

Status of the saltwater intrusion in Jaffna, Sri Lanka

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Abstract: The objective of this study is to assess the present status of saltwater intrusion in the proximity of lagoons (Vadamarachchi and Uppuuru) in Jaffna, Sri Lanka. Ten villages along the periphery of the said lagoons were selected for a questionnaire survey (n=150) and groundwater quality analysis. The results revealed that the villages; Thondaimanaru, Atchuveli, Ariyalai, Kaithady and Karanavai are less affected (<33%) whilst Chemmani, Madduvil, Navatkuli, Irupalai and Neerveli are highly affected (>60%) in terms of intolerable level of salt content in the sandy aquifer. In Irupalai alone, more than 80% of the wells are highly affected where more than 80% of the wells monitored are exceeded the tolerable limits of EC (>2.5 S/cm) and salinity (>900 ppm), thus unsuitable for human consumption. The field mapping of water quality parameters (EC and salinity) revealed that the villages influenced by Vadamarachchi lagoon was lesser affected (<33%) than the villages influenced by Uppuuru lagoon. There is a trend of decreasing salinity from boarder of the lagoons to inland. As an initiative, water quality monitoring, establishing monitoring wells, and educating the people about adverse effects of over pumping of water are essential to reduce the saltwater intrusion in the area. Renovation of existing saltwater barrages would be an appropriate solution to enhance the groundwater quality in future.

Keywords: saltwater intrusion, barrage, lagoon, groundwater quality.

INTRODUCTION

The Jaffna Peninsula, lies in the longitude and latitude 79° 45' N – 90° 30' E and 80° 20' N - 90° 50' E and covers the extent of 1000 km² forms the northern edge of Sri Lanka. Groundwater is the prime source of water for the people in Jaffna peninsula as the surface water resources are lacking due to karstic nature of the limestone, unpredictable rainfall leaving no rainfall harvesting and flat terrain (Kumara *et al.*, 2013; Hidayathulla and Karunaratna, 2013; Wijesekera *et al.*, 2012). Salt water intrusion is a serious issue in the coastal zone wells of Jaffna, since the wells are now producing low quality groundwater unsuitable for drinking and agricultural purposes (Rink *et al.*, 2016). This eventually left hundreds of acres of arable lands abandoned and caused hundreds of wells with brackish water in the coastal zone (Kumara *et al.*, 2013; Sivakumar, 2013).

The Jaffna peninsula falls within dry zone of Sri Lanka and underlain by Miocene limestone. There are two major types of aquifers in Jaffna Peninsula - limestone and sand dune aquifer (Vigneswaran *et al.*, 2017). The peninsula has four main aquifers namely Chunnakam (Valikamam), Thenmaratchi, Vadamaratchi and Kayts (Mikunthan *et al.*, 2013). The geology of the western side of the peninsula is limestone, and the eastern part is sandy with limestone base. The limestone aquifer together with thin sand layer provides a source of drinking water for the peninsula. The caverns and crevices exist in the limestone facilitates the movement of groundwater through the limestone aquifer (Sivakumar, 2013; Mikunthan *et al.*, 2013). Rainfall is the only source that replenishes the limestone aquifer (Mikunthan *et al.*, 2013).

The freshwater is less dense than the saltwater thus it floats on the top of salt water. The rainwater percolates through limestone and floats as lens-shaped bodies over the denser sea water. The thickness of the freshwater lens is highest in the middle of the peninsula, whilst the thickness is lesser in the coast (Mikunthan *et al.*, 2013). According to Krupavathi and Movva (2016), the saltwater intrusion is usually caused by two mechanisms - one is lateral encroachment and the second is upward movement. Lateral encroachment occurs from the ocean due to over extraction of groundwater from wells located in coastal zone. Upward movement generally happens from deeper coastal zone due to pumping wells. Sivakumar (1993) and Kumara *et al.* (2013) reported that the over extraction of water in Jaffna from a sandy/limestone aquifer pulls the underlying saltwater upward, forms up coning effect along the interface, and mix up with the fresh water above and deteriorate the water quality. According to past research studies, digging of deep wells and over extraction of groundwater for extensive agricultural activities are the major causes for salt water intrusion into the groundwater (Rink *et al.*, 2016; Janen and Sivakumar, 2014). This happens especially in dry season as the thickness of freshwater lens is less when compared to the thickness in wet season (Mikunthan *et al.*, 2013).

Groundwater naturally flows from higher hydraulic head to lower. This natural movement of fresh groundwater from inland to sea prevents sea water entering into sandy

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aquifer in the coastal region (Barlow, 2003). According to Ghyben-Herzberg lens, a saltwater interface generally be exist 40 m below the mean sea level (MSL). In case of extraction of fresh water i.e., reduction in the freshwater volume, the reduced volume would be compensated by saltwater (Mikunthan *et al.*, 2013). Maintaining a seaward hydraulic gradient and the sufficient freshwater recharge flowing into the sea is essential to minimize the intrusion of seawater into freshwater aquifer (Oladapo *et al.*, 2014). The construction of saltwater barrages (which is considered as saltwater barriers) across the sea mouth is one of the techniques to maintain seaward hydraulic head, thereby let the intruded seawater to move backward from inland to sea. This eventually reduces the seawater intrusion into groundwater.

Jaffna peninsula has two major saltwater lagoons – Vadamarachchi and Uppuaru with the surface areas of 75 km² and 25 km² respectively (Sivakumar, 2013). These lagoons are replenished by North East monsoon rains from the commanding area of about 50% of the peninsula (Arumugam, 2013). Construction of saltwater barrages across the said lagoons would be a measure to reduce intrusion of saline water into the sandy aquifer in the coast. In this context, Thondaimanaru barrage (1947 – 1953) and Ariyalai barrage (1955) were built across the Vadamarachchi lagoon, and Uppuaru lagoon to convert the respective lagoons to freshwater bodies (Sivakumar, 2013). Followed by these, there were noticeable benefits

observed and many saline wells became potable water wells. However, by year 2000, the prolonged negligence and improper management of the saltwater barrages of the said lagoons affected their functionality i.e., the barrages were no longer capable to hold freshwater in the lagoon. This resulted in sea water entering into the Vadamarachchi and Uppuaru lagoons and eventually aggravated saltwater encroachment which turned more saline wells in the sandy aquifers (Janen and Sivakumar, 2014).

As the Jaffna peninsula depends on groundwater resources, ensuring the sustainability of the fresh water resource is vital. As an initiative, the renovation of said barrages is under construction in which 80% of the Thondaimanaru barrage was completed (Fernandopulle, 2018). In this juncture, the need on the study on the quality of drinking water in terms of salt content was highly emphasized in the previous researches. However, there is no previous researches on the quantitative assessment of drinking water in terms of EC and pH in the study area. In addition, determining the status of the saltwater intrusion is necessary in the study area as the saltwater barrages are not up-to-date. The objective of this research was to assess the existing level of salt water intrusion in an area which is highly influenced by Vadamarachchi lagoon and Uppuaru lagoon. In addition, the trend of decreasing groundwater salinity from the said two major lagoons also was studied to assess the direction of saltwater intrusion from barrages.

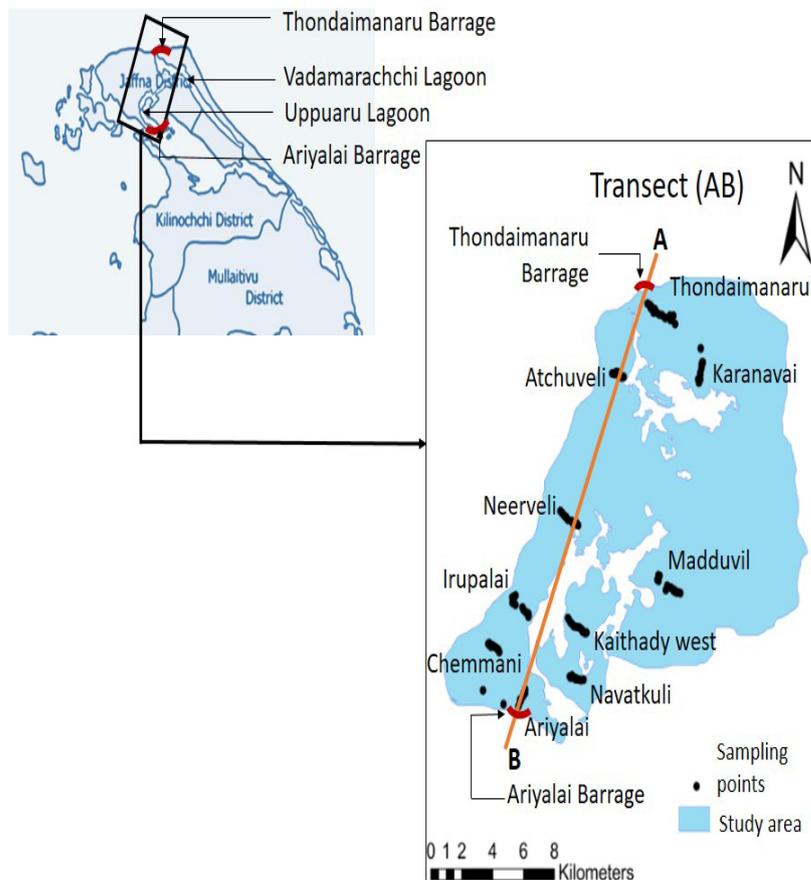


Figure 1: Study area showing the selected villages, barrages and sampling pattern.

METHODOLOGY

Selection of Study area

The area extending along both sides of the selected approximately nine km long transect (AB) (Figure 1) which connects Thondaimanaru barrage and Ariyalai barrage was selected for this survey. This study was undertaken for 03 months (November 2016 to January 2017). Ten villages, Thodaimanaru, Atchuvveli, Karanavai, Neervely, Kaithady west, Irupalai, Madduvil, Navatkuli, Chemmani and Ariyalai fall within the selected study area were considered for data collection (Figure 1). The total study area including the selected transect and sampling points is approximately 320 km². The study area falls within the longitude and latitude northward 9°49'1.31"N and 80°8'4.92"E southward 9°39'28.61"N and 80°5'50.84".

Sampling

Google Earth Pro 7.3 was used to select the sampling points and fifteen points were randomly selected from each village, so that the total sample population of 150 households were selected from the whole study area. Google maps and Global Positioning systems (GPS) device were used to select, navigate, and to collect geo address of the sampling points for the field survey. All sampling points were selected perpendicular to the selected transect (Figure 1) maximum up to 2km from the lagoon. In every villages, the first sample was collected at the close proximity to the respective lagoon boarder whilst the last sample was collected towards inland. The distance between two consecutive sampling points was maintained at 100 – 200 m.

Among the ten villages selected and according to the proximity of village to the lagoons, the EC and the salinity of Thodamanaru, Atchuvveli and Karanavai divisions were considered to be influenced by Vadamarachchi lagoon whilst the rest were considered to be influenced by Uppuaru lagoon.

Questionnaire survey and water sample collection

During the field visits, questionnaire survey and water sample collection were carried out in all the 150 households. The questionnaire was comprised of around 30 questions focused to collect some basic information regarding the source of water used for drinking, irrigation, and any other activities by the households, quantity and quality of ground water and willingness to accept and consume by the sample population. This survey was conducted in three days by an enumerator who is an Environmental Science Graduate.

Water samples were collected from dug wells in clean dry sample bottles and transported to the laboratory of Central Environmental Authority, Jaffna for water quality analysis. During the 03 days of sample collection, no significant rainfall was recorded in the study area.

Water Quality Analysis

EC and salinity are considered as the basic indicators to determine the degree of saltwater mixing into the groundwater (Sylus and Ramesh, 2015), such water

quality parameters were determined for the collected water samples. The laboratory analysis was done on the same day of sample collection at the laboratory of the Central Environmental Authority, Jaffna. The measurements of EC and salinity were conducted by a Multi Parameter Water Quality Sonde, YASSONDE' probe (Model number: YSI 6820 V2, USA). It should be noted that maximum tolerable/permisible level for EC and salinity is not given in the WHO or SLS standards for drinking water. Hence the study used the standard value available at the URL: <http://www.google.lk/url?sa=t&source=web&rct=j&url=http://mrccc.org.au/wp-content/uploads/2013/10/Water-Quality-Standards>. The standard for salinity was obtained from EPA (2018) URL: https://www.epa.sa.gov.au/environmental_info/water_quality/threats/salinity.

Mapping the spatial distribution of saltwater intrusion

Arc GIS 10.2.2 was used as a tool for mapping the spatial distribution of groundwater salinity in the study area. The geo references obtained onsite during the field survey and the respective water quality parameters were used as inputs for the mapping. GPS receiver inbuilt with Samsung galaxy J5 (SM- J500F) was used to obtain the geo references via Google maps version 9.26.1.

RESULTS AND DISCUSSION

Questionnaire survey

The results obtained from the questionnaire survey on the number of households utilize groundwater for drinking and irrigation purposes are illustrated in Table 1. It is observed that the number of households utilizes groundwater for irrigation is higher than the number of household for drinking purpose. The household not willing to use their own dug well water for drinking purpose are getting drinking water from pipe borne water supply as well as from community wells. Among the households surveyed, less than 50% (Table 1) of the households use the groundwater for drinking purpose mainly due to the elevated salinity as the water was not palatable. In addition, it is observed, the groundwater is being extensively used for irrigation purposes. This might further aggravate the saltwater intrusion in sandy (limestone) aquifers and eventually might end up with elevated salt content in the groundwater.

It was further noticed that only 20% of the households in Navatkuli, Irupalai, Chemmani, and Neerveli use groundwater for drinking purpose. In such villages EC and salinity levels are noticed to be highly elevated. Thus, the over extraction of water might have elevated the levels of salt content in the sandy aquifer.

Quality of groundwater

Influence of Vadamarachchi lagoon

As shown in Figure 2, the EC and salinity levels of the groundwater of the sampled points were gradually decreased from the boarder of Vadamarachchi lagoon towards the center of the village. For example, in Thondaimaru, the EC and salinity measurements were 5.4 S/cm and 3190 ppm for

Table 1: Number of households utilize their groundwater for drinking and irrigation purposes obtained from Questionnaire survey

Area	Drinking	Irrigation
Thondaimanaru	8	15
Navatkuli	3	15
Ariyalai	6	11
Kaithady	7	10
Irupalai	3	15
Chemmani	3	13
Neerveli	3	15
Madduvil	4	15
Karavanai	7	15
Atchuvveli	8	15

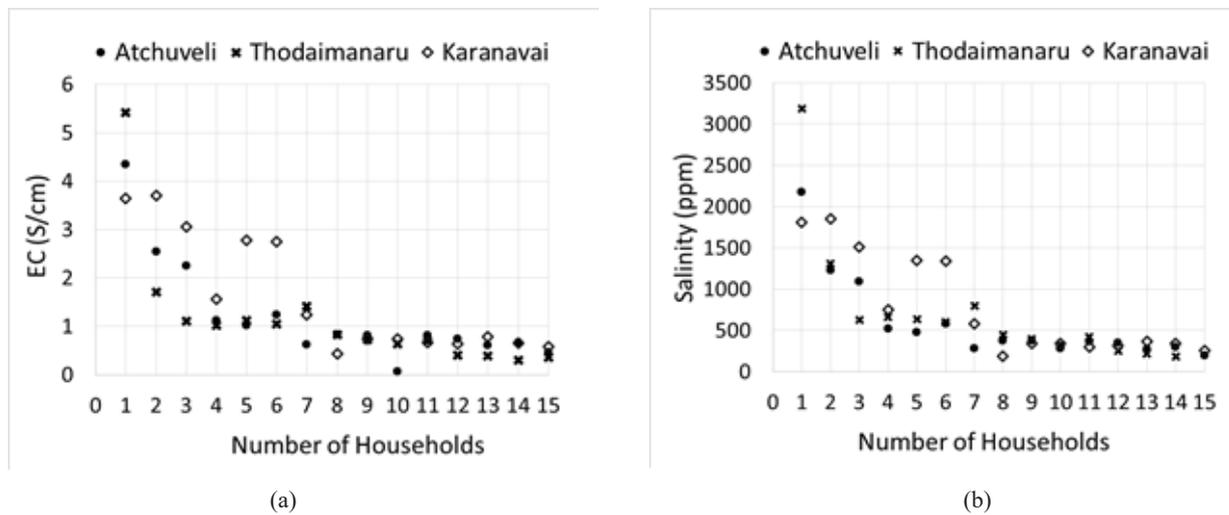


Figure 2: Water quality parameters of groundwater from Atchuvveli, Thodaimanaru and Karanavai (a) EC (b) Salinity.

the first sample which was selected at the close proximity of the lagoon and 0.4 S/cm and 230 ppm for the last sample which was 2 km away from the first sample. The distance between the first and the last sample was 2 km.

Among the three villages (such as Thondaimanaru, Atchuvveli and Karanavai) sampled 6.7%, 13.3% and 33.3% of wells were identified with intolerable levels of EC (< 2.5 S/cm) whilst 13.3%, 20%, and 33.3% were observed with intolerable levels of salinity (> 900 ppm) (Figure 2a and 2b). Karanavai is identified as highly affected village where five wells out of 15 are not suitable for human consumption as the salinity (> 900mg/L) and EC (> 2.5 S/cm) are exceeded the standards (MRCCC, 2013).

Influence of Uppuaru lagoon

The villages Navatkuli, Ariyalai, Kaithady, Irupalai, Chemmani, Neerveli, and Madduvil are considered to be influenced by Uppuaru lagoon. Similarly, the saline content of the well water is observed to be increasing with the decreasing of distance from the boundary of the said lagoon

(Figure 3). The villages Irupalai and Kaithady are located on either side of the lagoon but with the same distance from the lagoon. However, the EC and the salinity of most of the sampling points taken at village Irupalai are observed to be exceeded the maximum tolerable level, whilst most of the wells in Kaithady is within the tolerable level. The percentage of wells not suitable for human consumption in terms of EC and salinity are tabulated in Table 2.

According to this study, Irupalai, Navatkuli and Neerveli, Chemmani and Madduvil are observed to be highly affected by salt water intrusion effect as more than 60% of wells are identified with intolerable levels of either EC or salinity. The villages such as Ariyalai, Kaithady, Thondaimanaru, Atchuvveli and Karanavai are the least affected areas where less than 33% of the wells are observed with more than maximum tolerable limits of EC and salinity (Table 2).

Table 2: Percentage of wells not suitable for human consumption among the sampling areas based on EC (> 2.5 S/cm) and salinity (> 900 ppm) measurements.

Influencing Lagoon	Villages	Percentage of wells exceeded the maximum tolerable levels based on EC and salinity measurements	
		EC > 2.5 S/cm	Salinity > 900 ppm
Vadamarachchi	Thondaimanaru	6.7	13.3
	Atchuvveli	13.3	20.0
	Karanavai	33.3	33.3
Uppuaru lagoon	Navatkuli	66.7	66.7
	Ariyalai	13.4	13.4
	Kaithady	6.7	26.7
	Irupalai	73.4	80.0
	Chemmani	40.0	60.0
	Neerveli	60.0	66.7
	Madduvil	46.7	60.0

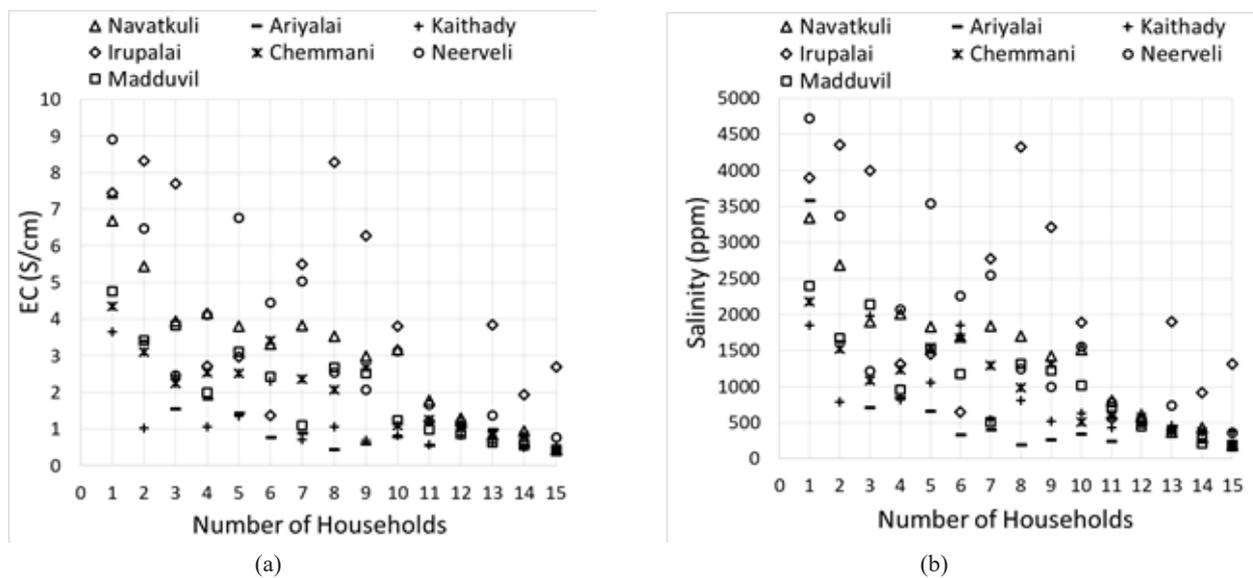


Figure 3: Water quality parameters of Navatkuli, Ariyalai, Kaithady, Irupalai, Chemmani, Neerveli and Madduvil (a) EC (b) Salinity.

The cause for the level of saltwater intrusion could be manifold. The villages influenced by Vadamarachchi lagoon is found to have low effect on saltwater intrusion compared to the villages influenced by Uppuaru lagoon. The inefficiency and poor maintenance of the salt water barrages could be one of the main reasons for elevated level of saltwater intrusion. The large extent covered by the Vadamarachchi lagoon could be another reason for the reduced saltwater intrusion. The terrain elevation of the sampling points were generally within the range of mean sea level (MSL) 4 m to 12 m which was obtained from Google Earth Pro 7.3.2.5776. The link between the terrain elevation and the salt water intrusion was not that remarkable.

Several researchers reported that the over extraction of groundwater in coastal areas is the major cause for saltwater intrusion into groundwater (Rink et al., 2016; Gunaalan et al., 2018). More than 60% of the households sampled in the villages - Irupalai, Neeveli, Chemmani, Madduvil and Navatkuli are having intolerable levels of

salt content (EC > 2.5 S/cm and salinity > 900 ppm) for drinking purpose. However, they continue to use the water for irrigation. Atchuvveli is observed to be least affected in which 16.6% of the wells are exceeded the intolerable levels of salt content. In this village 53% of the households are using the groundwater for drinking purpose and 100% of the households are using for irrigation at least for some gardening purpose. In this study, a positive correlation between salt water intrusion (EC and salinity) and over pumping (for irrigation) is not well established.

Spatial variability of seawater intrusion

The spatial distribution of the saltwater intrusion effect in terms of tolerable level of EC and salinity of the study area is illustrated in Figure 4 (b) and (c). As shown, the distribution of both EC and salinity shows a similar pattern. The area denoted by green, yellow and red in Figure 4 (b) and (c) can be interpreted as the water quality is suitable, moderately suitable, and not suitable for drinking purposes in terms of salt content. It seems the area surrounded by

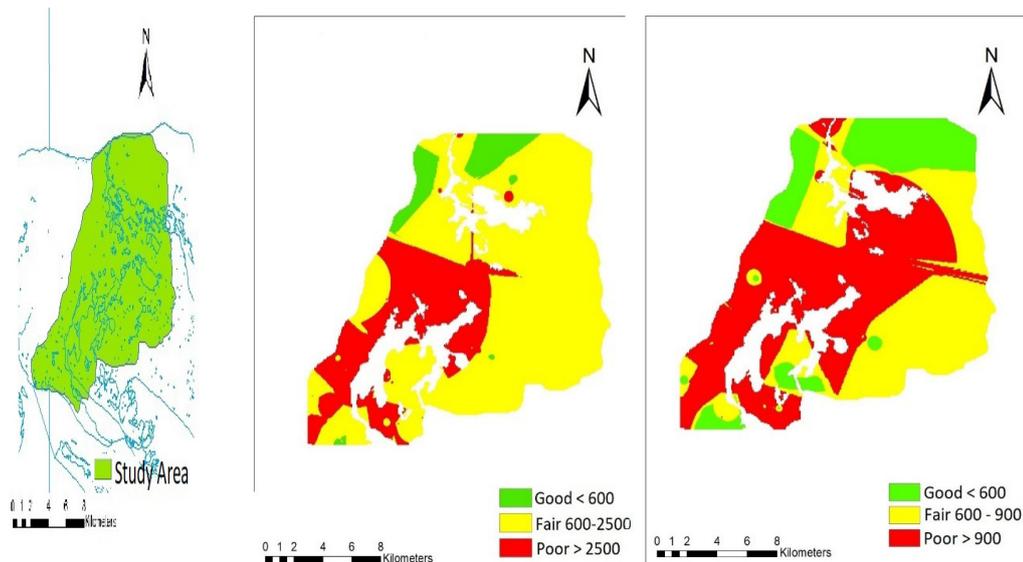


Figure 4: Mapping of the spatial distribution of saltwater intrusion (a) study area (b) EC (c) Salinity.

Uppuaru lagoon is prone to salt water intrusion effect compared to the area surrounded by Vadamarachchi lagoon. A similar observation was reported by Balendran *et al.* (2013) and Gunaalan *et al.* (2018) where the southward part of Vadamarachchi lagoon has been affected by severe salt water intrusion effect.

CONCLUSIONS

This study reveals that all the villages sampled have saltwater intrusion effect despite the percentage of wells are affected. More than 60% of the wells in Irupalai, Navatkuli, Chemmani, Neerveli, and Madduvil are highly affected villages where either EC (> 2.5 S/cm) or salinity (> 900 ppm) are exceeded the maximum tolerable limits. Thondaimanaru, Atchuveli, Karanavai, Ariyalai and Kaithady are the least affected villages where one third of the wells were observed with more than maximum tolerable level of EC and salinity. The village Irupalai is the highly affected village where 80% of wells are with intolerable levels of salt content whilst Thodaimanaru is the least affected village in which less than 33% of wells are with intolerable salt content.

According to the spatial distribution, the Southern part of the study area is highly affected with saltwater intrusion than the villages located in Northern part. This shows the villages influenced by Vadamarachchi lagoon have lesser effect of saltwater intrusion than the villages influenced by Uppuaru lagoon. The functionality and maintenance of Thondaimanaru barrage may be better than that of Ariyalai barrage in minimizing the saltwater intrusion.

Recommendations

As the decreasing trend of saline level was observed from the boundary of the lagoon to inland, attempts should be taken to maintain the hydraulic head in saltwater and freshwater transition zone. This can be achieved by proper maintenance of salt water barrages by the relevant authorities to reduce the saltwater intrusion effect. It was further noticed, the household living closer to lagoon extensively

pump the ground water for irrigation purpose even after the groundwater exceeded the tolerable limits of salt content. Continuation of this action may further aggravate the impact of saltwater intrusion. Lack of knowledge of the village households may be the reason for these issues. Therefore, awareness programs should be conducted especially to the people living in the coastal region on the mechanism of saltwater intrusion effect. Moreover, proper water quality monitoring network comprised of regular checkups of water quality parameters especially EC and salinity should be carried out by the relevant governmental or non-governmental organization. In this regard, setting few monitoring wells at the close proximity of lagoons and automated alarming systems would be beneficial. Based on the signal, the nearby households should be instructed to stop over pumping of water for any use. In addition, alternative arrangements should be made to facilitate them to receive adequate water supply through pipe borne water supply systems. Besides this the communities living in coastal region should be encouraged to build the rainwater harvesting system for non-potable uses.

The lack of scientific data in the study area is one of the major drawbacks to understand the dynamics of saltwater intrusion. Therefore, in order to identify the causal factors and to establish strong correlations, further studies are recommended. Data on population, water consumption including irrigation, Geographic Information Systems (GIS) and remote sensing, groundwater flow together with seasonal changes should be incorporated.

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