kms. away from each other. Dispersal of flying species aided by wind cannot be ruled out when the macroclimatic conditions are same. Annual scenario showed more resemblance between TIR and JIR with highest similarity in post-monsoon which is the flight period for many Odonates. The seasonal species composition differed leading to low similarity index. Dragonflies react quickly to the disturbances that are caused due to human pressures which forces them to move to better location (Bried, 2005). In the present study, the influence of disturbance caused by the human movements is seen at TIR which probably disturbed the colonization of the dragonflies forcing them to disperse during different seasons of the year resulting in low number and hence lower similarity. Overall higher numbers of species were observed during summer and post-monsoon at TIR while at other two reservoirs the differences were not so significant, the results of undisturbed and stable habitat over all the seasons.

**Species Richness**

The highest annual odonate mean species richness at JIR can be accredited to the maximum species present around the reservoir which offered the most suitable perches on the edges of the water body. In addition, a cluster of trees is also present on the earthen dam itself with the scrub vegetation on both the slopes. At WIR the grasses growing in the marshy areas created due to seepage from the reservoir provided good perching posts increasing odonate species richness. The effect of larger size also cannot be ruled out. The GroundSkimmer (*D.*
trivialis), Ditch Jewel (B. contaminate) and Ruddy Marsh skimmer (C. servilia) preferring the Ground level were regularly present here. The species richness at both these reservoirs was mainly due to the presence of the species that prefer stagnant water for breeding. At TIR, the species richness was comparatively low due to human disturbances caused by domestic activities and the presence of the scrub a little far from the dam. Though urbanization does not affect the dragonfly diversity (Lubertazzi and Ginsberg, 2010) human presence has been reported to disturb Odonates (Bried, 2005; Maiolini and Carolli, 2009) as they react quickly by appearing or disappearing from the habitat.

Several species prefer moving in sunlight and during summer there is good sunlight which encourages them to come out and fly. Being Poikilothermic and of tropical origin (Krishnaraj and Pritchard, 1995; Sternberg, 1994), the distribution, seasonality and inter-habitat variations of Odonates are strongly restricted by climatic factors, especially temperature (May, 1978). Ubukata (1973) and Purse and Thompson (2003) have reported the odonate emergence to be facilitated by high temperature. Odonates are also reported to postpone their emergence in the absence of the suitable climatic conditions (Purse and Thompson, 2003). Hence, the higher species richness during summer is due to larval emergence into imago as well as the higher temperature that facilitate the suitable conditions for the adults to forage.

Monsoon too is a favourable season for odonates as they exhibited good species richness around the three reservoirs. During monsoon many species perform breeding activities. The basic requirement for this group of insects is the availability of water for egg laying which is easily available in monsoon. Post-monsoon is also a suitable period for Odonates as water is still plenty around, which also facilitates their reproduction. During this season places for perching are available as vegetation flourishes and clouds disperse bringing in sunshine. For
Odonates, although the potential emergence pattern is determined by the mode of seasonal regulation, the actual pattern depends on proximate climatic factor like temperature (Corbet, 1957; Lutz, 1968; Gribbin and Thompson, 1990). Though the temperature in post-monsoon is comparatively high the other proximate factors like adequate water sources, emergence of macrophytes and availability of food encourage the species to reproduce successfully. During winter the temperature drops creating somewhat unfavourable conditions for both the dragonflies and the damselflies when they are observed only during the afternoon hours when the sun is high. In winter the lower temperatures were more influential than the water availability accompanied by the death of the macrophytes which has been reported to be unsuitable for Odonates (Hawking and New, 2002).

Temperature has been implicated in determining the structure of aquatic communities (Carpenter et al., 1992; Heino, 2002; Burgmer et al., 2007). Mesocosm experiments have suggested that a 3°C increase in water temperature would have negligible impacts on the structure of aquatic macro invertebrate communities (Feuchtmayr et al. 2007). Although natural Odonate communities appear to exhibit high rates of turnover in response to changing season, changing climate with change in temperature does not influence the high rate of odonate turnover (Flenner and Sahlén, 2008; Hassal and Thompson, 2008). Hence comparatively high species richness of Odonates was found during summer as well as other parts of the year in the subtropical semi arid zone of Gujarat where the temperature are comparatively high irrespective of dry or wet season.

As none of the three reservoir dried off completely during study, water was available all throughout the year. Hence, good species richness of Odonates was observed all round the year except winter.
Climatic and habitat stability are known to increase the level of endemism (Fjeldså et al., 1997). Many researchers have reported rainfall to be a precursor for increased insect activities (Anu et al., 2009). However, in the present study, the species richness of Odonata was not influenced by rainfall. As water is the basic requirement for the nympha l odonates, these are mostly observed in the areas with adequate water and hence, may not solely depend on rainfall for their development. However, the species richness was reported to be higher during these periods, i.e. Monsoon and post-monsoon and also in summer which is considered the flight period of most of the Odonates. As discussed earlier, the comparatively low species richness at TIR in all seasons may be attributed to the human disturbance along with the sparse vegetation present a little far from the earthen dam. Here also the highest species richness was recorded during post-monsoon. The comparative low species richness in summer as well as monsoon was mainly due to the absence of most of the damselflies which ultimately decreased the species richness. At JIR, the species richness was recorded to be high all throughout the year except in winter when it was comparatively low. This can be mainly attributed to water availability, presence of bushes/vegetation for perching and relatively undisturbed habitat. Hence it can be said that the change in season is minor factor if other conditions are favourable. The species richness was higher at WIR during the two seasons when the temperature and other climatic factors are suitable for this group of insects. **Density** Even though annually JIR supported maximum species, it did not support maximum density of Odonates which was noted at WIR-the probable influence of the size. However, with reference to other fauna it has been reported that larger the area more is the possibility of the dispersion leading to decline in density (Smallwood and Schonewald, 1996; Gaston and
Blackburn, 2000). The density at TIR and JIR did not show much difference. Clausnitzer (2003) has reported an increase in the dragonfly species with increase in light penetration and the river width. WIR being larger reservoir the depth is greater and being located in semi arid zone light availability is high with greater penetration due to submergent vegetation. This probably increased the breeding rate leading to higher density of Odonates. Annual Density of Odonates was mainly influenced by the presence of Ditch Jewel, Long legged Marsh Glider (T. pallidinervis) and Wandering Glider (P. flavescens) at TIR and WIR, while Common Picture wing (R. variegata) and Ditch Jewel at JIR.

The seasonal density also suggests that post-monsoon is the most favourable period for Odonates. This season provides most suitable climatic conditions for dragonflies and damselflies. Ditch Jewel and Ground Skimmer contributed to the higher density in post-monsoon at WIR and TIR, while Wandering Glider was an additional species at TIR. The latter along with Common picture wing contributed to the density at JIR. The higher population of odonates recorded during this season can be accredited to the presence of more exposed macrophytes that emerged out of the water providing perching posts over clear water (to guard the eggs and larvae). Samways and Steytler (1996) have reported that shade and exposed macrophytes are important environmental variables determining Odonata distribution.

The seasonal variations at TIR showed very low density in winter as none of the species were present in higher numbers in contrast to good numbers of Ruddy Marsh skimmer (C. servilia) and Ditch jewel at JIR and Ditch Jewel, Long legged Marsh Glider and Wandering Glider at WIR in early as well as late winter (beginning of December and February end). The sensitivity to physical habitat quality makes Odonates useful indicators of habitat quality above as well as below the water surface. However, the water quality and aquatic
habitat morphology, such as bottom substrate and vegetation structure, are critical to
dragonfly larvae while the adult habitat selection is strongly dependent on vegetation
structure, including degrees of shading (Clausnitzer, 2006). Hence, any change in the habitat
influences the dragonfly population and their number declines. This was found to be evident
at TIR where during 2010-11 winter large number of *Acacia* and *Prosopis* species were
removed for restoration of dam leading to change in the habitat that in turn reduced the
dragonfly density. However, relatively higher density present at JIR and WIR during winter
can be indication of the low level of changes present around the reservoirs surrounded by
higher agricultural matrix.

Although there was good variation in the species richness in summer and monsoon at TIR
and JIR, the variations in the density were not significant. The density at all the three
reservoirs showed a drastic drop by the end of summer and in the early monsoon *i.e.* in late
May and Early June. This may be principally attributed to the hot weather with decline in
the availability of water as well as disturbance due to fishing activities especially at WIR.
Further, as is said by Maiolini and Carolli (2009), human disturbances trigger the dispersal
of very sensitive Odonate groups. At TIR also the fishing activities are carried out, but not
as extensive as WIR. Due to Narmada inundation the water spread was also larger which
probably facilitated the activities of the Odonates at TIR hence they were reported in higher
number as compared to WIR. At JIR as there is no fishing activity as well as the water was
adequate in the summers of the study period the density was higher.

Common species dominate in disturbed habitats while species with tight habitat preferences
and regional importance disappear with increasing habitat disturbances (Clausnitzer, 2003)
as is also noted for TIR where *Brachythemis contaminata* was the main density determining
species. Further, as excess of water is not favoured by odonates (Subramaniam, 2005) the


input of rain water decreased the odonate density in monsoon. Among the three reservoirs, the density of Odonates at Wadhwana was always high compared to other two reservoirs in all seasons, except summer when the conditions were more favourable at JIR with water as well as vegetation on the earthen dam providing perches.

Shannon Weiner Species Diversity Index (H')

Highest annual H' reported at WIR suggests that the odonates are more established here compared to other two reservoirs. Lowest H' at TIR can be attributed, firstly to the higher numbers of generalist species, and secondly to the overall low number of species present. Diversity index depends on the number of species present in addition to the number of individual of each species.

Diversity index also indicated that the post-monsoon is the favourable season due to presence of higher numbers of species with moderate population. In winter the lowest density was due to overall low number of species. However, the moderate H' reported for this group of insects suggests the population to be stable in the semi arid zone of Gujarat. The non-significant seasonal differences in H' clearly shows that the Odonates were never extreme in their numbers and their population was regulated by one or the other environmental factors. In the present study, at all the three reservoirs the low variation in the seasonal diversity index suggests that the odonate community in the area is reasonably good.

Absence of the major differences in H' among the reservoirs clearly suggests that all three reservoirs have equally well suited habitats for this group of flying insects.

Evenness (E)

Evenness at the three reservoirs did not show much of the variations in the annual scenario with almost high evenness recorded at the three reservoirs. The high evenness indicates the uniformity of the community. However TIR had the most even distribution of the species.
Heterogeneity is known to be higher in a community when there are more species and also when the species are equally abundant (Krebs, 1985). In the present study the numbers of species were high at all three reservoirs, but many species were found to be rare and hence the variation in the evenness was recorded. As far as water birds are concerned Deshkar (2008) reported that low species richness leads to high evenness, while the high species richness results in low evenness. This was not found to be completely true for this group of organisms as both species richness and evenness were high during post-monsoon while, in winter the low species richness at TIR resulted in highest Evenness. However, at JIR the evenness was more or less same in all the seasons except winter when it was lowest. The low number of species that also unevenly distributed with some species with very high numbers while others observed in ones and twos resulted in the low winter evenness. At WIR the evenness was found to be high when more number of species was present i.e. in monsoon and post-monsoon, while the lowest evenness in summer mainly due to the presence of exceedingly high numbers of *Trithemis pallidinervis* and *Brachythemis contaminate*. In winter too, the higher number of some species and absence of the other led to low evenness.

**Percentage occurrence**

Families belonging to both the sub-orders Anisoptera and Zygoptera of order Odonata are considered together. Highest number of Odonate species belonging to family Libellulidae (Anisoptera – Dragonflies), with widespread distribution (Subramaniam, 2005; 2009) led to its higher percentage occurrence. Most of the species belonging to this family were common and hence higher in numbers. The other family with moderate percentage occurrence is the Coenagrionidae (Zygoptera – Damselflies) which is the largest family of the damselflies. Although Gomphidae (Anisoptera – Dragonflies) was represented by only
two species it had higher percentage occurrence due to the commonness of *Ictinogomphus rapax*, the species that was observed many times at all the reservoirs. Other families had low percentage occurrence or were even absent completely at one of the three reservoirs. Lestidae (Zygoptera – Damselflies) was present at all the reservoirs but all three species of genus *Lestes* were observed rarely and hence did not contribute much to the total odonate population. A single species *Copaera marginipes* contributed to higher percentage occurrence of family Platycnemididae (Zygoptera – Damselflies) at TIR. Families Cordulegasteridae and Aeshnidae (Anisoptera – Dragonflies) as well as Protoneuridae (Zygoptera – Damselflies) could not find preferable niche at the reservoirs and hence were observed during their exploratory visits only, leading to their low percentage occurrence.

The seasonal scenario also showed Libellulidae to be the most dominant family with highest percentage occurrence due to their round the year presence along with their higher density during some part of the year. Coenagrionidae and Gomphidae were also present all throughout the year and hence had higher percentage occurrence. In case of Gomphidae, *Ictinogomphus rapax* was present in all the seasons of the year with good percentage occurrence. Libellulidae and Coenagrionidae were represented by the generalist species that are active all throughout the year while other specialist were active in different seasons of the year resulting in the perennial presence of this family. However, the species present all throughout the year were *Brachythemis contaminata*, *Trithemis pallidinervis* and *Crocothemis servilia* of family Libellulidae at WIR, *Pantala flavasens*, *Brachythemis contaminata* and *Trithemis pallidinervis* at TIR and *Rhyothemis variegate* and *Brachythemis contaminata* at JIR. Many authors have reported Libellulidae to be the dominant family in terms of abundance at different places in India as well as outside India (Asahina, 1993; Hamalainen, 1994; Gupta et al., 1995; Norma-Rashid, 1995; Norma- Rashid et al., 1996;
Family Coenagrionidae present in all the seasons was not common in summer, hence it could be said that the dry hot summer is unfavourable for these weak fliers. Coenagrionidae had highest percentage occurrence during winter at all the reservoirs. This was opposing to Gomphidae and Libellulidae which had higher percentage occurrence during post-monsoon and summer respectively. The higher percentage of Coenagrionidae in winter may be mainly attributed to the flight period of many species of this family from September to January (Subramaniam, 2005). This family also had good percentage occurrence in post-monsoon. As the percentage occurrence is a comparative index where the higher percentage occurrence of one family affects the percentage occurrence of the other, it ultimately decreases the percentage of others (Hurd et al., 1971). In the present study also it was noted that the increase in the percentage occurrence of Coenagrionidae influenced the percentage occurrence of Libellulidae. All other families were either absent during some seasons of the year or were rarely sighted and hence did not affect the percentage occurrence of the families Libellulidae and Coenagrionidae.

Lestidae is a family of damselflies that normally prefers temporary pools hence its adults are found in the vicinity of the water bodies. Although the flight period of this family is recorded to be June to September in the Peninsular India (Subramaniam, 2005) these were not recorded in monsoon and were most common during summer and showed occasional
presence in post-monsoon at TIR while in winter at JIR. This indicates that some species of Lestids have wider and different flight period in semi-arid zone of Gujarat, India.

Protoneuridae was a rare family found at WIR only during summer, and hence did not affect the overall percentage occurrence. Similarly Platycnemididae had a single species but was observed all throughout the year except winter at TIR. Its higher percentage occurrence during monsoon and post-monsoon was due to its flight period from August to November (Subramaniam, 2005). However, its appearance in summer at TIR and single appearance at JIR during winter may be exploratory.

As for annual percentage occurrence, *Ictinogomphus rapax* increased the seasonal percentage occurrence of Gomphidae in all the seasons at the three reservoirs. Hence it can be said that the species present all throughout the year are more important for the percentage occurrence of a family. The flight period of Cordulegasteridae only from April to September (Subramaniam, 2005) resulted in their lower percentage occurrence.

Coenagrionidae and Libellulidae are the two dominant families of the study. Libellulidae was more dominant in summer when other families had low percentage occurrence. However in post-monsoon and winter the dominance of Libellulidae was shared by Coenagrionidae.

Most of the odonate species have their flight period during monsoon and post-monsoon (Subramaniam, 2005), but in the present study all the families recorded at WIR and TIR were present during summer. This can be in response to the extended hydro period due to Narmada inundation in the semi-arid zone of Central Gujarat, India. On the contrary, winter which is considered to be the unfavourable season for the Odonates recorded presence of all the five families at JIR. This can be primarily due to the presence of species belonging to the
three common families Coenagrionidae, Gomphidae and Libellulidae and the accidental presence of Lestidae as well as Platycnemididae during winter.

**Importance of Odonates as Indicators of Environmental Health**

Of all the habitats being affected by land conversions, wetlands are among the most impacted ones (Reece and McIntyre, 2009). They are usually poorly protected, and their important biological resources are easily lost through clearance and overuse (Clausnitzer, 2004). These are one of the major ecosystems that support the odonate density and diversity as many of the odonates prefer standing water which are present at wetlands. Hence to save the extinction of the several Odonate species supported by these ecosystems, wetlands need to be conserved. Major threats to wetlands are excessive exploitation, changes in water quality due to industrial effluent, agricultural pesticides, siltation and the introduction of exotic species. An immediate cessation of these activities is need of the time for preventing the habitat destruction of the Odonate species. Wetlands are crucial resources, and as their degradation continues to occur as a result of indirect and direct human activities, it is vital to elucidate the proximal effects of land use on odonate community structure (Reece and McIntyre, 2009).

There have been numerous recent studies from around the world that have documented that odonates respond to anthropogenic activities and thus may serve as useful indicators of habitat quality in terms of species occurrence (Samways and Steytler, 1996; Kadoya et al., 2008), diversity (Rith-Najarian, 1998; Sahlén and Ekestubbé, 2001; Clausnitzer, 2003; Sahlén, 2006; Suhling et al., 2006), distribution (Flenner and Sahlén, 2008), morphology (Taylor and Merriam, 1995; Hardersen and Frampton, 1999), and dispersal (Jonsen and Taylor, 2000).

Different ecological requirements are linked to different dispersal capacities. Species with narrow niches often disperse poorly, while pioneers of temporal habitats (often created by disturbance) are excellent colonizers. Odonates in particular are good aerial species for evaluating habitat connectivity (Clausnitzer et al., 2009). In summary, Odonata are an easy-to-study group and are useful for monitoring the overall biodiversity of aquatic habitats and have been identified as good
indicators of environmental health (Samways and Steytler, 1996; Corbet, 1999; Sahlén and Ekestubbe, 2001; Clausnitzer, 2003; Suhling et al., 2006; Kalkman et al., 2008). According to Clausnitzer et al. (2009), most of the threatened species are clustered in the Indo-Malayan and Australian realms and hence they need to be documented at least before they get extinct. Conservation strategy needs to be developed and implemented to stop further deterioration of the Odonate species. The species inhabiting lotic waters are at greater risk than those in lentic waters, may be partly due to lentic habitats being less predictable in space and time. Species in lentic systems tend to be more generalised and have a higher dispersal capacity (Corbet, 1999), resulting in larger ranges and wider ecological preferences, and therefore lower extinction risk (Clausnitzer and Jodicke, 2004; Hof et al., 2005).

Odonates are currently the only insect group for which a representative global assessment of conservation status with reference to taxonomy and distribution has been completed and analysed (Clausnitzer et al., 2009). Hence, looking at its importance in the global assessment, for planning the conservation strategy of the wetlands they first need to be documented and later the indicator species may be identified.

Apart from butterflies, probably no other group of insects has received so much attention from the general public and has many organizations devoted to its study (Kalkman et al., 2008). If conservation measures are to succeed then preparation of baseline inventory has been stressed with regular monitoring of changes in their species richness and abundance to assess the ecological health of the area (Chelmick et al., 1980; Clark and Samways, 1994). Hence the present study is expected to provide information regarding status of Odonates around three reservoirs in the semi-arid zone of Gujarat, India.