

Effect of Salinity Intrusion and Coastal Erosion on Marawila Coastal Area, Sri Lanka

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Abstract— Coastal erosion has become a major threat to coastal areas all around the world while salinity intrusion has also become a problem due to erosion mitigation measures in coastal area. Coastal erosion (and accretion) in Marawila coastal area was investigated by analyzing satellite images using spatial analysis techniques. The effect of salinity intrusion on Marawila coastal area was identified by travelling along the coastline, conducting interviews and analyzing the reports. In this study it was identified that both coastal erosion and salinity intrusion are nexus problems in Marawila coastal area. This study highlights the effect of salinity intrusion and coastal erosion on Marawila coastal area.

Keywords— Salinity intrusion, Coastal erosion, Groynes, Lagoon, Sri Lanka

I. INTRODUCTION

Fresh water is becoming a limited resource in the world and ensuring the quality of fresh water has become a critical sustainability problem. Salinity intrusion is one of the major source for saline water pollution in coastal areas and it is increasing with the urbanization and population growth in coastal zones [1]. Out of all fresh water sources groundwater is about 90% of the world's readily available fresh water. Salinity intrusion has directly affected to the ground water resources in coastal areas. Salinity intrusion is a process that occurs naturally by which the saline water displaces and mixes with the ground water due to the density difference between water of different salinities. One of the main causes of water salinity is climate change, which raises sea levels and exacerbates cyclones and storm surges. Human activities such as excessive groundwater extraction and canal and dam development worsen the problem [2]. Nowadays salinity intrusion has become a major concern in groundwater in coastal zones as excess amount of salinity makes water unsuitable for human uses both drinking purposes and agricultural uses [3]. Consumption of salinity affected water negatively impact on human health and well-being. Drinking water with too much salt has been related to a number of negative health impacts. However, numerous studies have linked a higher risk of hypertension to excessive salinity in drinking water. Salinity of drinking water has also been linked to a higher incidence of gestational hypertension and preeclampsia. Other than that salinity in water causes diseases

such as cholera epidemics, newborn mortality, and skin and diarrheal disorders. Consequently, increased water salinity may have a number of negative health impacts [2]. Further the salinity intrusion also effects on degradation of natural ecosystems and contamination of urban, industrial and agricultural water sources [4].

Coastal erosion is a natural phenomenon which has become a major problem in coastal areas all around the world. It is also a great threat to the properties and livelihood of coastal communities and causes complicated issues. In order to reduce coastal erosion coastal protection structures (both hard structures and soft structures) have introduced [5]. Hard engineering measures such as sea walls, revetments and breakwaters are mostly used in both developed and developing countries to manage such erosive coasts [6], but in some cases those measures can also contribute to make some issues as well [7]. For example even though revetments protect coast from erosion, it increases the seaward side erosion [5] and thus creates the salinity problem. So that coast protection structures need to be introduced carefully in order to prevent salinity intrusion.

The Marawila coastal area which is a sandy linear beach in Sri Lanka's Northwestern coast, is chosen as the study area for this study. Marawila beach is found in Northwestern coast of Sri Lanka, which provides livelihood to people who depend on fisheries and tourism [6]. Coastal erosion in Marawila area became a significant environmental issue in Sri Lanka [8]. Due to a lack of integration between the beach and the entire sediment system, erosion of Marawila Beach started between 2005 and 2010 and has continued ever since. Revetments, detached breakwaters and submerged breakwater groynes has constructed and beach nourishment schemes has implemented to manage the erosion in this area since 2004 [6]. The northwestern coast of Sri Lanka faces serious environmental issues due to salinity intrusion. According to the Sri Lankan National Water Development Report from 2006, one of the main risks to the area's ground water is salinity intrusion in the northwestern province [9]. The saline intrusion in the Maha oya area has reached a critical level and is endangering a number of factors, including not just the use of water but also the ecosystem located in and around the river. The impact of salinity intrusion along the river may increase to the point where it contaminates groundwater and influences it [10].

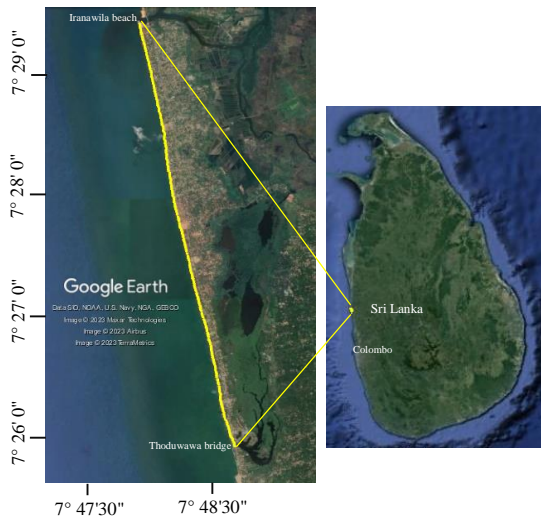


Fig. 1. Spatial distribution of studied shoreline stretch (Source: Google Earth, Data SIO, NOAA, U.S. Navy, NGA, GEBCO)

Fig 1 shows the selected study area for this study. The selected coastline is protected by groynes. This area is heavily affected by salinity intrusion and most of the wells in the area have affected by salinity. Therefore, studying salinity intrusion together with coastal erosion in this area is important. In this background the objectives of this study is to identify the erosion propagation and interaction of groynes in Marawila coastal area and identify effect of salinity intrusion on Marawila coastal area.

II. METHODOLOGY

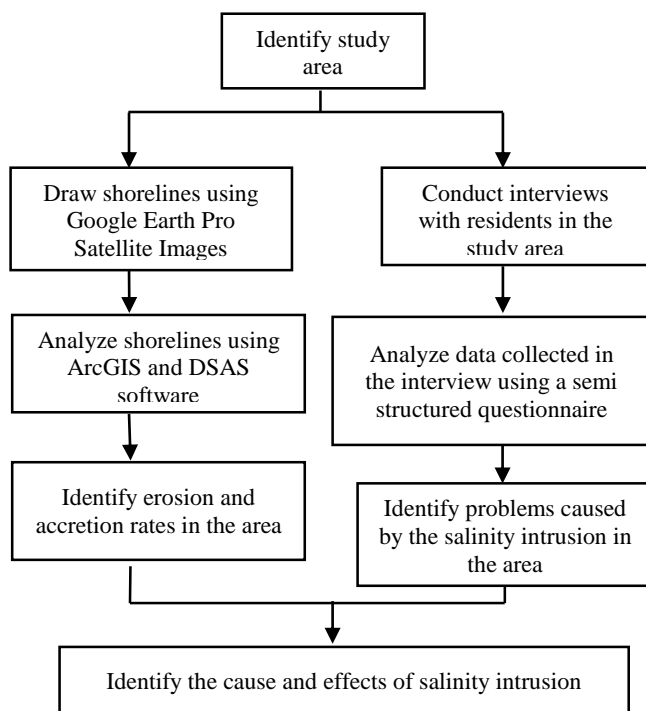


Fig. 2. Methodology Flow Chart

A. GIS and DSAS Analysis of Satellite Images

Average position of the shoreline of selected beach area was marked using polylines on visible digital globe satellite images in Google Earth Pro. Images were captured on 26th

March 2019, 11th April 2020, 11th February 2021, 22nd December 2021 and 26th April 2023. Each shoreline was entered into Digital Shoreline Analysis System (DSAS – Version 5.1) for computation of shoreline change. The End Point Rate (EPR) was calculated by dividing the distance of shoreline movement by the time elapsed between the two shorelines. Positive signs and negative signs were considered as accretion and erosion respectively.

B. Field Observation and Interview

A total of 15 residents were randomly selected and interviewed during the field visit. Questions were asked focusing on the impacts and their opinion of the cause of salinity intrusion on the ground water of the study area. Identifying the severity of the salinity intrusion in the area and the effect of salinity intrusion on the area was focused in the questions. The data collected during the interviews were then analyzed.

In situ measurements of Electrical Conductivity(EC) and Total Dissolved Solids(TDS) of 110 well water samples were collected during the field visit. The measurements were taken using COM-80 TDS/ EC/ TEMP meter.

III. RESULTS AND DISCUSSION

A. Beach Erosion/Accretion in Marawila Beach

Fig. 3 represents the time series of beach erosion and accretion rates estimated from the analysis of selected Google Earth Pro satellite images. The construction of the groynes during the time periods is represented in the graph.

Fig. 3 (a) represents the shoreline erosion/accretion rates between 26th March 2019 to 11th April 2020. The maximum erosion and accretion rates during that 12-month time period were 30.5 m/y and 18.4 m/y respectively. 8 groynes were introduced during the period. Significant amount of erosion was observed in the beach area where no coastal protection structures were constructed. A considerable amount of erosion was observed in the area where groynes were constructed within the observed time period.

Fig. 3 (b) shows the shoreline accretion/ erosion rates between 11th April 2020 and 11th February 2021. During that 10-month time period, 8 groynes were newly constructed. During that time period maximum erosion and accretion rates were 35.5 m/y and 12.7 m/y respectively and the erosion was predominant.

Fig. 3 (c) represents the erosion/ accretion rates between 11th February 2021 and 22nd December 2021. 6 groynes were newly constructed during the 10-month time period. A significant accretion can be observed during the time period. Maximum erosion and accretion rates during the time period were 24.8 m/y and 20 m/y respectively.

Fig. 3 (d) shows the erosion/ accretion rates from 22nd December 2021 to 26th April 2023. Groynes were not introduced during this period. Maximum erosion rate of 12.2 m/y and maximum accretion rate of 14.9 m/y was observed during the time period.

The implementation of the groynes was undertaken in response to the severe erosion observed in the study area. As the natural flow of sediments is towards the north, the series of groynes have trapped the transported sediments towards the north which leading to the accumulation of groynes in the same direction.

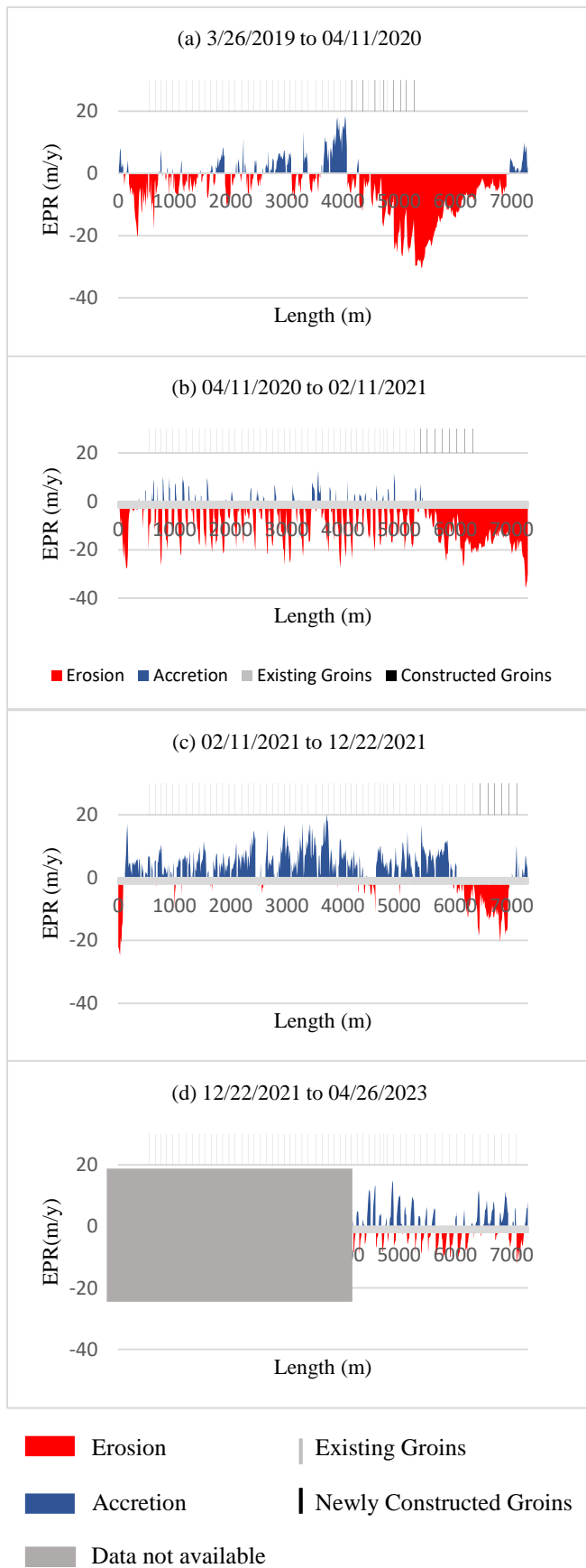


Fig. 3. Rate of beach accretion/ erosion between (a). 26th March 2019 and 11th April 2020, (b). 11th April 2020 and 11th February 2021, (c). 11th February 2021 and 22nd December 2021 and (d). 22nd December 2021 and 26th April 2023 with records of construction of groynes along the beach

B. Problems Facing People in Marawila Coastal Area Due to Salinity Intrusion

The findings of the interviews conducted with residents of Marawila coastal area provides insights about the salinity intrusion into the groundwater sources in the area and its impact on the community. Keyword analysis of the interview data is illustrated in the Table 1.

Table 1. Keyword analysis of interview data

	Respon- dent	Femal e/ Male	Duration	Keywords
1	Fisherm an wife (middle aged)	F	7 minutes	Water is saline because of the lagoon, Salty water, Well water became saline due to the groynes, Drinking water is bought for money
2	Old lady	F	3 minutes	When the sea is rough salinity of water increases, In the rainy season water quality increases
3	Young man	M	10 minutes	Because of the erosion, Because of the lagoon, In the rainy season water quality increases, Salty water, Well water became saline due to the groynes, No solution, Drinking water is bought for money Low quantity and quality of water from tap lines
5	Fisherm an wife (young)	F	2 minutes	Salty water, Filtered water for drinking
6	Old lady		2 minutes	Salty water
7	Old man	M	3 minutes	Well water can be drunk, Water becomes salty with the high tide
8	Housew ife (middle aged)	F	1 minutes	Drinking water is bought for money, Water is not salty but can't drink
9	Young man	M	2 minutes	Water from the tap line is not good for drinking, Drinking water is bought for money from water

				browsers, Saline water
10	Fisherman wife (middle aged)	F	2 min	Drinking water is bought for money from water browsers, Salty water, Saline water
11	Fisherman wife (young)	F	1 minutes	Salty water, Saline water
12	Housewife (middle aged)	F	2 minutes	Water from the tap line is not good for drinking, Drinking water is bought for money
13	Fisherman (middle aged)	M	2 minutes	Low quantity of water from the tap line, Salty water, Water quality increases in the rainy season, Water quality was good before construction of groynes
14	Fisherman wife (middle aged)	F	1 minutes	Salty water, Saline water, Drinking water is bought for money
15	Housewife (young)	F	1 minutes	salty water, Drinking water is bought for money

The residents who were interviewed all agreed that none of them are using well water for drinking purpose due to the high salinity level of the water. According to the insitu measurement of well water samples collected during the field visit, maximum EC value of 8873 μ s and maximum TDS value of 7515ppm were observed. This highlights the severity of the groundwater salinity problem in the area, as not a single resident relies on well water for their primary source of drinking water. It was revealed that residents in the area must have to buy drinking water, implying a financial burden on the community due to the unavailability of safe drinking water sources. Even though there are some rural water supply networks in the area people face challenges due to the issues related to both quality and quantity of water along with irregular water supply schedules. This depicts a situation where there is insufficient access to clean drinking water, which provides an additional financial burden on the people and it can be quantified through cost calculations for drinking water. According to the World Health Organization (WHO), the daily water intake for an individual is estimated at 4.6 liters [11]. This corresponds to 138 liters per person per month. According to the interview data 1 liter of drinking water costs LKR 3. Thus the monthly cost per person to procure safe drinking water amounts to LKR 414. When considering the average household size of 4 people, the monthly cost to purchase drinking water for a family totals LKR 1656. Alternatively, the National Water Supply and Drainage Board (NWSDB) offers water supply services at a cost of LKR 60

per unit along with a monthly service charge of LKR 300 [12]. Calculating the cost per water required for a household per month yields LKR 341.4. Comparing the costs incurred by residents between procuring drinking water independently and utilizing NWSDB service, there is a substantial additional cost of LKR 1314.6 per month that have to be paid by residents of the area when purchasing drinking water due to the unavailability of safe drinking water. The relevant calculations for above costs is shown in Table 2. This added expense emphasize the economic implications faced by community due to the salinity intrusion.

Table 2. Summary of Additional cost for drinking water calculation

Cost of drinking water	LKR 3 per liter
Monthly cost per person to get drinking water	LKR 414
Average household size	4 people
Monthly cost per family to get drinking water	LKR 1656
If water is taken from NWSDB, monthly cost per family to get drinking water	LKR 341.4
Additional cost per drinking water for a family per month	LKR 1314.6

Land degradation due to coastal salinity has become a significant problem arises from salinity intrusion which can affect the economic development of the country as well [4]. According to the current estimates about 10-35% of global agricultural lands have been affected by salinity, leading to increase of unusable lands. Salinity can affect the plants at any stage of their life cycle and can cause to complex changes of their characteristics [13]. Thus salinity can be negatively impact on the crop productivity. This is crucial problem that represents an unforeseen economic loss in the affected area.

C. Engineered Measures and Coastal Topology Induced Salinity

Residents provided insights into potential factors contributing to the salinity intrusion problem. Some attributed the increase in salinity levels due to the construction of coastal protection structures, while others believed that the nearby lagoon might be the primary source of high salinity in groundwater.

Topographic influence of lagoon is shown in Fig. 4 (a). According to the studies it was found that near a lagoon net groundwater flow is in the landward direction because of the time averaged maximum wave induced water table over height (Fig. 4 (b)). This groundwater flow towards landward direction can have a significant impact on the increase of salinity intrusion. The problem worsens with the beach erosion. As shown in the Fig. 4(c) when the erosion increases head difference increases as well. Thus the salinity intrusion also increases. When considering the effect of structures on salinity intrusion, as the run-up level increase due to wave setup due to structure and the wave reflection, head difference also can increase as shown in Fig. 5. That increase in head difference can significantly impact on the increase of salinity intrusion.

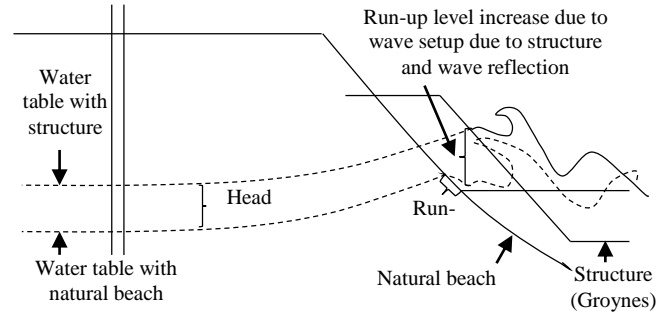
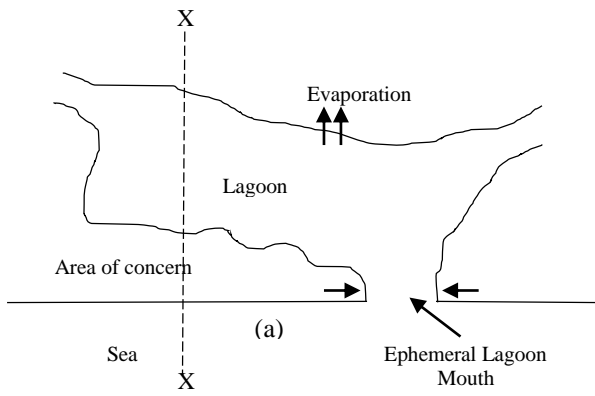


Fig. 6. Structure (groynes) induced salinity

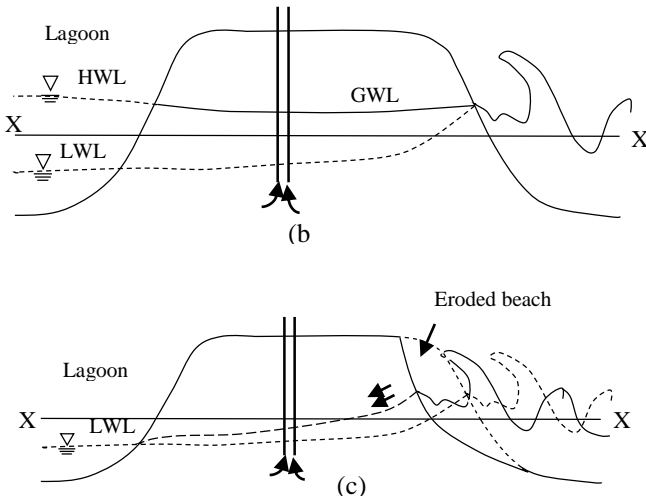


Fig. 4. (a) Topographic influence on salinity increase (b) Physical features and salinity (c) Effect of erosion on salinity

D. Sustainability Impact of Salinity Intrusion

Key stakeholders of the salinity intrusion in this study area were identified during the interviews and the identified stakeholders and their connectivity is shown in the Fig. 6. The mainly affected group by salinity intrusion is the local residents living in the area. Poor access to safe drinking water is a major issue faced by local residents in the area. Salinity intrusion into the groundwater is a critical challenge to the sustainability of water resources as well. This problem is closely aligning with the sustainable development goal 6 “clean water and sanitation”. The drinking water suppliers in the area also plays a major role within this problem by providing drinking water to the community. NWSDB and rural water supply networks have a huge responsibility in managing water resources and supplying clean water to the community. CC & CRMD (Coast Conservation and Coastal Resources Management Department) and other government authorities need to be concerned about the environmental impact of salinity intrusion on coastal zone and providing sustainable coastal management practices is essential. In order to effectively address the salinity intrusion problem proper engagement of all the stakeholders while considering the sustainability impacts of the problem is essential.

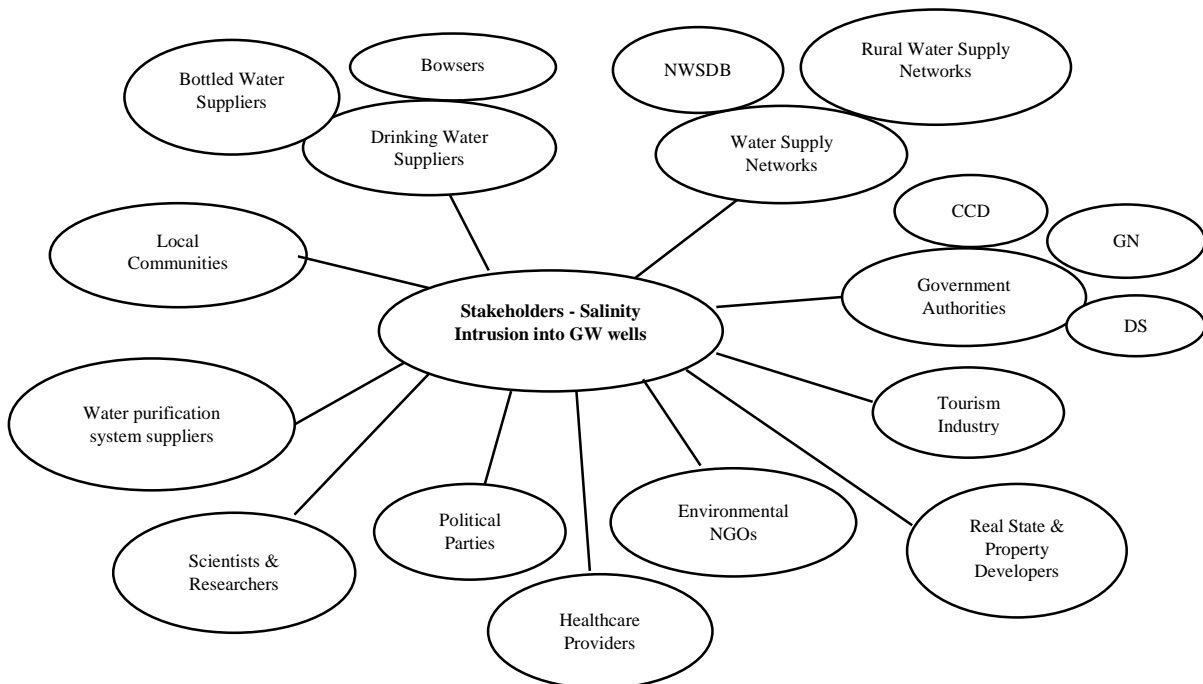


Fig. 5. Stakeholder's of the salinity intrusion problem and their connectivity

IV. CONCLUSION

Marawila coastal area has affected by both coastal erosion and salinity intrusion problems. Groynes were implemented to mitigate severe erosion occurred in the study area. Salinity intrusion into groundwater has made a financial burden by reaching to a level that well water is not suitable for drinking. Further the residents understand that the construction of groynes and the lagoon may have affected to the salinity intrusion in the area. Thus an integrated and sustainable approach to overcome this nexus of erosion mitigation and salinization in area is needed.

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