International Research Journal of Biological Sciences _____E-ISSN 2278-3202
Vol. **5(12),** 28-37, December **(2016)** *Int. Res. J. Biological Sci.*

Surveillance of the Tolerance Limit of *Sonneratia alba* Sm. to certain Hydrogeochemical Parameters from Heterogenous Natural Habitats of Kerala, South India

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Available online at: www.isca.in, www.isca.me
Received 12th November 2016, revised 1st December 2016, accepted 4th December 2016

Abstract

Efforts for the restoration of mangroves entail unswerving information on their growth sustaining conditions. Present study attempts to assess the tolerance of Sonneratia alba, the mangrove apple, grown in diverse natural conditions in the coastal environments of Kerala, to varied ranges of water quality parameters influencing their growth and establishment. Such information is appropriate in finding out regions which are ideal for their introduction in pursuit of coastal conservation and management. The year round study indicated a marked difference in all water quality parameters in their habitats, with respect to seasons. The range of tolerance of imperative water quality parameters like salinity (ppt) during pre-monsoon, monsoon and post monsoon seasons was noted to be 33.93 – 38.5, 0.299 – 11.68 and 7.107 – 35.15 respectively. Similarly the ranges of Hardness (6840 - 8760, 32 - 520 and 280 – 6800 mg/l), Calcium (448.56 – 528.66, 1363.4 – 1830.86, 9.62 – 134.67 mg/l), Magnesium (1.46 – 44.79, 84.17 – 488.61, 8.28 – 1397.49 mg/l), Sodium (23.9 – 29.8, 0.002 – 8.17, 5.33 – 31.1ppt) and Potassium (0 – 1.65, 0 – 0.26, 0.12 – 2.56 ppt) were analysed and reported. Correlation of these vital hydrogeochemical parameters from diverse sampling stations proved that the changing trends in related parameters are coherent and all the three sampling stations are highly unswerving and persuasive. More over wide range of tolerance of S. alba to salinity (0.299 to 38.5 ppt) is indicative of their potentialities for inclusion in various coastal restoration activities.

Keywords: *Sonneratia alba***,** Water quality, Restoration/ Afforestation, Salinity.

Introduction

Mangroves are highly productive bio resources of the intertidal zone, which spread across the tropics and subtropics, offering tremendous ecosystem services[1]. Over-exploitation of these resources resulted in the degradation and thereby disruption of intertidal ecosystems[2]. These ecologically important coastal ecosystems are declining at a disquieting rate, particularly in developing countries, that they may completely disappear within the next 100 years[3]. India has a mangrove cover of 3150 km^2, of which 80% occurs along the east coast and in the Andaman Islands. It was reported that during the past 25 years, almost 30% of the mangrove forest in the country was cleared[4]. Most degraded mangrove cover reported is in the Gulf of Kutch, Gulf of Khabayat and Kerala coast[5]. A drastic decline in the mangrove cover from 700km^2 to17km^2 was evidenced in the state of Kerala that posed a 'threatened' status in the State[6]. Thus, an urgent fortification and conservation of this ecosystem is necessary.

Afforestation of mangroves seems to be a promising solution for the restoration of their lost habitats[4]. Since the establishment of mangrove population depends mostly on their growth necessities and habitat uniqueness, research regarding the above areas needs to be carried out prior to any afforestation programme. A study on "Restoration of Mangroves in Kerala and Karnataka States" during 2005-06 summarized that the major species used for plantation in Kerala are *Rhizophora apiculata*, *Kandelia candel*, *Avicennia officinalis*, *S. alba* and *Aegiceras corniculatum*. Among these *R. apiculata* and *K. candel* are the major species used for raising plantations as more than 80 % of the area planted are with these species[7].

In the present study, an attempt has been carried out to assess the range of water quality parameters favouring the growth of *S. alba* (Lythraceae), which are growing naturally in various heterogeneous conditions along the coast of Kerala. Such information on their natural growth conditions will help in the selection of sites ideal for afforestation activities in the coastal environments of any nation.

Materials and Methods

Study Area: The present investigation was carried out in three different natural habitats of *S. alba*, straddling in 3 regions of Kerala namely Vallikkunnu (Malappuram, 11°07'35.14"N, 75°49'51.77"E), marked as Station I; Kadalundi (Malappuram, 11°07'35.42"N, 75°49'50.72"E), marked as Station II and Thekkumbad (Kannur, 11°58'04.32"N, 75°17'45.38"E) marked as Station III. Station I and II are part of Vallikkunnu -

Kadalundi wetlands and Kadalundi river is the main source of water to these wetlands. Thekkumbad (Station III) is a small Island in Valapattanam River, situated at Mattool Panchayath of Kannur district. Thekkumbad is characterized by the presence of a biodiversity rich coastal sacred grove namely 'Thazhekkavu'. The Thekkumbad -Thazhekkavu habitat is bordered by Valapattanam River in the south, Pazhayangadi River in the east and backwaters of the Arabian Sea in the west. Details of sampling locations are given in Figure-1.

The physico-chemical characteristics of water bodies associated with the habitats of *S. alba* were monitored monthly for a period of one year for assessing their periodic changes, which are likely to influence the growth of mangrove species. For this, water samples were collected and the collected samples were subjected to the analysis of quality parameters like pH (Systronics, 6373), Turbidity (Digital Nephelometer, 341), Salinity, Conductivity, Resistivity (Eutech PCD, 650), Sodium and Potassium (Systronics, 128) using standard analytical instruments. Parameters like Total Alkalinity, Total Acidity, Total Hardness (Calcium and Magnesium) and Chloride content were assessed following APHA (1995)[8].

Results and Discussion

Afforestation efforts on mangroves necessitate reliable information on their growth supporting conditions. The present study attempts to assess the range of different water quality parameters that expectantly influence the growth and development of *S. alba* along its natural habitats in the coastal environments of Kerala.

The mean values of water quality parameters together with their standard deviation noticed at three sites under study in the Pre-monsoon, Monsoon and Post-monsoon seasons are depicted in Tables-1, 2 and 3 respectively.

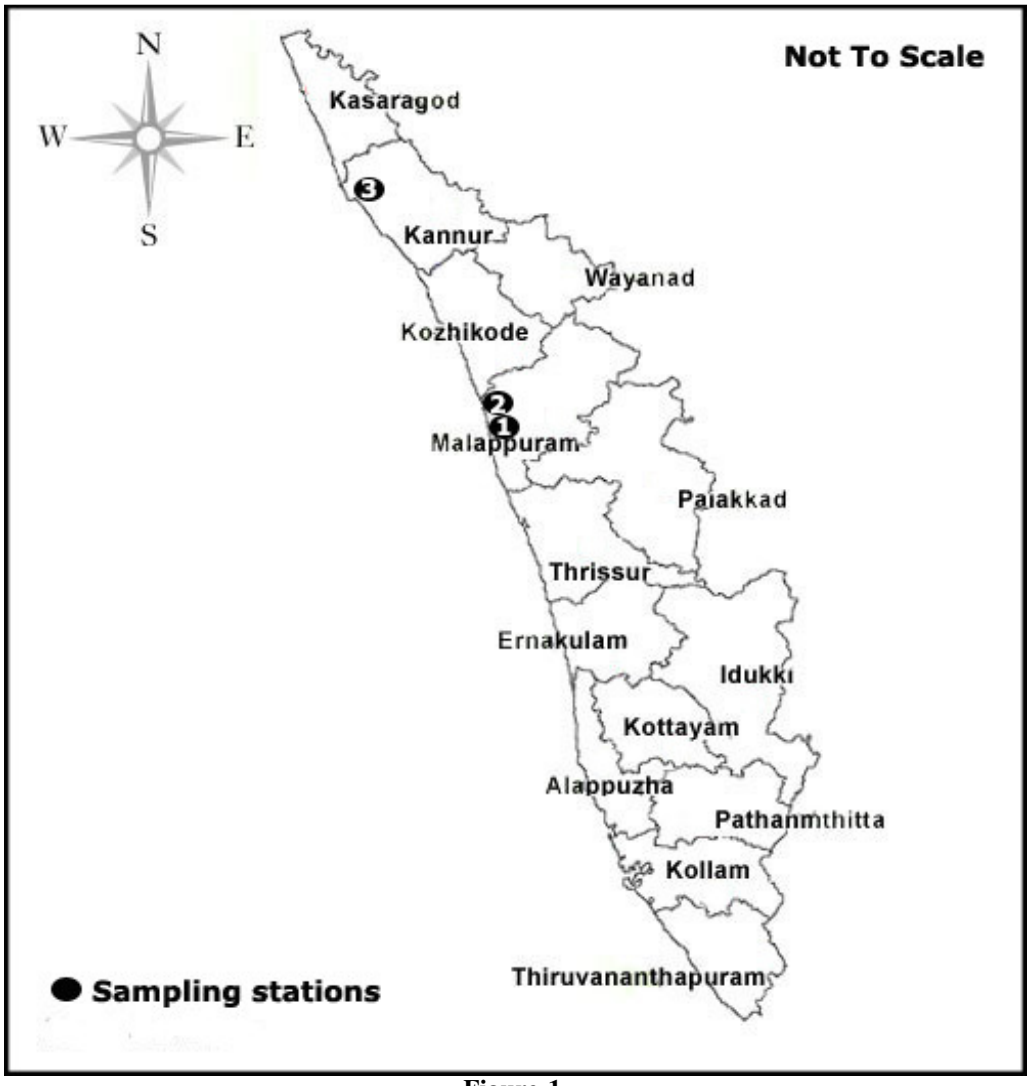

Figure-1
Sampling Stations

Table-1
Results of water quality parameters from Station 1 (Vallikkunnu)

Parameters	Pre Monsoon	Monsoon	Post Monsoon
pH	7.935 + 0.26	7.86 + 0.63	8.253 + 0.266
Turbidity	16.1 + 8.08	18 + 14.24	15.1 + 15.012
Acidity (mg/l)	45.1 + 13.69	18.33 + 8.86	27.28 + 19.29
Alkalinity (mg/l)	182.5 + 39.61	135 + 38.94	212.5 + 66.097
Hardness(mg/l)	7440 + 773.95	236.33 + 153.62	3137.5 + 2630.14
Calcium(mg/l)	490.61 + 19.92	53.44 + 39.12	322.07 + 150.01
Magnesium(mg/l)	1513.1 + 188.8	25.08 + 13.82	568.13 + 557.65
Chloride(mg/l)	25347 + 3118.35	3488.47 + 2321.35	19702.5 + 13339.83
Sodium (ppt)	27 + 1.5	0.23 + 0.27	17.6 + 8.04
potassium(ppt)	0.24 + 0.14	0.08 + 0.097	0.35 + 0.144
Salinity (ppt)	34.87 + 0.65	3.022 + 3.75	23.88 + 9.57
Conductivity (mS)	50.97 + 0.71	5.14 + 6.22	36.06 + 13.15
Resistivity (Ω)	19.17 + 0.26	938.99 + 650.26	31.62 + 12.58

Table-2
Results of water quality parameters from Station 2 (Kadalundi)

Parameters	Pre Monsoon	Monsoon	Post Monsoon
pH	8.23 + 0.09	7.463 + 0.698	8.12 + 0.29
Turbidity	14.025+ 11.84	26.967 + 19.059	7.33 + 3.98
Acidity (mg/l)	31.9 + 12.97	11 + 4.75	28.27 + 17.37
Alkalinity (mg/l)	200 + 41.83	133.33 + 37.71	195 + 61.85
Hardness(mg/l)	6925 + 72.63	227.67 + 207.05	3540 + 2975.16
Calcium(mg/l)	480.6 + 29.43	54.37 + 56.797	283.41 + 146.98
Magnesium(mg/l)	1393.838 + 28.88	22.4 + 15.956	689.62 + 637.49
Chloride(mg/l)	24672.5 + 922.32	1898.07 +2071.91	18616.2 + 13161
Sodium (ppt)	25.375 + 1.15	4.347 + 3.292	16.25 + 8.21
potassium (ppt)	0.25 + 0.17	0.148 + 0.10	0.27 + 0.12
Salinity (ppt)	35.09 + 0.41	6.724 + 4.695	22.93 + 11.64
Conductivity(mS)	51.31 + 0.38	11.12 + 7.635	34.49 + 16.23
Resistivity (Ω)	19.042+ 0.15	432.66 + 524.28	39.54 + 25.29

Table-3
Results of water quality parameters from Station 3 (Thekkumbad)

Parameters	Pre Monsoon	Monsoon	Post Monsoon
pH	7.54 + 0.42	6.38 + 0.48	6.88 + 0.288
Turbidity	6.925 + 7.756	5.9 + 3.89	15.525 + 10.59
Acidity (mg/l)	50.6 + 15.71	25.67 + 7.26	55 + 11.847
Alkalinity (mg/l)	210 + 29.15	106.67 + 33.99	180 + 27.39
Hardness(mg/l)	7670 + 249.2	102.67 + 50.39	3571 + 2938.796
Calcium(mg/l)	496.62 + 23.35	11.757 + 2.48	335.505 + 116.30
Magnesium(mg/l)	1565.483 + 54.82	17.86 + 11.598	665.51 + 651.54
Chloride(mg/l)	26021.5 + 943.93	762.07 + 57.19	20785.25 + 3189.226
Sodium (ppt)	26.975 + 1.91	0.537 + 0.09	24.205 + 7.037
potassium (ppt)	3.73 + 5.97	0.003 + 0.005	0.98 + 0.92
Salinity (ppt)	36.493 + 1.62	0.817 + 0.023	30.92 + 5.22
Conductivity (mS)	53.27 + 2.04	1.575 + 0.042	45.89 + 7.15
Resistivity (Ω)	18.37 + 0.71	621.467 + 15.86	21.94+ 4.11

The pH of water is dependent on the relative quantities of calcium, carbonates and bicarbonates[9] and can determine the growth and development of plants in associated environments. It also gives insight on the extent of various gaseous components associated with it. The present study revealed that Station1 has highest pH (8.253) in post monsoon season and lowest (7.86) in monsoon season. In Station 2 maximum pH was observed in pre monsoon season (8.23) and minimum in monsoon season (7.463). Higher (7.54) and lower (6.38) values of pH at Station 3 was observed in the pre monsoon and monsoon seasons respectively. Station 1 was thus reported for sustaining a higher pH in the post monsoon season and station 3 for a lower pH in the monsoon season. Generally, fluctuations in pH values during different seasons of the year especially low pH observed during the monsoon season is attributable to certain factors such as removal of CO_2 by photosynthesis through bicarbonate degradation, dilution of seawater by freshwater influx, decrease of salinity and the decomposition of organic material[10,11]. Intrusion of sea water and enhanced biological activity in the aquatic system may result in an increased salt concentration and carbon dioxide emission respectively. These factors might have ensued in the varying levels of pH of water samples during different seasons[12].

Alkalinity values provide an idea of natural salts present in water and it is a measure of ions that can aid in the process of averting any change in hydrogen ion concentration[13]. Decomposition of organic waste in the water body and subsequent evolution of CO_2 may increase the level of alkalinity[14]. Alkalinity of water sample also varies in accordance with the fluctuation in the pollution load of aquatic systems[15.] In accordance with the range of pH, water from all the stations showed alkalinities in varying range. Station 1 has maximum alkalinity (212.5mg/l) in the post monsoon and minimum (135 mg/l) in the monsoon season. Maximum (200mg/l) and minimum (133.33 mg/l) alkalinity pertaining to Station 2 was observed during pre-monsoon and monsoon seasons respectively. In Station 3, higher alkalinity was observed in pre monsoon (210mg/l) and lower in monsoon season (106.67 mg/l). Thus on the whole, Station 1 was reported for having a higher alkalinity in the post monsoon season and station 3 for a lower alkalinity in the monsoon season. Merge with the above paragraph. Acidity of water samples from both Station 1 and 2 reported highest values (45.1 mg/l and 31.9 mg/l respectively) during pre monsoon season. Lowest values of 18.33mg/l and 11 mg/l respectively were noticed in these sites during monsoon season. Acidity of water pertaining to Station 3 indicated highest (55mg/l) and lowest (25.67 mg/l) values during post monsoon and monsoon seasons respectively. The overall result showed that maximum value of acidity was noticed at Station 3 in the post monsoon season and minimum value at Station 2 in the monsoon season.

In natural waters, there is a close relationship between alkalinity and hardness. Highly alkaline waters have excessive hardness and high concentrations of Sodium salts[16]. In the present study, hardness of water samples from all the three stations showed maximum (7440, 6925 and 7670 mg/l) and minimum (236.33, 227.67 and 102.67 mg/l) values in the pre monsoon and monsoon seasons respectively. The lower values of total hardness could be due to the high monsoonal precipitation, which might have diluted the salt content in water. On the contrary, natural accumulation of salts and decrease in water volume during post and pre monsoon seasons might be the reasons for increase in the total hardness[17].

In the present study correlation of pH with alkalinity showed all the three sampling stations with positive correlation (0.32072, 0.270571, 0.618203 respectively) and a dissimilar trend with acidity that a negative (- 0.10243) in Station I, positive (0.267385) in Station II and weakly positive (0.008245) in Station III. This supports the statement that Acidity and alkalinity are related to pH [18]. Changes in pH can also affect alkalinity levels (as pH lowers, the buffering capacity of water lowers as well) and high alkalinity is usually associated with high pH values[19].

The major cations imparting hardness to water are calcium and magnesium. Calcium forms the most abundant element in freshwater, contributing hardness and serves as one of the micronutrient that influences the growth and metabolism of ecosystem flora[20, 21] . Here, Station1 showed maximum Calcium (490.61 mg/l) in pre monsoon season and minimum (53.44 mg/l) in monsoon, whereas higher (480.6 mg/l) and lower (54.37 mg/l) Calcium at Station 2 was noticed in the pre monsoon and monsoon seasons respectively. In Station 3, maximum Calcium was observed in pre monsoon season (496.62 mg/l) and minimum in monsoon season (11.757 mg/l). The higher concentrations of calcium were mainly due to the influx of riverine source, rapid decomposition of organic matter and dissolution of sedimentary rocks[22, 23].

Likewise, Magnesium is an essential element for chlorophyll growth, often associated with calcium in all kinds of water but the concentration often remains lower than calcium[24.] Magnesium concentration at Station1 was maximum (1513.1 mg/l) in the pre monsoon season and minimum (25.08 mg/l) in the monsoon season. Highest magnesium concentration pertaining to Site 2 (1393.838 mg/l) and Site 3 (1565.483 mg/l) were reported in the pre monsoon season and lowest values for these sites (22.4 mg/l and 17.86 mg/l) were noticed in the monsoon season. Thus, from the results it can be inferred that, in accordance with the alkaline nature of water, Station 3 sustains a higher values of Hardness, Calcium and Magnesium in the pre monsoon season and lower in the monsoon season. Diminished water level and high rate of evaporation may contribute to the higher values of these parameters during summer season. Here, also in all the three sampling stations hardness of the water samples with Calcium (0.942989, 0.975797, and 0.931061) and that of magnesium (0.998296, 0.999252, and 0.998121) depicted strong positive correlation.

Sodium plays an important role in buffering the pH changes in aquatic environments[25]. Total hardness is attributed to sodium concentration in the surface water and it is understood that sodium induces hardness in water quality[26]. Here, Station1 showed maximum Sodium (27ppt) in pre monsoon and minimum (0.23 ppt) in monsoon season. Higher (25.375 ppt) and lower (4.347 ppt) values of Sodium at Station 2 was observed in the pre monsoon and monsoon seasons respectively. In Station 3, maximum Sodium was observed in pre monsoon season (26.975 ppt) and minimum in monsoon season (0.537 ppt). Like that of Hardness, higher and lower concentrations of Sodium were noticed at Station 1 in the pre monsoon and monsoon seasons respectively. The high sodium concentrations during dry seasons are largely due to the proximity of sea (salinity intrusion), addition of fertilizers by means of agricultural runoff and shrinkage of water volume[27]. Increased rainfall and river flow along with good mixing of water in the monsoon season might have resulted in a lower concentration of sodium[28,29].

Chloride occurs in all types of waters whose concentration is an index of natural and anthropogenic interferences, such as run-off containing road de-icing salts, the use of inorganic fertilizers, landfill leachates, septic tank effluents, animal feeds, industrial effluents, irrigation drainage and seawater intrusion in coastal areas[30].Cholride concentration also vary in accordance with temperature, precipitation, evaporation and the rate of flow of water[31]. Present data revealed that Chloride concentration at Station1 was highest (25347 mg/l) in the pre monsoon and lowest (3488.47 mg/l) in the monsoon season. Station 2 was reported for having a maximum Chloride level in the pre monsoon season (24672.5 mg/l) and minimum in monsoon season (1898.07 mg/l). Higher (26021.5 mg/l) and lower (762.07 mg/l) Chloride values pertaining to Station 3 was noticed in the pre monsoon and monsoon seasons respectively. From the results it has been noticed that in accordance with other parameters like alkalinity, hardness, calcium, and magnesium, Station 3 sustains a higher chloride concentration in the pre monsoon season and a lower in the monsoon season. Higher values of chloride in water during dry season might be attributed to the accumulation of wastes mainly of anthropogenic origin that later on get acted upon by microbial consortium present [32]. Also, factors like tidal flow, less fresh water mixing and high salinity might have contributed towards the high level of chloride during non-monsoonal season. Rain water and subsequent mixing of fresh water from riverine systems have contributed towards a lower chloride values in the monsoon season[33].

Potassium is one of the main cations present in the aquatic ecosystem and its occurrence is mainly by meteorological and agricultural factors[33]. In the present study, results of mean values of Potassium in water from Station 1 have maximum

level (0.35ppt) in the post monsoon and minimum (0.08 ppt) in the monsoon season. Higher (0.27 ppt) and lower (0.148 ppt) values of Potassium pertaining to Station 2 was reported in the post monsoon and monsoon seasons respectively. Station 3 has been noticed for maximum Potassium (3.73 ppt) level in the pre monsoon and minimum (0.003 ppt) in the monsoon season. Thus, from the results it has been evidenced that Station 3 sustains maximum and minimum values of potassium during different seasons of the year. Organic waste deposition and physiological weathering might have contributed to the high potassium content in water during pre monsoon season[34]. During monsoonal season, low potassium concentration was experienced due to its high sedimentation, followed by preferential absorption and incorporation into silicate minerals and also by utilization by aquatic biota[35].

Chloride concentration of water with Sodium revealed a strong positive correlation in Station I (0.923513), Station II (0.907144) and Station III (0.851492) as well as that of Potassium showed negative correlation in Station I (-0.10686) and Station II (-0.09743) moreover positively correlated in Station III (0.695799). This supported the statement chloride ions in the environment can come from sodium chloride or from other chloride salts such as potassium chloride, calcium chloride and magnesium chloride. When a salt such as sodium chloride dissolves in water it breaks up into positively and negatively-charged ions. Thus the amount of dissociated anion increases along with that of the cation[36].

The main sources of turbidity in water are erosion, living organisms and those from human activities. Suspended solids or particles are one of the natural pollutants in surface water that reduces its transparency and causes turbidity[37]. In the present study, Station 1 shows maximum Turbidity (18NTU) in the monsoon season and minimum (15.1 NTU) in the post monsoon season. Higher (26.967 NTU) and lower (7.33 NTU) Turbidity at Station 2 was observed in the monsoon and post monsoon seasons respectively. In Station 3, maximum Turbidity was observed in the post monsoon season (15.525 NTU) and minimum in monsoon season (5.9 NTU). Thus, higher range of Turbidity was observed in Station 2 in the monsoon season and lower in Station 3 in the monsoon season. Anthropogenic disturbances received by the estuary during monsoonal season might have resulted in a higher turbidity in this season[38].

Water and soil / sediment salinity has got enormous impact on the growth and development of mangroves[39]. The effects are in accordance with varying ranges of salinity and also with different species of mangroves. Some of the physiological and biochemical effects of salinity on mangroves include root initiation, stem elongation, propagule germination, seedling growth and emergence, biomass accumulation and stomatal closure[40]. Most of the mangrove species prefer growth conditions in which the salinity of adjoining water sources fluctuates within a range and may be as high as that of the open sea[41] . In the present study, Station 1 sustains maximum salinity (34.87 ppt) in the pre monsoon season and minimum (3.02 ppt) in the monsoon season. Higher (35.09 ppt) and lower (6.72 ppt) values of salinity pertaining to Station 2 was reported in the pre monsoon and monsoon seasons respectively. Station 3 has been noticed for a maximum salinity (36.49 ppt) in the pre monsoon and minimum (0.817 ppt) in the monsoon season. Salinity and conductivity can be related as both depends on the extend of dissolved mineral salts present in water[42]. Here, results of the mean values of Electrical Conductivity (EC) of water in all the sampling stations indicated that, Station 1 has maximum Conductivity (50.97 mS) in the pre monsoon season and minimum (5.14 mS) in the monsoon season. Higher and lower values of Conductivity pertaining to Station 2 reported in the pre monsoon and monsoon seasons were 51.31 mS and 11.12 mS respectively. Station 3 has been noticed for a maximum Conductivity (53.27 mS) in the pre monsoon season and minimum (1.

The overall result thus indicated that Station 3 sustains higher Salinity and Conductivity in the pre monsoon and lower levels in the monsoon season. This station is located in an estuarine zone, which is almost 2km away from the Arabian Sea. The higher salinity noticed with this station may be due to the proximity of the station with that of the sea. Factors like shallowness of the area, evaporation due to the increased temperature, lack of fresh water influx and intrusion of sea water as well as the presence of salt impregnated marshy soil might have also contributed to the enhanced salinity of the area. Comparatively less salinity may be due to the direct influx of rain water during North East and South West monsoon period[43]. The maximum and minimum levels of electrical conductivity are due to the presence of varying levels of ions such as chloride, sodium and ammonium. The occurrence of such ions in aquatic systems are mainly due to different factors such as dissolved carbon dioxide along with fresh water influx and mix up with ebb and flow[22].

Salinity is a strong contributor to conductivity while conductivity is formally defined as the reciprocal of resistivity, which is worth elaborating on[44]. Likewise here also, correlation of Salinity with Conductivity provided a strong positive correlation in all the three sampling stations with a correlation coefficient of 0.999362, 0.999468, and 0.999812 respectively while that of resistivity is negative with values - 0.66258, - 0.5346 and - 0.96819.

Salinity is the measure of all the salts dissolved in water. The salt in the ocean is mostly from sodium and chlorine. The other major components of seawater are magnesium, calcium, potassium and sulfate[45] that show positive correlation with salinity. In the present study all the three stations showed a strong positive correlation between salinity and hardness (0.938812, 0.97067, 0.822583 mg/l), calcium (0.992076, 0.980067, 0.966207 mg/l), magnesium (0.918489, 0.964129, 0.787188 mg/l) and chloride (0.895354, 0.927842, 0.993413 mg/l).

In the present study, results of the mean values of Resistivity of water from Station 1 showed maximum Resistivity (938.99 Ω) in the monsoon season and minimum (19.17 Ω) in the pre monsoon season. Higher (432.66 Ω) and lower (19.042 Ω) values of Resistivity pertaining to Station 2 was reported in the monsoon and pre monsoon seasons respectively. Station 3 has been noticed for a maximum Resistivity (621.467 Ω) in the monsoon and minimum (18.37 Ω) in the pre monsoon season. The overall result thus supported the statement, Resistivity is the reciprocal of Conductivity and here, Station 1 was reported for sustaining a higher Resistivity in the monsoon season and a lower in Station 3 in the pre monsoon season.

Physicochemical characteristics of water samples and their relationships do not occur autonomously, but are allied with each other[46]. Upon assessing the physico-chemical characteristics of water bodies adjoining mangrove habitats of *S. alba*, it has been noticed that, out of 13 parameters studied, most showed reasonable variation in all the three seasons. Station 1 showed highly alkaline (post monsoon) nature with comparatively high sodium concentration (pre monsoon) and high resistivity (monsoon). Station 2 has been noticed for higher turbidity (Monsoon) and Station 3 for comparatively higher Hardness, Calcium, Magnesium, Chloride, Potassium, Salinity and conductivity in the pre monsoon season. From the above surveillance, correlation of important water quality parameters from the sampling stations of *S. alba* proved that the changing trends in related parameters are coherent and all the three sampling stations are highly unswerving and persuasive.

Previous researches revealed assorted opinions regarding the salinity requisite of *S. alba*. The salinities experienced by *S. alba* range seasonally from16 to 35 ppt and 1 to 34 ppt [47]. The *S. alba* species can grow in areas where salinity is as high as 44 ppt(Wells 1982). Studies on the salinity requisite of *S. alba* revealed that it's an obligate halophyte growing near the tidal river mouth and shows enhanced growth under extreme saline conditions[48].

Here in the present study, Station 1 seizes a range of salinity from 18.5 to 32.67 ppt in Pre monsoon season, 1.043 to 4.422 ppt in Monsoon season and 16.99 to 30.72 ppt in the Post monsoon season. Station 2 possesses a salinity range of 34.01 to 35.51 ppt in Pre monsoon season, 1.846 to 8.98 ppt in Monsoon season and 10.8 to 34.19 ppt in the Post monsoon season. Likewise Station 3 sustains a salinity range of 37.21 to 37.49 ppt in Pre monsoon season, 0.097 to 0.394 ppt in Monsoon season and 1.139 to 41.32 ppt in the Post Monsoon season. Thus, from the present study it was evident that, *S. alba* can tolerate a wider range of salinity extending from 0.299 to 38.5ppt. The data is indicative of the higher salinity tolerant limit of the mangrove species *S. alba*.

The 'Best Practice Guidelines on Restoration of Mangroves in Tsunami Affected Areas' (WWF, IUCN, WETLANDS International, Environment and Development service for NGO's, 2014) grouped mangrove species in to three different categories like highly tolerant (> 25 ppt), moderately tolerant (15- 25 ppt) and less tolerant (< 15 ppt) based on the responses of species to salinity. The present study proposed that, *S. alba* can tolerate salinity concentration ranging from 0.299 to 38.5ppt and upon considering such a higher range, these species can also be included in the 1st category (> 25 ppt) along with *Avicennia marina*, *Avicennia officinalis*, *Aegiceras corniculatum*, *Lumnitzera racemosa*, *Rhizophora mucronata* and *Pemphis acidula*[49]. Being an extremely high salinity tolerant species, the incorporation of *S. alba* in almost all coastal restoration and afforestation programmes is highly recommended.

In addition to salinity, it has also been noticed that S. alba is surviving in various water quality parameters like pH, Acidity (mg/l), and Alkalinity (mg/l) were in the range of 6.98 – 8.31, 17.6 – 70.4 and 150 – 270 in pre-monsoon season, 6.02 – 8.45, 6.6- 30.8 and 60 – 180 in monsoon season and 6.39 – 8.57, 3.08 – 66 and 100 – 280 in post- monsoon season respectively. Hardness (mg/l) during pre monsoon, monsoon and post monsoon seasons were 6840 - 8760, 32 - 520 and 280 - 6800, where as those of Calcium and Magnesium (mg/l) were noted to be in the range of 448.56 – 528.66, 1363.4 – 1830.86, 9.62 – 134.67 and 1.46 – 44.79, 84.17 – 488.61 and 8.28 – 1397.49 correspondingly. The tolerance limit of Sodium and Potassium were in the range of 23.9 – 29.8 and 0 – 1.65 ppt in Pre monsoon season, 0.002 – 8.17 and 0 – 0.26 ppt in Monsoon and 5.33 – 31.1and 0.12 – 2.56 ppt in Post Monsoon season. Chloride (mg/l) level was in the range of 22720 - 30672 (pre monsoon), 383.4 – 4828 (monsoon) and 4316.8 – 41322 (post monsoon). Tolerance limit of conductivity (mS) and resistivity (Ω) of *S. alba* were in the range of 49.83 – 55.87 and 17.49 – 19.59 in pre monsoon season, 0.5996 – 19.1and 51.14 – 1634 in monsoon season and 12.02 – 51.55 and 18.98 – 81.46 in post monsoon season respectively. Turbidity was in the range of 1.6 – 32.8, 2.9 – 53.9 and 3.4 – 41.1 in pre monsoon, monsoon and post monsoon seasons correspondingly.

Summary: Efforts on the restoration of mangroves necessitate reliable information on their growth sustaining circumstances. The present study attempts to assess the range of tolerance of *S. alba,* the mangrove apple, grown in diverse environmental conditions in the coastal environments of Kerala, to the range of water quality parameters influencing them. The physico-chemical attributes of water bodies adjoining selected mangrove habitats having *S. alba* were monitored monthly for a period of one year for assessing the growth sustaining conditions.

Monthly assessment of water quality confining to three natural habitats of *S. alba* were monitored for a period of one year. The parameters studied include pH, Turbidity, Salinity, Conductivity, Resistivity, Sodium, Potassium, Total Alkalinity, Total Acidity, Total Hardness (Calcium and Magnesium) and Chloride.

It is noted that the species *S. alba* occupying these habitats have wider range of tolerances to varying water quality parameters. The present study reveals that *S. alba* can tolerate salinity ranging from 0.299 to 38.5ppt and considering the higher limits of salinity tolerance, they can be incorporated in the1st category of salinity tolerant species (> 25 ppt). The study also reveals the range of other water quality parameters like pH , Acidity (mg/l), and Alkalinity (mg/l) were in the range of 6.98 – 8.31, 17.6 – 70.4 and 150 – 270 in pre-monsoon season, 6.02 – 8.45, 6.6-30.8 and 60 – 180 in monsoon season and 6.39 – 8.57, 3.08 – 66 and 100 – 280 in post- monsoon season respectively. Hardness (mg/l) during pre monsoon, monsoon and post monsoon seasons were 6840 - 8760, 32 - 520 and 280 - 6800, where as those of Calcium and Magnesium (mg/l) were noted to be in the range of 448.56 – 528.66, 1363.4 – 1830.86, 9.62 – 134.67 and 1.46 – 44.79, 84.17 – 488.61 and 8.28 – 1397.49 correspondingly. The tolerance limit of Sodium and Potassium were in the range of 23.9 – 29.8 and 0 – 1.65 ppt in Pre monsoon season, 0.002 – 8.17 and 0 – 0.26 ppt in Monsoon and 5.33 – 31.1and 0.12 – 2.56 ppt in Post Monsoon season. Chloride (mg/l) level was in the range of 22720 - 30672 (pre monsoon), 383.4 – 4828 (monsoon) and 4316.8 – 41322 (post monsoon).Tolerance range of conductivity (mS) and resistivity (Ω) range of *S. alba* were in the range of 49.83 – 55.87 and 17.49 – 19.59 in pre monsoon season, 0.5996 – 19.1and 51.14 – 1634 in monsoon season and 12.02 – 51.55 and 18.98 – 81.46 in post monsoon season respectively. Turbidity was in the range of 1.6 – 32.8, 2.9 – 53.9 and 3.4 – 41.1 in pre monsoon, monsoon and post monsoon seasons correspondingly.

The data indicated a marked difference in all water quality parameters in their habitats, with respect to seasons. The overall study thus elucidated the basic water quality indices affecting the growth and development of the mangrove species *Sonneratiaalba* and discusses the possibilities of including them in afforestation practices along the shorelines of Kerala.

Conclusion

The study comprehends the range of tolerance limits of different water quality parameters influencing the growth and development of the mangrove species *Sonneratiaalba* along its three natural habitats of Kerala. The results of the study indicated that there is a marked difference in almost all hydrogeochemical parameters in the three mangrove habitats studied, with respect to the seasons.

Correlation of important water quality parameters from the sampling stations proved that the changing trends in related parameters are coherent and all the three sampling stations are highly unswerving and persuasive. Thus it can be concluded that the species *S. alba* can be included in all mangrove afforestation programmes in the coastal environments of Kerala, considering their wide range of tolerances to almost all water quality parameters, especially salinity.

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