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IRRIGATION WATER QUALITY AND CORROSION INDICES OF GROUNDWATER SOURCES OF TSUNAMI AFFECTED ALAPPAD COAST, KOLLAM, KERALA, INDIA

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ABSTRACT

Physico-chemical parameters of shallow dug wells of Alappad coast in Kollam district, Kerala, recorded in the history as one of the severely devastated coastal areas by 26th December 2004 Indian Ocean Tsunami event. This coastal segment is evaluated continuously for a period of five years from 2012 to 2016 for hydrogeochemistry of the groundwater resources. The hydrochemicalfacies of the groundwater reveals that belong to temporary hardnesswater type. Irrigation water quality parameters and corrosion indices are evaluated to find the suitability of water for irrigation and other industrial purposes.Salinity hazard and sodium adsorption ratio (SAR) determined indicate groundwater available in Alappadbelongs to moderate to goodwater quality.Sodium to chloride ion ratio reveals prominence of ion exchange process(Na/Cl>1) in the region. Monthly mean of Revelle's co-efficient shows no instance of sea water intrusion visibly distinct for shallow dug well sources beingR<1. Langelier saturation index (LSI)evaluated in the month of December 2012 shows groundwater is super saturated with respect to calcium carbonate. Whereas, in December 2013, 2014, 2015 and 2016 groundwater has a tendency to remove the existing calcium carbonate, being moderately aggressive and corrosive behaviour.

KEYWORDS: Alappad, 26th December 2004 Indian Ocean Tsunami, Hill- Piper Trilinear plot,Irrigation water quality parameters, Corrosion indices.

Alappad coast (9^{0}2’57’’N to 9^{0}7’15’’N latitude and 76^{0}28’19’’E to 76^{0}30’13’’E) is a very narrow barrier coastal stretch situated between Arabian Sea and Kayamkulam estuary in Kollam district, Kerala, India. It is one of the severely devastated areas by 26th December 2004 Indian Ocean Tsunami killing 149 people caused enormous property and ecological damage (Achari et al., 2005; 2006; 2007; 2009; 2017). The beaches has the thickest deposit of economically valuable black mineral sand deposit- source of limonite, rutile, garnet and other rare earth minerals. Being an International spiritual tourist destination (Mata Amrithandamayi Math) and thickly populated by local inhabitants demand for fresh water to meet the requirements leads to more stress to groundwater sources. This fragile coastal land has heavy black mineral sand deposit making this region economically and geologically significant. The shallow and deep groundwater sources of this area are continuously monitored and studied from January 2005 after the tsunami event that collapsed the functions of all ecological system persisted. It is found that the soil formations deeply inundated with seawater and hence groundwater quality in this area is completely degraded. The pre-tsunami data obtained revealed that the water type in summer month (April 2001) is ofsaline water typereported in aprevous tsunami impact study (Jaison; 2012). In this studyhydrochemicalfacies of the groundwater from post tsunami period is evaluated to distinguish the water type prevailed in this coastal segment over the years. Study is mainly focussed on irrigation water quality parameters and corrosion indices of groundwater of the study area. Parameters are determined/ assessed to find the suitability of water for irrigation as well as for industrial application. The location map of the study area with sampling sites is given in Figure 1.

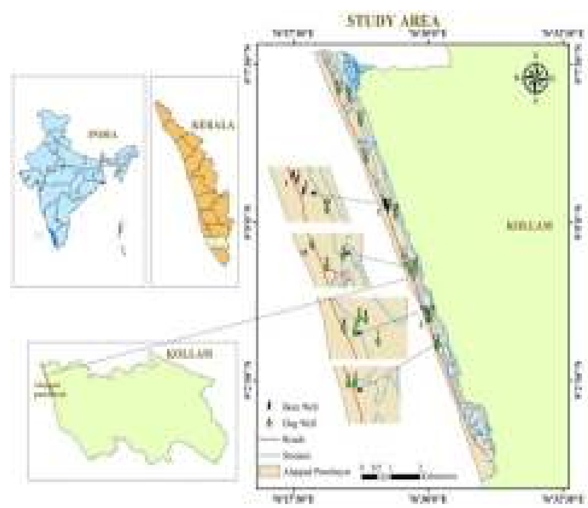

Figure 1: Location map of Alappad coast and groundwater sampling stations in Kollam, Kerala, India. Alappad coastal area heavily devastated by 24th December 2004 Indian Ocean tsunami (A coast having rich black mineral sand deposit and exposed to coastal hazard and sea water intrusion)

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Furthermore the study also compriseshydro analytical procedures to identify whether the region prevailsa water quality natural rejuvenation system in the post tsunami era or it is being accessible to continuous sea water intrusion hazard. There are many factors commonly used to express the gross hydrochemical features of a region's groundwater quality. Irrigation water quality symbolises the health status of soil to promote growth of vegetation, sustenance of natural characters and productivity. The common irrigationwater quality parameters evaluated in this study aresodium adsorption ratio (SAR), salinity hazard (EC in µS/cm), permeability index (PI), Kelley's index (KI), magnesium hazard (MH) and residual sodium carbonate (RSC).Quality statuses of the groundwater with respect to these parameters are critically evaluated for a sustainable livelihood of the inhabitants enabling them to formulate practices of survival.

MATERIALS AND METHODS

Groundwater samples were collected from 15 shallow dug well sources from the study area for five continuous years with one sampling per year in December 2012, 2013, 2014, 2015 and 2016. Physico-chemical parameters of water samples such as pH, electrical conductivity (EC), total hardness (TH), total Alkalinity (TA), calcium (Ca), magnesium (Mg), chloride (Cl^-), sulphate (SO_4^{2-}), phosphate (PO_4^{3-}), iron (Fe), nitrate (NO_3^-), sodium (Na), potassium (K) and total dissolved solids (TDS) were analysed following the standard analytical procedures recommended by APHA (APHA; 2005).Hill piper trilinear plots are made to find the overall characterisation of hydrochemical data by plotting hydrochemicalfaciesto identify the water types (Hounslow; 1995). The concentrations of anion and cation are expressed in milliequivalents per litre (meq/l).Extent of sea water intrusion is evaluated using Revelle's co-efficient (Kallergis; 2000). Sodium-Chloride ratio (Na^+/Cl^-) is calculated to find the process of ionic interaction prevailed in the study area.

The water quality for irrigation is essential for the growth and extent of vegetable cover of a region, maintenance ofsoil productivity and protection of environment. Irrigation water quality parameters such as sodium adsorption ratio (SAR), salinity hazard (EC in µS/cm), permeability index (PI), Kelley's index (KI), magnesium hazard (MH) and residual sodium carbonate (RSC) are also calculatedas per standard procedure (Elmabrok et al., 2017).These parameters and their selection criteria are shown in the Tables1 followed, for drawing inferences.

Langelier Saturation Index (LSI), Ryznar Stability Index (RSI) and Aggressiveness Index (AI) are evaluated (Singh et al., 2012)to find the suitability of water for industrial purposes as follows.

$$LSI = pH - pHs \quad (1)$$

$$RSI = 2pHs - pH \quad (2)$$

pHs can be calculated using the following equation

$$pHs = (9.3 + A + B) - (C + D) \quad (3)$$

Where:

$A = [Log_{10} (TDS) -1)/10]$, TDS in ppm; $B = [-13.12 \times Log_{10} (T + 273)) + 34.55]$, Temperature, T in ^oC;$C = [Log_{10}$ (Calcium hardness) - 0.4], Calcium hardness in ppm (as $CaCO_3$); $D = Log_{10}$ (Alkalinity), alkalinity in ppm (as $CaCO_3$).

$$AI = pH + log_{10}Alkalinity + log_{10}Calcium\ Hardness \quad (4)$$

The classifications of different corrosion indices (Langelier Saturation Index, Ryznar Stability index and Aggressiveness index)based on these equations are given in Table 2.

RESULTS AND DISCUSSION

Hill-Piper-Trilinear plots (Figure 2) give significant observation on water type characters based on cation and anion ratio (Hounslow; 1995). The water type of shallow dug well sources in Alappad coast belongs to categorysaline water type with hydrochemicalfaciesNa^+-K^+-Cl^- -SO_4^{2-} in December 2005 and 2008 being the data in the diamond are placed in the position signifies the instance of saline intrusion (right corner).This groundwater sources can be classified as Na^++ K^+ and Cl^- dominant type.

In December 2012 the water type moves marginally towards mixed water typefrom the temporary hardness region with non-dominant cations and anions. The hydrochemicalfacies of the mean of dug well sources in December 2012 are Na^+-K^+- Ca^{2+} -HCO_3^-. This may be due to slight increase in concentrations of Na^++$K^+$and the water type lies in the non-dominant area.It is seen from the cationand anion trianglesthe order of dominant ions are Na^++K^+ (50%)> Ca^{2+}(35%)> Mg^{2+}(15%) and HCO_3^- (70%)> Cl^- (29%)>SO_4^{2-}(1%).From 2013 to 2016 the water typeoccupies a position in Hill-Piper diamond plot in temporary hardnesswater typeregion. The hydrochemicalfacies of the mean of dug well sources from December 2013 to December 2016 are Ca^{2+}-Mg^{2+}-HCO_3^- .In 2013 the cation triangle of piper plot bears Na^++K^+(32%)>Mg^{2+}(40%)>Ca^{2+}(28%) and in the anion triangle HCO_3^-(73%)> Cl^-(20%)> SO_4^{2-}(7%)are observed. In 2014 the ions are Na^++K^+(35%)>Mg^{2+}(40%)> (25%) Ca^{2+}in cation triangleand from the anion triangle HCO_3^- (80%)>Cl^- (15%)>SO_4^{2-}(5%)are observed. During December 2015,water have cation and anion concentration in the order Ca^{2+} (45%)>Na^++K^+(30%)>Mg^{2+} (25%) and HCO_3(78%)>Cl^-(21%) >SO_4^{2-}(1%). InDecember 2016 the sequence of the abundance of major cations and anions are in the order Ca^{2+}(45%) > Mg^{2+}(31%) > Na^++K^+(24%)and HCO_3^-(78%)> Cl^-(21%)>SO_4^{2-}(1%).

Ion-exchange process (Na/Cl<1) is prominent in Alappad coast during the study period (December 2012 to December 2016). During ion exchange, calcium and magnesium ions from water are get exchanged with sodium ions in soil. Monthly, mean of all stations for Revelle's co-efficient, is observed as R<1 as shown in Table 3.This assures no sea water intrusion occurred in the study area except few instances in December 2012 at station 8 (R=1.07) and station 15 (R=1.52). These stations are located near or close to sea. InDecember 2015 also saline water intrusionis observed (R >1) at station 8 with R=1.66 (proximity to sea).

Irrigation Water Quality Parameters

Sodium (Na^+ ions) is an important irrigation water quality parameter especially for reporting water quality of coastal regions as sodium from seawater can contaminate the groundwater aquifers through instance of sea water intrusion/ halide contamination. The value of irrigation water quality analysed were shown in Table 4. Sodium adsorption ratio (SAR) is less than 10 forgroundwater sources for all the 5 year of study period with low sodium hazard (Class S1) behaviour. Monthly mean of electrical conductivity in December 2012 & 2013 is within the classC3 category, indicates high saline water (750 µS/cm -2250 µS/cm) i.e. moderate water quality for irrigation.In December 2014, 2015 and 2016 water is medium saline(250 µS/cm –750 µS/cm) and falls in class C2 category which is good for irrigation.From USSL diagram it is clear that groundwater in shallow dug wells are high salinity low sodium water (C3S1) in December 2012 & 2013 where as in December 2014, 2015 & 2016 medium saline with low sodium water (C2S1) behaviour is distinct.

Permeability index (PI) shows that water sources are being placed comes under class I (>75%) and class II (25%-75%) both are suitable for irrigation.According to classification under Kelley's index (KI<1) most of the groundwater sources are suitable for irrigation.In December 2012, 2015 & 2016 magnesium hazard is less than 50% (MH<50%), hence water is suitable for irrigation. December 2013 & 2014 water sources are unsuitable for irrigation having MH>50%.

Residual sodium carbonate (RSC) for December 2012 & 2013 is good to moderate, December 2014 water samples falls in moderate to bad water quality and December 2015 & 2016 water quality lies as excellent to good in terms of irrigation purpose.

Corrosion Indices

Aggressive behaviour hence the nature of water to promote corrosion, immune and passivation could be evaluated by corrosion indices. In December 2012,Langelier saturation index, LSI>0,hence water is super saturated where $CaCO_3$ scales tends to deposit. December 2013, 2014, 2015 & 2016 has LSI <0, indicating water is in undersaturated state and is corrosive.Ryzner index (RSI) of monthly mean of all the five year study periodof groundwater sources shows water is aggressive and corrosion is likely.Aggressiveness index (AI) for monthly mean of December 2012 to December 2016 confirms the groundwater behavenon-corrosiveto moderately corrosive.

This observation is based on primary data generated by intensive analytical research on groundwater chemistry of the water. Actual character of the groundwater is well defined without any approximation. The results of the following years are meant for the random observation to confirm is there any gradual/ rapid fluctuation in groundwater chemistry due to any kind of incidences of hazard leads to contamination.

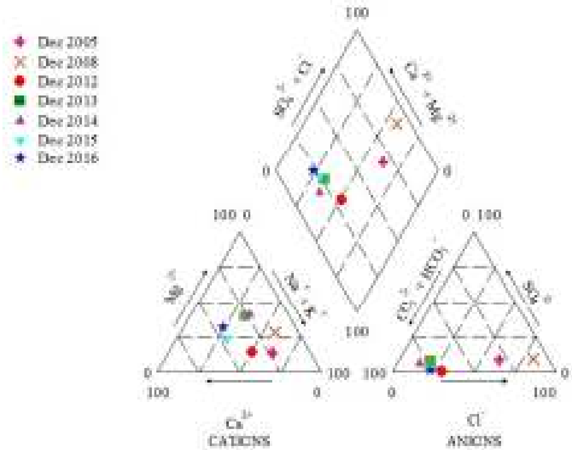

Figure 2: Hill-Piper trilinear plot showing water type for shallow groundwater sources during December 2005, 2008, 2012, 2013, 2014, 2015 and 2016 of Alappad coast, Kollam, Kerala, India

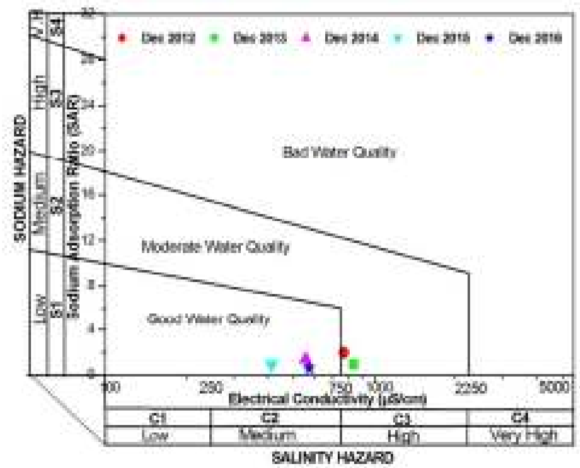

Figure 3: USSL diagram forshallow dug wells of Alappad coast, Kollam, Kerala, India during December 2012, 2013, 2014, 2015 & 2016

Table 1: Irrigation water quality parameters and groundwater classification method selected to study hydrogeochemistry of Alappad coast (Elmabrok et al., 2017 &Achari et al., 2017)

SI No:	Parameters	Unit	Range	Remarks	Class
1	Sodium Adsorption Ratio (SAR)	meq/l	< 10	Excellent	S1
			10 – 18	Good	S2
			19 – 26	Doubtful	S3
			> 26	Unsuitable	S4
2	Salinity Hazard	µS/cm	< 250	Excellent	C1
			250 – 750	Good	C2
			750 – 2250	Doubtful	C3
			> 2250	Unsuitable	C4
3	Permeability Index (PI)	%	> 75	Suitable for irrigation	
			25-75%	Suitable for irrigation	
			0-25%	Unsuitable for irrigation	
4	Magnesium Hazard (MH)	meq/l	< 50%	Suitable for irrigation	
			> 50%	Adversely affect soil	
5	Kelley's Index (KI)	meq/l	< 1	Suitable for irrigation	
			> 1	Indicates an excess level of sodium	
6	Residual Sodium Carbonate (RSC)	meq/l	< 1.25	Excellent	
			1.25- 2.0	Good	
			2.0-2.5	Medium	
			2.5-3.0	Bad	
			> 3.0	Very bad	

Table 2: Classification of ground water on the basis of corrosion indices-Langelier Saturation Index (LSI), Ryznar Stability index (RSI) & Aggressiveness index (AI) (Achari et al.; 2017)

<table>
<tr><th>LSI</th><th>Tendency of water</th><th>RSI</th><th>Tendency of water</th><th>AI</th><th>Tendency of water</th></tr>
<tr><td>< -2.0</td><td>Intolerable corrosion (IC)</td><td>7.5 – 9.0</td><td>Heavy corrosion(HC)</td><td rowspan="2">< 10.0</td><td rowspan="2">Highly aggressive (HA)</td></tr>
<tr><td>-2.0 - -0.5</td><td>Serious corrosion (SC)</td><td>7.0 – 7.5</td><td>Corrosion significant(CS)</td></tr>
<tr><td>-0.5 - 0</td><td>Slightly corrosive but non scale forming(SCNSF)</td><td>6.0 – 7.0</td><td>Little scale or corrosion(LSC)</td><td rowspan="2">10.0-11.9</td><td rowspan="2">Moderately aggressive(MA)</td></tr>
<tr><td>0</td><td>Balanced but pitting(BP)</td><td>5.0 – 6.0</td><td>Light scale (LS)</td></tr>
<tr><td>0 – 0.5</td><td>Slightly scale forming and corrosive (SSFC)</td><td rowspan="2">4.0 – 5.0</td><td rowspan="2">Heavy scale (HS)</td><td rowspan="2">> 12.0</td><td rowspan="2">Non-aggressive (NA)</td></tr>
<tr><td>0.5 – 2.0</td><td>Scale forming but non corrosive (SFNC)</td></tr>
</table>

Table 3: Revelle's co-efficient (R) for groundwater from shallow dug well sources in Alappad coast, Kollam, Kerala, India, during December 2012, 201, 2014, 2015& 2016

Dug Well (DW)	Dec 2012	Dec 2013	Dec 2014	Dec 2015	Dec 2016
DW 1	0.35	0.3	0.24	0.53	0.09
DW 2	0.46	0.24	0.17	0.37	0.8
DW 3	0.48	0.32	0.02	0.8	0.3
DW 4	0.23	0.11	0.08	0.12	0.23
DW 5	0.27	0.22	0.28	0.26	0.08
DW 6	0.31	0.1	0.16	0.24	0.09
DW 7	0.22	0.21	0.08	0.54	0.4
DW 8	**1.07**	0.77	0.44	**1.66**	0.51
DW 9	0.25	0.36	0.37	0.38	0.66
DW 10	0.34	0.13	0.08	0.12	0.56
DW 11	0.28	0.16	0.08	0.07	0.33
DW 12	0.7	0.09	0.18	0.07	0.14
DW 13	0.46	0.56	0.14	0.15	0.17
DW 14	0.56	0.07	0.2	0.17	0.2
DW 15	**1.52**	0.27	0.61	0.4	0.59
$\bar{x}\pm\sigma$	0.50±0.36	0.26±0.19	0.21±0.16	0.39±0.4	0.34±0.23

Table 4: Irrigation water quality parameters shallow dug wells of Alappad coast, Kollam, Kerala, India during December 2012, 2013, 2014, 2015 & 2016

	Parameters	Unit	Dec 2012	Dec 2013	Dec 2014	Dec 2015	Dec 2016
1	SAR	meq/l	2.64±2.30	1.61±0.85	1.76±0.89	1.06±0.50	0.99±0.8
2	EC	µS/cm	770.64±793	840±525.13	562±266.22	415.33±201.6	578.83±390.38
3	PI	%	74.30±14.69	91.92±55.07	78.76±21.67	73.92±29.18	61.72±17.38
4	KI	meq/l	1.08±1.06	0.77±0.54	0.72±0.57	0.52±0.28	0.42±0.47
5	MH	%	30.77±17.12	54.57±12.54	64.15±9.13	37.94±20.77	41.14±15.29
6	RSC	meq/l	0.50±1.81	1.13±1.43	2.31±1.43	-0.62±1.35	-0.43±3.06

Table 5: Corrosion indices of shallow dug wells of tsunami affected Alappad coast, Kollam, Kerala, India during December 2012, 2013, 2014, 2015 & 2016

Corrosion Indices	Dec 2012	Dec 2013	Dec 2014	Dec 2015	Dec 2016
LSI	0.18±0.77	-0.01±0.44	-0.29±0.90	-0.11±0.77	-0.32±0.65
RSI	7.45±1.23	7.81±0.95	7.94±1.66	8.18±1.50	7.95±1.15
AI	12.05±0.78	11.91±0.45	11.59±0.92	11.77±0.79	11.54±0.66

CONCLUSION

The overall water type of groundwater in Alappad coast is temporary hardness water type during 2012-2016.Based on the irrigation water quality parameters evaluated, majority of groundwater sources are suitable for irrigation falling in good to moderate category.Even though, LSI shows groundwater is supersaturated state in December 2012, Ryzner index (RSI) shows the scaling capacity of water is not sufficient to prevent corrosion tendency hence aggressive character remains. The groundwater in shallow dug well sources of the study area is moderatelyaggressive in nature. Hence, proper treatment prior use in irrigation proposes is needed to be recommended.

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