2. REVIEW OF LITERATURE

2.1 BIODIVERSITY

“Biodiversity is the variety of and among the living organisms, biological system and biological process found on Earth”. The term is neologism obtained by joining words biology, the study of life and diversity, meaning difference and variety. Biodiversity (or biological diversity) then is the diversity of and living nature (Wilson, 1988).

The presence of several plant species and genotypes within the same tropical level appear to play a significant role in the ecosystem services. So scientists usually defined biodiversity in terms of genes, species and ecosystems and of plant and animal life within species (genetic diversity), among species (species diversity) and among ecosystems (ecosystem diversity), corresponding to three fundamental and hierarchically kind of biodiversity i.e. genetic diversity, species diversity or taxonomic diversity and ecosystem diversity (Heywood and Watson, 1995).

When, Harrison (2004) distinguishes seven levels of biodiversity: genetic diversity, species diversity, ecosystem diversity, community diversity, landscape diversity, population diversity and organismal diversity.

Biodiversity has several components, such as the numbers abundance, composition, spatial distribution and interactions of genotypes, populations, species, functional types and traits and landscape
units in a given ecosystem (Diaz et al., 2005). All these components may play a role in maintaining life support systems in the long term.

A community comprises the populations of different species that naturally occur and interact in a particular environment. Some community are relatively small in scale and may have well-defined boundaries and other communities are larger, more complex and may be less clearly defined (Stachowicz and Tilman, 2005).

The factors that determine the diversity of a community are extremely complex. Environmental factors, such as temperature, precipitation, sun-light and the availability of inorganic and organic nutrients are very important in shaping communities and ecosystems (Hunter, 2002).

Throughout the history of angiosperms, diversification has been a complex process, in which the propensity to diversify was highly labile and dependent upon many different traits at different times (Davies et al., 2004).

India has a long mainland coastline of about 5700 km and comprises 60 coastal districts. Coastal zone in India assumes its importance because of the high productivity of its ecosystems, concentration of population, exploitation of renewable and non-renewable natural resources, discharge of waste effluent and municipal sewage, development of various industries and spurt in recreational activities in and around the coastal zones (Nayak et al., 1996).
Gujarat coast is characterised by typical salt marshes spread in about 796-km, sand-dunes in approximately 440-km and rocky shores in ~ 319-km (Ramachandran, 2001).


Similarly, definitions of biodiversity too, were not precise in the beginning. The first most standard definition sponsored by the United Nations was included in the Convention on Biological Diversity (CBD) (UNEP, 1992). According to this definition, biodiversity refers to ‘The variability among living organisms, *inter alia*, terrestrial, marine and other aquatic systems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems’. The second most–used definition of biodiversity is sponsored by the Global Biodiversity Strategy (WRI, IUCN and UNEP, 1992) as ‘The totality of genes, species and ecosystems in a region’.

Diversity within the natural environment is important. It provides variety that people enjoy, both in species and landscape. Species variety plays a dual role of ensuring and signalling the variety of the natural environment. Furthermore, it protects the health of natural environments,
which provide services, on which people need to depend (SIG, 2007).

Biodiversity is a very popular approach in environmental science too, and has long remained a central theme in ecology. In recent years, many countries have established biological monitoring programs in different ecosystems to assess their state and / or to draw inference about changes in state over time (Yoccoz et al., 2001). The term biodiversity is a simple contraction of biological diversity and at first sight the concept is simple too: biodiversity is the sum total of all biotic variation from the level of genes to ecosystem (Andy Purvis and Andy Hector, 2000). The diversity in ecosystems, habitats and the prevailing environmental conditions is reflected upon the plant life. Each habitat, and even each microhabitat, supports different plant assemblages. The variation is not only spatial, but it is also temporal (Batanouny, 2001). According to Wilson (Wikipedia, 2007), although the biodiversity is one of the bigger wealth of the planet, it is not recognized as such.

Recent studies indicate that a more diverse ecosystem has greater capacity to withstand environmental stress and consequently is more productive. The total loss of species is thus, likely to decrease the ability of the system to maintain itself or to recover from damage or disturbances. Just like a species with high genetic diversity, an ecosystem with high biodiversity may have a greater chance of adapting to environmental changes (Wikipedia, 2007). Moreover, we are still only beginning to understand in depth the processes that generate and maintain the global biodiversity (Storch et al., 2007).
Indeed, habitat destruction caused by human economic activity is described as a major cause of current rapid loss of species and as one of the main cause of biological invasions on all spatial scales (di Castri, 1989; Kowarik, 1990). Direct and indirect anthropogenic changes in climates, rates and other environmental constraints will have a major impact on successional dynamics and the maintenance of biodiversity (Schulze and Mooney, 1993) as well as on plant invasions (Kowarik, 1990).

Aquatic ecosystems are the most productive ecosystems and provide a resource of food and raw materials with a very high economical value to the national and regional economy (Mitsch & Gosselink, 2000; Zahoor et al., 2012). These fragile ecosystems include different biotopes like; sand-dune, marshes, lakes and rivers. Much work has been carried out on the floristic, phytosociology and pollution aspects of these ecosystems in different regions of the India and world notable among these being; Ozturk & Guvensen (2002), Banerjee et al., (2002), Naskar, (2004), Kavgaci (2007), Sakcali et al., (2009), Ozturk et al., (2010, 2011a) and Altay Volkan and Ozturk Munir (2012).

For ecologists, biodiversity means the diversity of durable interactions among species. It not only applies to species, but also to their immediate environment (biotope) and the eco-regions the organisms live in. In each ecosystem, living organisms are part of a whole; they interact with one another and as well as with the air, water, and soil that surround them (Wikipedia, 2007). On the other hand, a narrow definition of biodiversity is to focus on genetic diversity and a broader definition is to focus not just on species but on habitat and ecosystem diversity. Here
varied landscapes, uplands, lowlands, wetlands and coastal areas all contribute to the diversity of the natural environment (SIG, 2007).

Based on rates of discovery and geographical scaling-up, it seems that the roughly 1.75 million described species of organism may be only around 10 % of the total existing on the earth (Hawksworth and Kalin-Arroyo, 1995). Likewise, biodiversity is not static; it is a system in constant evolution, from a species, as well as from an individual organism point of view. The average half–life of a species is estimated at between one and four million years and 99 % of the species that have ever lived on earth are today extinct (Wikipedia, 2007).

Theory and small–scale experiments predict that biodiversity losses can decrease the magnitude and stability of ecosystem services, such as production and nutrient cycling (Cottingham et al., 2001; Hooper et al., 2005). Most of this research, however has been isolated from the immigration and emigration (dispersal) processes that create and maintain diversity in nature (Gonzalez and Chaneton, 2002; Giller et al., 2004; Srivastava and Vellend, 2005).

Processes of climatic change and habitat loss which concurrently are an important example where synergistic effects may occur. Yet most studies reporting effects of climate change (Parmesan, 2006) or habitat loss and fragmentation on biodiversity (Brooks et al., 2002; Mantyka – Pringle et al., 2012) have examined each in isolation.

In 2002, the 188 countries that are signatories to the Convention on Biological Diversity committed themselves to “Achieve by 2010 a
significant reduction of the current rate of biodiversity loss at the global, regional and national level” (CBD, 2003). Unfortunately, this laudable target is very vague as regards practicalities. It presents both a challenge and an opportunity for biodiversity scientists (Balmford et al., 2005); a challenge because biodiversity is not a simple concept, and coming up with measures that encompass all its aspects will be difficult; an opportunity because when such measures are in place, it will be possible to guide and manage biodiversity better, and so make progress towards a more sustainable world.

A sensitive, realistic and useful measure of biodiversity loss needs to be based on changes in population abundance across a wide range of species and must consider the entire landscape. At a global scale, habitat loss, including reductions in both quality and quantity of suitable environment, is the main factor responsible for declines in species abundance (WCMC, 2000; Jenkins, 2003). Other important causes, such as excessive harvest pressure or the effects of pollutants, can also be expressed on the basis of area affected and intensity of impact.

Measures of diversity are regarded as indicators of the well–being of ecological systems (Magurran, 1988). However, any attempt to measure biodiversity quickly runs into the problem that it is a fundamentally multidimensional concept: it cannot be reduced sensibly to a single number (Whittaker, 1972; Magurran, 1988). Additionally, measures do not take into account changes in species composition, such as species turnover rates (invasive and elimination rates), because plant diversity can be directly affected by invasive species both by increasing the number of species and by replacing some of the existing species
through competition; and thereby affecting the character and functioning of ecosystems (Ramakrishnan and Vitousek, 1989; Heywood, 1996; Tilman et al., 1997).

Whereas there is no shortage of ways to express biodiversity (CBD, 2003; Magurran, 2004), none adequately meets the criteria set by the CBD. Most indices require essentially complete knowledge of the biota or the population sizes of individual species, neither of which are achievable conditions at regional to global scales for the next several decades. Many methods are scale-dependent and thus, hard to interpret in a comparative context. The most widely used indicators are based either on risk of extinction (Hilton-Taylor, 2000) or on land area under conservation protection (IUCN and UNEP, 2003).

Likewise, several indices have been offered that combine either a sparse and selective set of population estimates for indicator species (Lob, 2002), or combine a number of factors that are thought to relate to biodiversity status (Sanderson et al., 2002). Hill (1973); Patil and Taillie (1982) have elegantly demonstrated that all diversity indices are members of a family of statistics that spans a continuum from pure richness to pure evenness. Some diversity indices have more desirable statistical properties than other indices (Hurlbert, 1971; Peet, 1974; Pielou, 1975, 1977; Magurran, 1988) and depending on the question being evaluated, one index may be more appropriate than another.

It is clear that a single index of biodiversity is not sufficient for all purposes. The Biodiversity Intactness Index (BII) is not intended to highlight individual species that are under threat, and should be used
together with indicators, such as the IUCN red list of threatened species. Conceptually, the BII is very similar to the Natural Capital Index (NCI), which has been implemented in the Netherlands (Ten Brink et al., 2002). However, the method for estimating BII does not require actual population data, and it can, therefore, complement the NCI in data-sparse regions.

Likewise, species composition is more important than species or functional group richness in affecting a range of ecosystem properties (Hooper and Vitousek, 1997; Tilman et al., 1997; Wardle et al., 1997). Furthermore, the distribution of species abundance of non-native plants is a more sensitive measure of environmental disturbance than species richness alone (Kempton, 1979). Hence, total plant diversity alone does not seem to be an exact indicator of well-being of ecological systems (Magurran, 1988; Li and Krauchi, 2002).

The relationship between sampling scale and the processes that influence species diversity is the basis of the distinction between ‘within - habitat’ diversity and ‘between – habitat’ diversity (Whittaker, 1972, 1975). Within habitat diversity (called ‘alpha diversity’ by Whittaker, 1960, 1967) reflects coexistence among organisms that are interacting with one another by competing for the same resources or otherwise using the same environment. It is measured simply as the number of species (or other components of species diversity) within an area of given size.

Between – habitat diversity (called ‘beta diversity’ by Whittaker 1960, 1975) reflects the way in which organisms respond to environmental heterogeneity. Between – habitat (beta) diversity is
somewhat more complex to quantify, and depends not only on the number of species in the habitat, but on a comparison of the identity of those species and where they occur. Beta diversity is usually expressed in terms of a similarity index between communities or of a species turnover rate (Whittaker, 1960; Wilson and Mohler, 1983; Cody, 1986) between different habitats in the different geographical area. High beta diversity is the result of low similarity between the species composition of different habitats or different locations along a gradient.

A third type of diversity has been defined that applies to even larger scale phenomena, which reflect primarily evolutionary rather than ecological processes (Whittaker, 1960, 1972; Cody, 1986). Whittaker (1960) defined geographical or ‘gamma’ diversity as simply the number of species within a region, analogous to alpha diversity but at a regional scale. Like beta (between - habitat) diversity, geographical diversity is based on the differences in the species composition between habitats. However, Cody’s gamma diversity is based on differences in species composition between similar habitats in different geographical areas (e.g., species turnover with distance separating similar habitats), rather than between dissimilar habitats in the same geographical area.

The fact that ecologically similar but taxonomically different species are performing the same role in similar communities separated by a given distance implies that evolutionary processes involved in creating and maintaining separate species are operating effectively at that scale. Thus, geographical diversity must be expressed both in terms of the distance between similar habitats and the taxonomic differences between groups of ecologically similar species.
In a broad summary, it can be said that on average, greater diversity leads to greater productivity in plant communities, greater nutrient retention in ecosystems and greater ecosystem stability (Tilman, 2000).

It becomes very clear from the literature cited above, that a researcher must be cautious and confident in deciding the specific approach of describing diversity of any plant groups and also in selecting appropriate indices for arriving at a reliable answer to a pre-decided objective.

2.2 BIODIVERSITY OF COASTAL HALOPHYTES

Physiological disorders such as reduced growth is ultimately due to the cumulative effects of the causal factors on the physiological processes, necessary for plant growth and its development (Schutzki and Cregg, 2007; Rahman and Ibrahim, 2012). Due to immobility of higher plants, it needs a greater protection against several stresses, including low and high temperature, water stress, salinity, metal toxicity and others.

It is widely accepted now that among the various biodiversity regions, the marine and coastal zone ecosystems are of particular importance in terms of their utility to the human livelihood security. They are extremely important, both for the natural resources and ecological communities they contain and as areas of concentrated human activities. Similarly, while reviewing status and trends of global biodiversity, UNEP (1995) had also emphasized for developing research programs on biodiversity of inland, coastal and marine waters.
In a broader sense, coastal systems include rocky and sandy shores, beaches, estuaries, deltas, backwaters, lagoons etc. (Brink, 1993) and are usually covered with dry coastal beach vegetation, beach forest of sandy or rocky habitat types, wet coastal mangroves, salt marshes, seaweeds, sea-grasses, coral reefs and associated sub-tidal benthos (Goldberg, 1993).

Coastal zone represents 18% of earth’s surface providing space for the 60% of the human population, since about 70% of the world’s cities with population more than 1.6 million are located in the coastal area. Furthermore, this zone has high biological potential as it serves as feeding, nursery and spawning grounds with rich biodiversity and as an intermediately biotope between marine and freshwater environments (Balasubramanian, 1999).

Marine phytoplankton and algae, sea grasses, mangroves and halophytes are major components of marine flora. While marine phytoplankton, algae and sea grasses occur in oceanic waters, subtidal and intertidal zones in various parts of the world, mangroves grow in intertidal tropical and subtropical regions (Dawes, 1981). However, halophytes generally occur in habitats like salt marshes and salt desert across the globe (Mitsch and Gosselink, 2000; Nybakken, 2001; Chakraborty et al., 2011).

Seaweeds are one of the commercially important living marine resources, which grow submerged in intertidal, shallow and some time subsurface waters up to 100 m depth in the sea and also in brackish water estuaries. In India, seaweeds are present abundantly along the Tamilnadu,
Seagrass communities are the vital part of the marine ecosystem because they function as primary producers with high rate of production (Dawes, 1981) and serve as shelter and swim-in-restaurants for a variety of marine animals (Kannan et al., 1999). Marine botanists have rigorously worked out eco-physiology of seagrasses, which abundantly grow in tropical and temperate seawaters. Jagtap (1991) described the distribution of seagrasses along the Indian coast, whereas Rejith Kumar (1998) studied eco-physiology of *Ruppia rostelata* growing on Saurashtra coast in Gujarat.

Biodiversity in the coastal ecosystem differs from terrestrial ecosystem both in respect to pattern of diversity and to the functional application of those patterns. Nevertheless, the most frequently used quantitative measure of coastal biodiversity is for a given area rather than for a given biological community. In ecological terms, physical areas and the biotic components they contain are termed habitats. Habitat diversity is a more useful term than that of ecosystem diversity since habitats are easy to envisage (e.g., a mangrove forest, a coral reef, an estuary). Likewise, habitats often have clear boundaries and have been termed “The template for ecology” (Kannan et al., 1999).

Coastal ecosystems command the world’s highest importance by virtue of their biological productivity, specialized adaptive capacity of the biodiversity, complexity in the ecological processes and finally importance of the resources that have a wide range of natural functions.
and that are variously used for sustainable life support to the human and other biological components directly or indirectly (Ray, 1991; Grassle et al., 1991).

This high level of diversity in the coastal system reveals that species within the functional group are physiologically and genetically more distinct from one another than the terrestrial assemblage. More the differences among the members of a functional group, more that members may respond differently to the gradation of environmental changes and more will be the physiological and genetic base for adaptation to change and finally it confers a great potential for ecosystem resilience (Heywood and Watson, 1995).

Accounts of salt marsh ecology with particular emphasis on vegetation and topography appear in Tansley (1949), Chapman (1960), Ranwell (1972), Beeftink (1976, 1977), and Long and Mason (1983), while other aspects are included in Jefferies and Davy (1979) and Price et al. (1980).

Similarly, Green (1997) noted that coastal flora of the New South Wales, Australia comprised of mangroves and salt marsh communities and emphasized that a typical zonation of halophytes from the sea to the land needed special efforts of conservation.

Floristic and vegetative studies on tidal marshes of 3 rivers of the Chesapeake Bay showed that as salinity decreased, the number of species found in a marsh increased (Anderson et al., 1968; Wass and Wright, 1969; Atkinson et al., 1990). Odum et al. (1984) described the change in
dominant plant communities of the Atlantic east coast along salinity 
gradients and observed a large increase in species diversity of tidal 
freshwater marshes over their polyhaline and mesohaline counterparts. 
Mitchell (1991) and Hershner et al. (1991) documented the transition of 
dominant plant composition along an oligohaline and freshwater salinity 
gradient on the Mattaponi River, Virginia. However, these studies did not 
measure or quantify plant species diversity parameters along the salinity 
gradient.

It may be mentioned here that the IUCN in its regional marine 
program for 15 countries in Asia (2002) further stressed the need to 
protect coastal and marine diversity covering a varied range of 
ecosystems, such as coastal lagoons, mangroves, coral reefs, marshlands 
and deep sea trenches.

The vegetation and flora of the Indian coastline have not been 
studied in their proper perspective although a large number of references 
on the occurrence of seashore plants find place in several floras and 
papers, since the time of the publication of the “Flora of British India” 
(Banerjee et al., 2002). The coastal region, which supports diverse 
ecosystem, presents very interesting aspects for ecological, physiological 
and phyto-geographical studies. Only certain physiologically specialized 
and ecologically adapted plants, which have evolved remarkable 
adaptations to survive in the saltwater conditions, grow in this sensitive 
ecosystem.

As mentioned above, perusal of published work until 1970’s 
indicate that the studies on Indian coastal flora were mainly focussed on
taxonomy, listing, distribution and ecology of coastal plant communities occurring in different parts of the country (Banerjee et al., 2002). However, researchers at Kolhapur University (Joshi, 1976) significantly contributed in the field of photosynthesis in mangroves. Later on, concept of wetlands was added to research on coastal vegetation, because of the fact that unique plant species occurred in coastal wetlands. This was followed by an additional dimension of biodiversity (Nandi, 2002), which should be addressed seriously, as few authentic reports are available at present.

Although extensive research has been carried out on distribution and survey (Blasco, 1975; Joshi and Shinde, 1978; Rao and Suresh, 2001); physiology (Joshi, 1976); ecology (Naskar and GuhaBakshi, 1987) and other biological aspects (Untawale, 1985; Kathiresan and Bingham, 2001) of mangroves growing in coastal areas in India, much remains to be done on biodiversity and phytosociology of halophytes.

Halophytes are considered to be rare plant forms that arose separately in unrelated plant families during the diversification of angiosperms (O’Leary and Glenn, 1994) and in this process they resemble epiphytes, saprophytes, xerophytes, aquatics, and marsh plants (Kremer and Van Andel, 1995). No comprehensive list of halophyte species exists, partly due to the problem of defining the lower salt tolerance limit at which a plant should be considered a halophyte. Aronson (1989) compiled a partial list of halophytes containing 1560 species in 550 genera and 177 families. He used a broad definition of halophyte that included any plant that was reportedly more tolerant than conventional crops, for which the upper salt content of irrigation water
was taken to be 5 g/L total dissolved solids (TDS) or 85 mM as NaCl (Ayers and Wescott, 1989).

Ozturk et al. (2008) reported 137 halophytic species belonging to 88 genera and 34 families in Irano-Turar phyto-geographical region of Turkey. Whereas, according to Akhani (2006), a total of 365 species within 151 genera and 44 families of Iranian vascular plants are known to be true halophytes, or species capable of successful growth on salty soils. The Chenopodiaceae family with 139 species ranks first, followed by the Poaceae (35), Tamaricaceae (29), Asteraceae (23) and Plumbaginaceae (14).

From what has been said regarding the number of halophytic species in preceding paragraphs, it becomes apparent that some researchers include only eu/true halophytes (Waisel, 1972); some others include eu and facultative halophytes, while remaining all scientists include all species occurring on slightly saline soils to highly saline salt marshes for determining the total number of halophytic species. Such discrepancy obviously leads to ambiguous understanding of this unique and interesting group of plants.

Salinization of soils and groundwater is a serious land-degradation problem in arid and semi-arid areas, and is increasing steadily in many parts of the world due to poor irrigation and drainage practices, which cause a great reduction for crop productivity (Lambers, 2003). As an alternative method to restore saline land, the utilization of halophytes attracted more attention due to their salt tolerance characteristics and potential economic values (Flowers, et al., 1977; Zhao et al., 2002).
Dicotyledonous halophytes generally accumulate more NaCl in shoot tissues than monocotyledonous halophytes (especially grasses), which led early researches to characterize the former as “includers” and the latter as “excluders” (Ahmad et al., 1981).

Some reviews and books (Rains, 1972; Waisel, 1972; Reimold and Queen, 1974; Flowers et al., 1977; Ungar, 1978; Sen and Rajpurohit, 1982; Khan and Ungar, 1995; and Pessarakli, 1999) include exhaustive information on biology, eco-physiology and utility aspects of halophytes. Similarly, recent reports elucidate mechanism of salt tolerance in plants at cellular and molecular levels (Zhu, 2002). Most of the published data reflect studies on eco-physiology of an individual species in relation to edaphic and climatic conditions but much remains to be done on eco-physiological behaviour of morphologically different halophytic species growing at the same locality and the same species occurring at characteristically two different habitats.

Abd El-Ghani (2000), while working on vegetation composition of Egyptian inland saltmarshes, observed twelve halophytic plant communities linked to two main habitats (wet-moist and dry-mosaic). *Alhagi graecorum, Tamarix nilotica, Cressa cretica, Juncus rigidus* and *Phragmites australis* were the most common in the two oases, whereas communities of *Cyperus laevigatus, Suaeda aegyptiaca, Suaeda vermiculata, Typha domingensis* and *Aeluropus lagopoides* were recorded from the Dakhla oasis and *Cladium mariscus* and *Arthrocnemum macrostachyum* communities were recorded from the Siwa Oasis.

El-Sheikh and Abbadi (2004) described five plant communities in
the Jal Az- Zor national park, Kuwait, namely, (I) *Haloxylon salicornicum*-Stipacapensis community, (II) *Cyperus conglomeratus-Plantago boissieri* community, (III) *Zygophyllum qatarense* community, (IV) *Nitraria retusa*; *Zygophyllum qatarense* community and (V) *Halocnemum strobilaceum*; *Bienertia cycloptera* community.

Base data of mangrove diversity in the Sunder bans (India) have been collected by Naskar (2004), whereas enormous investigations on coastal flora occurring on 5700-km-long Indian coast have been cited by Banerjee *et al.* (2002). However, these studies, though many in numbers, include only details of either occurrence or distribution of halophytes in different parts of the country. Significant contribution on eco-physiology, phyto-sociology and biodiversity of halophytes has been carried out at Physiology laboratory of Life Science Department since 27 years (cf. Khot, 2003; Shukla, 2007; Vyas, 2007; Talekar, 2009 and Pawar 2012). Nevertheless, much remains to be done on diversity of coastal flora occurring on Indian coast.

2.3 **SALT MARSHES**

Salt marshes are complex coastal environments usually located within estuarine systems. Estuaries receive important inputs of pollutants as they are often situated in the vicinities of highly populated and industrialized areas. The release of heavy metals into the aquatic environment may cause detrimental effects to the receiving environment. Most metals entering into the aquatic system become associated with particulates and may accumulate in sediments (Reboreda *et. al.*, 2008).
Salt marshes are depositional environments characterized by weak hydrodynamic forcing and sedimentary surfaces with high physiochemical and biogenic cohesion. Salt marsh surface sediment typically develops high erosion thresholds that preclude entrainment by tidal currents and shallow-water waves (Chen, Si et al., 2012).

Salt marshes are the most productive ecosystems and provide a buffer zone between terrestrial and aquatic ecosystems. Physical, chemical, and biological interactions between freshwater and saltwater systems can have significant influences on the transportation of trace and heavy metals in the estuarine environment (Ip et al., 2006). Therefore, salt marshes are excellent areas to study the pollution chronology of coastal and estuarine systems because of their fine sediments with high organic content (Ashraful et al., 2009). Salt marshes act as protective filters and repositories for runoff pollutants (Teal & Howes, 2000), pathogens and different types of nutrients (Weis & Weis, 2003).

Salt marshes generally develop in areas that are protected from the full force of the surf, in locations, such as river mouths and sheltered bays and are typically vegetated by a variety of unique low shrubs, herbs and grasses (Clarke and Hannon, 1971; Zedler et al., 1995).

Diversity of emergent plant species has attracted attention of researches in recent years. For instance, Perry and Atkinson (1997) measured plant diversity in four tidal marshes on the York and Pamunkey Rivers, in the U. S. Each marsh represented a different salinity regime (polyhaline, mesohaline, oligohaline, or tidal freshwater). The tidal freshwater marsh had the highest species diversity index of the sites.
However, the next highest diversity index was seen in the marsh with the highest salinity, possibly due to an obligate halophytic component absent from the other sample plots. Facultative halophytes dominated the polyhaline, mesohaline, and oligohaline marshes. No similarity existed between the dominant flora of the tidal freshwater marsh and that of the other three marshes.

Farrar and Gersib (1991) noted that the Nebraska salt marshes in the U. S. supported many plant genera typically occurring in coastal salt marshes. The most saline parts of these marshes were dominated by salt-tolerant macrophytes, such as saltwort (*Salicornia rubra*), sea blight (*Suaeda depressa*), and inland salt grass (*Distichlis spicata*), whereas the open ponds and their fringes were dominated by plants, such as sago pondweed (*Potamogeton pectinatus*), wigeon grass (*Ruppia maritima*), prairie bulrush (*Scirpus maritimus* var. *paludosus*), and even cattails (*Typha angustifolia* and *T. latifolia*). Similarly, deSzalay and Resh (1996, 1997) observed that the major species in brackish marshes in California included pickle weed (*Salicornia virginica*) and alkali bulrush (*Scirpus robustus*).

Gopal and Sah (1995) noted that the Indian subcontinent had a large variety of freshwater, saline and marine lands. Whereas the mangroves were relatively well documented, very little was known about the other wetlands, with few exceptions.

Drought and salinity are the most important environmental factors inhibiting photosynthesis and decreasing growth and productivity of plants in many parts of the world. They are the major causes of crop loss
worldwide, reducing average yields for most major crop plants by more than 50% (Naz et al., 2010).

Conventional water resources and crops do not meet all the requirements of human societies living in dry and saline areas. Using seawater or brackish water and salt tolerant crops may be options to be considered, since there could be a greater focus on developing halophytes as cash crops in the future (Breckle, 2009; Mohammad Kafi and Masoume Salehi, 2012).

Mangrove plants are known to tolerate extreme environmental conditions. A halophyte is a plant that naturally grows where it is affected by salinity in the root area or by salt spray in saline semi-deserts, mangrove swamps, marshes and seashores. Mangrove and halophytic plants have been used in folklore medicine for the treatment of human diseases for centuries (Kirtikar and Basu, 1991).

2.4 MINERAL COMPOSITION - HALOPHYTES

Though inorganic ions help in maintenance of high internal osmotic potential facilitating absorption of water, some of the ions may be harmful to enzymes in salt tolerant plants, which are as sensitive as that of glycophytes. But then, these plants regulate their internal salt levels by various mechanisms like exclusion, accumulation, excretion, succulence etc. (Walter, 1961).

Halophytes are unique in their ability to accumulate high concentrations of salts equalling or exceeding those of seawater in their
leaves without detriment (Flowers et al., 1977). However, high concentrations of salts cause ion imbalance and hyper osmotic stress in plants, as a consequence of which, secondary stresses, such as oxidative damage often occurs (Zhu, 2001). Xiong and Zhu (2002) suggested that ion homeostasis was a key to salt tolerance and its regulation might distinguish salt tolerance capacity of salt tolerant and salt sensitive plant species. Yokoi et al. (2002) further reviewed the functional essentiality of ion homeostasis mechanism in salt tolerance of plants.

Distribution of various plant species in coastal environment depends upon their capacity of enduring salt tolerance and the latter characteristic is often manifested by the mineral composition of vegetative organs. Khot (2003) reported 2.94 to 12.3 meq. g\(^{-1}\)Na\(^+\) and 2.6 to 11.6 meq.g\(^{-1}\)Cl\(^-\) and Shukla (2007) found 3.64 to 5.86 meq.g\(^{-1}\) Na\(^+\); and 4.55 to 6.97 meq.g\(^{-1}\)Cl\(^-\) in different succulent halophytes.

Most of salt tolerant grasses are usually salt excretes and therefore, accumulate less amounts of Na\(^+\) and Cl\(^-\). For example, Joshi et al. (2002a) reported 0.15 to 0.78 meq.g\(^{-1}\) Na\(^+\) and 0.15 to 0.53 meq.g\(^{-1}\) Cl\(^-\) in vegetative organs of salt tolerant grass *Heleochloa setulosa* collected from Ghogha, Gujarat. Misra (1989) observed that accumulation of Na\(^+\) varied from 0.32 to 0.66 meq.g\(^{-1}\) and that of Cl\(^-\) from 0.37 to 0.77 meq.g\(^{-1}\) in *Sporobolus madraspatanus*. Recently, Vyas (2007) and Pawar (2012) recorded 1.02 to 1.37 meq.g\(^{-1}\) Na\(^+\) and 1.53 to 1.59 meq.g\(^{-1}\)Cl\(^-\) in *Sporobolus coromandelianus* and *Aeluropus lagopoides* growing in ‘Bhal’ and lower part of Gujarat region.

Glenn (1987) reported that the salt tolerant grasses, which were
commonly found in intertidal zones (\textit{Sporobolus, Aeluropus, Paspalum, puccinellia, Distichlis and Spartina}) survived 540 mM NaCl; while other species from the high zone of salt marsh or other brackish habitats did not survive these conditions.

A study on mineral composition of salt tolerant shrubs indicated that Na\(^{+}\) in different organs of \textit{Prosopis juliflora} varied from 0.29 to 0.81 meq.g\(^{-1}\), whereas Cl\(^{-}\) content reached up to 0.81 meq.g\(^{-1}\) (Hinglajia, 1997). According to Joshi \textit{et al.} (1993), leaves of another salt tolerant shrub \textit{Salvadora persica} collected from Gujarat coast accumulated 1.48 to 2.78 meq.g\(^{-1}\) Na\(^{+}\) and 2.11 to 3.41 meq.g\(^{-1}\) Cl\(^{-}\). Likewise, Vyas (2007) also noticed similar amounts of Na\(^{+}\) and Cl\(^{-}\) in the same species and 0.12 to 0.31 meq.g\(^{-1}\) Na\(^{+}\) and 0.22 to 1.23 meq.g\(^{-1}\)Cl\(^{-}\) in \textit{Prosopis chilensis}.

Studies on Na\(^{+}\) content in different species of \textit{Atriplex} (2.87 to 3.65 meq.g\(^{-1}\) d. wt. in \textit{A. halimus} and; \textit{A. confertifolia}, Moore \textit{et al.} (1972), 2.91 to 3.93 meq.g\(^{-1}\) in \textit{A. versicaria} and \textit{A. leptocarpa}, and 0.43 to 2.0 meq.g\(^{-1}\) in \textit{A. triangularis}; Osmond \textit{et al.}, (1980) showed a close range of fluctuations.

It is evident from the above cited literature, restricted to the principal ions \textit{viz.}, Na\(^{+}\) and Cl\(^{-}\) constituting a major fraction of salts, that halophytic plants accumulate greater amounts of these ions in their organs than those of salt tolerant grasses or shrubs or facultative and strand plant species growing in coastal areas.

It may be mentioned here that it will be beyond the scope of objectives of the present investigation, to review a detailed role of other
cations, such as $\text{Ca}^{2+}$, $\text{Mg}^{2+}$ and $\text{K}^+$ in the said categories of coastal plants, which do exhibit differential behaviour in accumulating such inorganic ions, (Vyas, 2007; Talekar, 2009 and Pawar 2012).

In the light of the above facts, it will be of interest to examine spatial and temporal changes in mineral composition of succulent, non-succulent, shrubby, facultative, strand and mangrove to relate such variations with diversity of such morphologically different plant species.

### 2.5 HEAVY METALS - HALOPHYTES

Heavy metals are extremely toxic and they are present in our immediate environment. They occur in soil, surface water, plants and are readily mobilized by human activities that include mining and discarding industrialized waste materials in natural eco-systems that include forests, rivers, lakes, and ocean. Heavy metals pose a potential threat to various terrestrial and aquatic organisms including human health (Hsu et al., 2006; Agoramoorthy, et al., 2008; and Milic et al., 2012).

Conventional biological processes are generally inadequate for removing humic substances in landfill leachate to meet direct effluent discharge standards. Landfill leachate after biological treatment is composed mainly of humic substances. Humic substances significantly affect the behavior of persistent organic pollutants and heavy metals in natural environments (Chai et al., 2012).

Some plant species have developed mechanisms to survive in high external concentrations of elements, thus becoming tolerant to heavy
metal pollution. Several of these hyper tolerant plants have the ability to accumulate high concentration of metals in their tissues (Boularbah, et al., 2006).

Furthermore, human impact on environment can be scaled by the measurements of heavy metals in soil, plants and animals because metal pollution adversely affects the density and diversity of biotic communities including human (Mountouris et al., 2002; Hsu et al., 2006).

Heavy metals might be degraded either by microbial or by chemical process and tend to accumulate in soils or to be transported by streaming water and contaminate surface water and ground water (USEPA, 2000). For these reasons, it would be interesting to develop techniques for heavy metal removal from soils.

With increasing urbanization and industrialization, coastal areas of all tropical littoral countries in Asia, especially India, have been subjected to considerable environmental stress due to domestic sewage, industrial effluents, heavy metals and other toxic waste (Agoramoorthy and Hsu, 2005; Hsu et al., 2006).

Some plant species are known to accumulate very high concentrations of toxic metals, which far exceed to that of the soils (Baker and Brooks, 1989).

In many ways, living plants can be compared to solar driven pumps, which can extract and concentrate several elements from their environment. From soil and water, all plants have the ability to
accumulate heavy metals which are essential for their growth and development. These metals include Mg, Fe, Mn, Zn, Cu, Mo and Ni.

Certain plants also have the ability to accumulate heavy metals, which have no known biological function. These include Cd, Cr, Pb, Co, Ag, Se and Hg. However, excessive accumulation of these heavy metals can be toxic to most plants.

A halophyte is a plant that naturally grows where it is affected by salinity in the root area or by salt spray in saline semi-deserts, mangrove swamps, marshes and sea-shores (Agoramoorthy et al., 2008).

The ability to both tolerate elevated levels of heavy metals and accumulate them in very high concentrations has evolved in a number of different plant species (Ernst et al., 1992).

Plants distribute metals internally in many different ways. They may localize selected metals mostly in roots and stems, or they may accumulate and store other metals in non-toxic form for latter distribution and use. A mechanism of tolerance or accumulation in some plants apparently involves binding potentially toxic metals at cell walls of roots and leaves away from sensitive sites within the cell or storing them in a vascular compartment (Memon et al., 2001; Hall, 2002).

It has been suggested that salt-tolerant plants would be better adapted to coping with environmental stresses, including heavy metals (Lopez-Chuken and Young, 2005), than salt-sensitive (glycophytic) crop plants (Zea mays L., Brassica juncea L., Pisum sativum L.) commonly
chosen for phytoextraction studies.

Several authors have pointed out that the use of plants that hyper accumulate heavy metals in their aerial parts could be an economically efficient method for cleaning the soils. Most studies dealing with phytoextraction focus on hyper accumulating plants able to concentrate high levels of heavy metals in their aerial parts without showing any symptom of injury. The strategies of resistance in those plants involve several mechanisms, such as the vacuolar sequestration of heavy metals linked to overproduced organic acids (malate, citrate or oxalate) or phytochelatins produced from glutathione (Salt et al., 1998).

Toxic metal contamination of soil and groundwater causes major environmental and human health problems, especially in arid zones with saline soils. The most commonly used methods for dealing with heavy metal pollution are still extremely costly (Memon et al., 2001; Singh et al., 2006).

Therefore, the investigation of physiological mechanisms of survival of salt-tolerant halophytes under the conditions of excessive heavy metal content becomes very urgent (Jordan et al., 2002; Shevyakova et al., 2003).

As mentioned earlier, heavy metals are known to pose a potential threat to terrestrial and aquatic biota. However, little is known on the toxic levels of heavy metals found in mangrove and halophytic plants that are used in traditional medicine in India (Agoramoorthy et al., 2008).
It has been shown that salt marsh sediments from unvegetated areas contain lower concentrations of metals than those sediments under vegetated areas (Cacador et al., 1996 a, b; Doyle and Otte, 1997) and the same was observed in pore water (Otero and Macias, 2002). Metals in halophytes are mainly accumulated in the roots with small quantities translocated to the stems and leaves (Cacador and Vale, 1997; Weis et al., 2002; Williams et al., 1994b; Windham et al., 2003), except in the case of more mobile elements, such as Mn, Cd and Zn (Cacador et al., 2000; Williams et al., 1994a; Milic et al., 2012).

It is off interest to halophytes are of significant since these plants are naturally present in environments with an excess of toxic ions and research findings suggest that these plants also tolerate other environmental stresses, especially heavy metals as their tolerance to salt and to heavy metals may, at least partly, rely on common physiological mechanisms. Therefore, halophytic plants have been suggested to be naturally better adapted to cope with heavy metals compared to glycophytic plants commonly chosen for heavy metal phytoremediation research. Under these considerations, halophytes are potentially ideal plants for phytoextraction or phytostabilization applications of heavy metal polluted saline and non saline soils.

Furthermore, a novel process for the phytoremediation of heavy metal contaminated soils termed phytoexcretion has been recently introduced based on findings that some salt-excreting halophytes use their excretion mechanism in order to remove the excess of toxic metal ions from their sensitive tissues and on the idea of using plants as biological pumps for heavy metals (Manousaki and Kalogerakis, 2012).
Thus, a brief review apparently indicates the need for further studies on heavy metal accumulation in plants species occurring in marshy, sandy and rocky habitats, such as found in along Gujarat coast from Kachchh to Diu (Fig. 6) selected for the present investigation and to correlate the process with diversity of halophytes.