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Indication of subsurface seawater intrusion into the Indus delta, Sindh, Pakistan

Ghulam Shabir Solangi [a,*], Altaf Ali Siyal [b], Pirah Siyal [c]

[a] *Department of Civil Engineering, Mehran University of Engineering and Technology, Shaheed Zulfiqar Ali Bhutto Campus, Khairpur Mir's, Pakistan*

[b] *Department of Land and Water Management, Sindh Agriculture University, Tandojam Pakistan*

[c] *National Centre of Excellence in Analytical Chemistry, Jamshoro Pakistan*

[*] Corresponding author: Dr. Ghulam Shabir Solangi, Email: solangi_shabir@yahoo.com

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IDW

ABSTRACT

Due to climate change impacts, seawater intrusion is a major issue in various river deltas around the globe, including the Indus delta, Pakistan. The seawater intrusion has severely affected the freshwater resources as well as the livelihood of the people living in the Indus delta. Thus, this study was aimed to evaluate the subsurface seawater intrusion into the Indus delta based on the groundwater quality data. Around 180 groundwater samples, randomly collected from the study area, were analyzed for chloride, carbonate, and bicarbonate concentrations. Based on these concentrations, the indication of subsurface seawater intrusion was determined using Simpson's ratio and ionic analysis, such as the ratio of chloride to bicarbonate. Also, an interpolated map using the analysis results of these ratios was developed using ArcGIS 10.5. Overall, the present study revealed that about 88% of the Indus delta is affected by the subsurface seawater intrusion. Also, the impact of subsurface seawater intrusion was observed in the wells near the Thatta and Sujawal towns of the study area. However, about 12% of the delta is still unaffected by the subsurface seawater intrusion. Various factors such as reduction in freshwater flow into the delta, climate change, sea-level rise are potential causes of subsurface seawater intrusion in the study area. This study may be taken as a baseline by the policymakers to start mitigation measures against the degradation of the delta to save the environment from further deterioration. Also, further an isotopic analysis of subsurface seawater intrusion in the study area is recommended.

1. Introduction

Groundwater plays an important role in living standards [1-2]. Due to the tremendous increase in population, the need for freshwater resources is also increasing for its domestic, irrigation, industrial as well as recreational purposes. In coastal areas, due to the shortage of freshwater, the entry of saline water has created so many problems. It constitutes the main environmental issues around the globe [3]. Seawater intrusion is the entry of salt water into the fresh groundwater [4]. Various factors such as excess withdrawal of groundwater from aquifers in coastal areas and density difference between the less dense aquifer water and highly saline water of the sea may contribute this problem [5-6]. However, the extent of seawater intrusion varies from area to area. It also depends on the hydro-geological setting of the area [6]. Werner et al. [4] reported that seawater intrusion into the aquifers of the coastal areas is a global issue, which starts by increasing demand for freshwater and rising sea level. In response to climate change, sea levels are projected to rise, causing the seawater intrusion into the coastal areas. In coastal regions where the topography is flat, this would limit the circulation and causes an increase in shallow water covered areas [7].

The literature reveals that seawater intrusion into the aquifers of the Indus delta, Pakistan is increasing at an alarming rate. Once fresh water was available at shallow depth. But at present, due to a shortage of fresh water in the Indus River below the Kotri Barrage, the last barrage before its delta, aquifers of the delta are being recharged with highly saline water of the Arabian Sea [8-11]. As a result, the area is facing an acute shortage of fresh water. Sylus and Ramesh [12] stated that freshwater aquifers in coastal areas are affected due to the entry of saline water. It makes the aquifers unsuitable for various purposes. Thus, the present study was designed to study the indication of subsurface seawater intrusion in the area based on the chemical analysis of groundwater samples. The study will be helpful to start mitigative measures against further contamination of the aquifers in the study area.

2. The Study Area

The river Indus forms its deltaic area when it empties into the Arabian Sea. It is in three administrative districts, such as Sujawal, Thatta, and Badin, Sindh, Pakistan [13-19]. A GIS map showing the study area is given in Fig. 1. However, its most of the area stretches in Sujawal and Thatta districts. It lies between the latitudes of 23º48'29" and 24º57'19" and longitudes of 67º40'01" and 68º14'04". The average annual rainfall in the area is about 220 mm, whereas temperature varies between 23 to 29 ºC [13]. About 1.76 million people are living in these districts. The main occupation of the people is agriculture, fishing, etc. River Indus is the main source of groundwater recharge, which remains most of the time dry due to the diversion of excess water at its upper sites. As a result of that, seawater intrusion into the aquifers of the area is increasing day by day, and spoiled freshwater aquifers in most of the areas of the delta. Altogether, socioeconomic conditions of the community are badly affected. People are migrating from their ancestral places in the research of food and shelter.

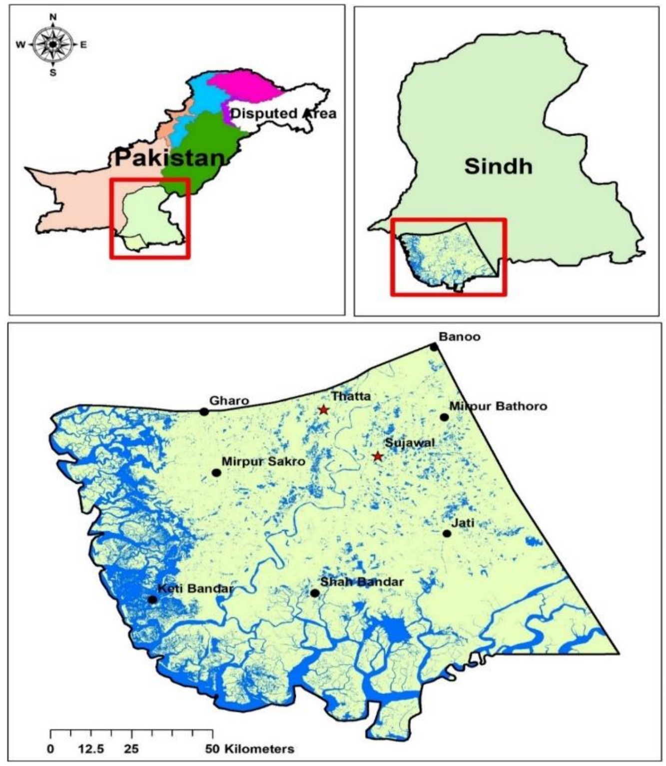

Fig. 1. GIS map of the Indus delta (study area) [14]

3. Materials and Methods

Around 180 georeferenced groundwater samples were randomly collected from the hand pumps, boreholes, electric motors already installed in different villages, public places located in different areas within the delta. Water samples were gathered in one-liter plastic bottles, washed, and rinsed properly with distilled water to remove any possible contamination [13]. Whereas sampling locations were recorded using a handheld Garmin 62s GPS. Water samples were analyzed for chloride (Cl^-), carbonate (CO_3^{2-}), and bicarbonate (HCO_3^-) concentrations using standard titration method. Based on these concentrations, the subsurface seawater intrusion in the Indus delta was determined using Simpson's ratio ($Cl^-/CO_3^{2-}+ HCO_3^-$) and ionic analysis, such as the ratio of chloride to bicarbonate (Cl^-/ HCO_3^-). Also, an interpolated map using the analysis results of these ratios was developed using ArcGIS 10.5 spatial analysis, IDW (inverse distance weighted) tool.

4. Results and Discussion

The presence of chloride in excessive amounts in water is an indication of seawater, whereas bicarbonate is the most abundant ion in the aquifers [20]. Furthermore, Bablani and Soomro [20] stated that a ratio among these two ions, i.e., chloride and bicarbonate, is a useful index, used to analyze the presence of seawater indication into aquifers. If this ratio exceeds by 2/3 (0.67), then it indicates the entry of seawater into the groundwater of the area. Whereas, according to Jamshidzadeh and Mirbagheri [21] as reported by Ebrahimi et al. [22], if the Simpson's ratio, i.e., the ratio of chloride to carbonate plus bicarbonate exceeds by 2.8, then there is an indication of seawater intrusion in groundwater of the area. Based on these concentrations, the indication of subsurface seawater intrusion into the Indus delta, Sindh, Pakistan was determined using Simpson's ratio and ionic analysis, such as the ratio of chloride to bicarbonate. Also, an interpolated map using the analysis results of these ratios was developed using ArcGIS 10.5. The results of these ratios in groundwater samples of the study area are summarized in Table 1 (Annexure).

Table 1 reveals that estimations of the considered ratios for most of the analyzed groundwater samples are exceeding the respective thresholds. A contour map illustrating spatial distribution of ionic ratios in the groundwater of the study area is shown in Fig. 2. It depicts that ionic ratios in the areas of the Indus delta nearer to the Arabian Sea are increasing. Whereas these ratios are decreasing towards land.

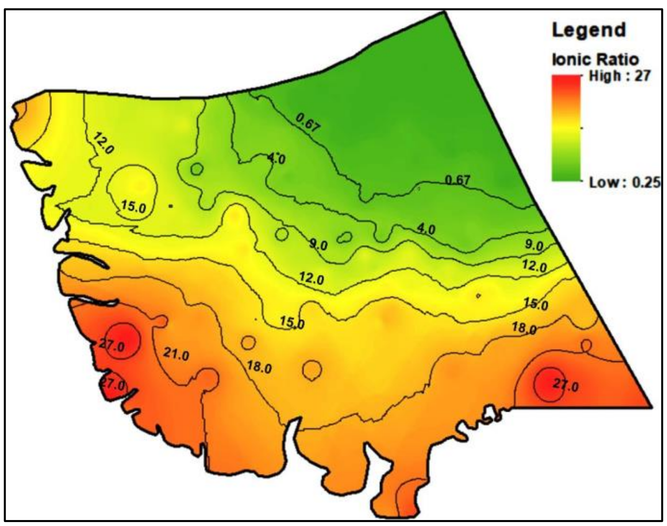

Fig. 2. A contour map showing spatial distribution of ionic ratios

Hence, it may be concluded that most of the area of the Indus delta is affected by the subsurface seawater intrusion. The subsurface seawater has intruded in vast areas of the delta such that its presence was observed in the wells near to Thatta and Sujawal towns of the Indus delta. Based on high chloride concentration (>250 mg/L), Simpson ratio (>2.8), chloride, and bicarbonate ratio (>0.67) in the groundwater samples, the seawater intrusion interpolation map depicted that about 11,540.4 sq. km (1.15 Mha) of land or 88.3% of the delta is affected by the seawater intrusion, while 1526.6 sq. km (0.15 Mha) or 11.7% of the delta is unaffected due to the intrusion of seawater.

Based on these ratios, the present study revealed that, on an overall, about 12% of the delta is still unaffected by the subsurface seawater intrusion. Also, the impact of subsurface seawater intrusion was observed in the wells near the Thatta and Sujawal towns of the study area. Various factors such as tidal fluctuations, climate change, sea-level rise, variation in evaporation rates, fractures in rock formations, groundwater recharge rates are influencing saltwater intrusion into aquifers of coastal areas [6].

5. Conclusion

Based on high chloride concentration (>250 mg/L), Simpson ratio (>2.80), chloride and bicarbonate ratio (>0.67) in groundwater of the study area, it is estimated that subsurface seawater intrusion has affected about 1.15 Mha (88.3% of the Delta). Overall, the present study revealed that about 88% of the Indus delta is affected by the subsurface seawater intrusion. However, about 12% of the delta is still unaffected by the subsurface seawater intrusion. Also, the impact of subsurface seawater intrusion was observed in the wells near the Thatta and Sujawal towns of the study area. A contour map of ionic ratios also depicts that such ratios in the areas of the Indus delta near to the Arabian Sea are increasing and decreasing towards land. Various factors such as reduction in freshwater flow into the study area, tidal fluctuations, climate change, sea-level rise, variation in evaporation rates, groundwater recharge rates are main causes of subsurface seawater intrusion into aquifers of the Indus delta. This study may be taken as a baseline by the policymakers to start mitigation measures against the degradation of the delta to save the environment from further deterioration. Also, further an isotopic analysis of subsurface seawater intrusion in the study area is recommended.

6. Acknowledgement

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7. References

[1] B. Datta, and D. Singh, “Optimal groundwater monitoring network design for pollution plume estimation with active sources”, International journal of GEOMATE: geotechnique, construction materials and environment, Vol. 6, No. 1, pp.864-869, 2014.

[2] K. Supriyadi, and A.S.P. Putro, “Geophysical and hydrochemical approach for seawater intrusion in north semarang, central java, Indonesia”, International J. Geomate, Vol. 12, No. 31, pp. 134-140, 2017.

[3] R. Trabelsi, R., Moncef Zairi, M., and Dhia, H.B., “Groundwater salinization of the Sfax superficial aquifer, Tunisia”, Journal of Hydrogeology, Vol. 157, pp. 1341–1355, 2007.

[4] A.D. Wenner and C.T. Simmon, “Impact of sea-level rise on sea water intrusion in coastal aquifers”, Physics and Earth Sciences, Vol. 47, No. 2, pp. 197-204, 2009.

[5] G.A. Robinson, A.A. Ahmed and G.A. Hamil, “Experimental saltwater intrusion in coastal aquifers using automated image analysis: application to homogeneous aquifer”, Journal of Hydrology, Vol. 538, pp. 304-313, 2016.

[6] O.T. Kayode, A.M. Odukoya and T.A. Adagunodo, “Saline water intrusion: its management and control”, Journal of Informatics and Mathematical Sciences, Vol. 9, No. 2, pp. 493-499, 2017.

[7] A.C. Dvorak, H.M. Solo-Gabriele, A. Galletti, B. Benzecry, V. Boguszewski and JasonBird, “Possible impacts of sea level rise on disease transmission and potential adaptation strategies, a review”, Journal of Environmental Management, Vol. 217, pp. 951-968, 2018.

[8] A. Alamgir, M.A. Khan, J. Schilling, S.S. Shaukat and S. Shahab, “Assessment of groundwater quality in the coastal area of Sindh province, Pakistan”, Environmental Monitoring and Assessment, Vol. 188, pp. 78–90, 2016.

[9] G.S. Solangi, A.A. Siyal, M.M. Babar and P. Siyal, “Groundwater quality evaluation using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools: a case study of Sujawal district, Pakistan”, Human and Ecological Risk Assessment: An International Journal, 2019.

[10] G.S. Solangi, A.A. Siyal, M.M. Babar and P. Siyal, “Application of water quality index, synthetic pollution index, and geospatial tools for the assessment of drinking water quality in the Indus Delta, Pakistan”, Environmental Monitoring and Assessment, 191:731, 2019.

[11] G.S. Solangi, A.A. Siyal, M.M. Babar, P. Siyal, “Evaluation of drinking water quality using the water quality index (WQI), the synthetic pollution index (SPI) and geospatial tools in Thatta district, Pakistan”, Desalination and Water Treatment Journal, Vol. 160, pp. 202-213, 2019.

[12] K.J. Sylus, and H. Ramesh, “The study of sea water intrusion in coastal aquifer by chemical parameter ratio method”, Proceedings of Hydro International, IIT Madras, India, 4-6 Dec. 2013.

[13] G.S. Solangi, A.A. Siyal, M.M. Babar, P. Siyal, “Groundwater quality mapping using geographic information system: a case study of district Thatta, Sindh, Pakistan”, Mehran University Research Journal of Engineering and Technology, Vol. 36, No. 4, pp. 1059-1072, 2017.

[14] G.S. Solangi, A.A. Siyal, M.M. Babar and P. Siyal, “Evaluation of surface water quality using the water quality index (WQI) and the synthetic pollution index (SPI): a case study of Indus Delta region of Pakistan”, Desalination and Water Treatment., Vol. 118, pp. 39-48, 2018.

[15] G.S. Solangi, A.A. Siyal, P. Siyal, “Spatiotemporal dynamics of land surface temperature and its impact on the vegetation”, Civil Engineering Journal, Vol. 5, No. 8, pp. 1753-1763, 2019.

[16] G.S. Solangi, A.A. Siyal, M.M. Babar, P. Siyal, “Spatial analysis of soil salinity in the Indus river delta, Pakistan”, Engineering, Technology and Applied Science Research, Vol. 9, No. 3, pp. 4271-4275, 2019.

[17] G.S. Solangi, A.A. Siyal and P. Siyal, “Analysis of Indus delta groundwater and surface water suitability for domestic and irrigation purposes”, Civil Engineering Journal, Vol. 5, No. 7, pp. 1599-1608, 2019.

[18] Solangi, G.S., “Impact assessment of seawater intrusion on soil, water and vegetation of the

indus delta using field and satellite data", A PhD thesis submitted to Mehran University of Engineering and Technology, Jamshoro, Pakistan, 2019.

[19] G.S. Solangi, A.A. Siyal, M.M. Babar and P. Siyal, "Temporal dynamics of vegetative cover and surface water bodies in the Indus delta, Pakistan", Mehran University Research Journal of Engineering and Technology, Vol. 39, No. 1, pp. 133-144, 2020.

[20] S.A. Bablani and S.A. Soomro, "Evaluation of seawater intrusions in left bank sediments of coastal district Thatta, Sindh, Pakistan", 1st SWIM-SWICA Joint Saltwater Intrusion Conference, Italy, September 24–29, 2006.

[21] Z. Jamshidzadeh and S.A. Mirbagheri, "Evaluation of groundwater quantity and quality in the Kashan Basin, Central Iran", Desalination, Vol. 270 (1-3), pp. 23-30, 2011.

[22] M. Ebrahimi, H. Kazemi, M. Ehtashemi and T.D. Rockawaya, "Assessment of groundwater quantity and quality and saltwater intrusion in the Damghan basin, Iran", Chemie der Erde, Vol. 76, pp. 227-241, 2016.

Annexure

Table 1

Results of Ions Ratio analyses in the Groundwater Samples of the Indus Delta

S. No.	Coordinates		$Cl^-/(CO_3^{2-}+HCO_3^-)$ Value	(Cl^-/HCO_3^-) value
	Latitude	Longitude		
1	24.30466	67.93565	5.12	5.51
2	24.34644	67.95039	5.97	6.63
3	24.35763	67.95816	6.19	7.20
4	24.35115	67.87633	5.25	6.52
5	24.38938	67.97619	7.00	7.85
6	24.39643	67.99397	3.57	4.36
7	24.49629	68.03799	3.17	3.95
8	24.55329	68.05845	3.14	3.85
9	24.61536	68.05257	2.99	3.67
10	24.19385	68.09342	15.63	16.41
11	24.1963	68.09732	5.16	5.72
12	24.18196	68.06881	5.65	6.10
13	24.21498	68.10415	3.63	3.95
14	24.27663	68.08894	7.01	7.34
15	24.30896	68.07053	4.15	4.39
16	24.32168	68.06401	3.33	3.49
17	24.35045	68.03904	4.42	4.67
18	24.81973	68.29413	0.63	0.66
19	24.78699	68.29371	0.60	0.62
20	24.74461	68.27159	0.65	0.65
21	24.7382	68.27082	0.66	0.67
22	24.74512	68.24457	0.62	0.66
23	24.75939	68.2231	0.53	0.55
24	24.77759	68.20148	0.58	0.61
25	24.79148	68.18692	0.59	0.61
26	24.82248	68.21873	0.48	0.49
27	24.82622	68.22093	0.65	0.67
28	24.81552	68.18834	0.65	0.67
29	24.85031	68.1897	0.55	0.56
30	24.90215	68.20659	0.74	0.74
31	24.90505	68.24686	0.62	0.64
32	24.28166	68.39128	3.07	3.15
33	24.42248	68.25742	4.22	5.15
34	24.45673	68.22771	1.13	1.38
35	24.49668	68.18729	1.31	1.43
36	24.51106	68.17261	1.20	1.47
37	24.58243	68.12988	2.53	3.09
38	24.58838	68.16457	2.65	3.24
39	24.61411	68.25465	3.51	3.59
40	24.62749	68.35305	5.76	6.10

41	24.60129	68.29439	3.42	3.62
42	24.55286	68.28204	2.55	3.12
43	24.51375	68.27484	3.70	4.02
44	24.28357	68.1515	3.74	4.10
45	24.41249	68.05337	4.76	5.16
46	24.39871	68.07845	4.25	4.35
47	24.20409	67.81847	4.60	4.94
48	24.13961	67.75243	5.10	5.50
49	24.18717	67.76549	7.08	7.47
50	24.18999	67.76748	4.92	5.21
51	24.19776	67.80119	3.43	3.53
52	24.2162	67.90746	11.50	11.76
53	24.68093	68.022325	0.75	0.77
54	24.68785	68.05158	0.62	0.63
55	24.71947	68.07122	0.60	0.62
56	24.79318	68.16827	0.62	0.63
57	24.79143	68.18552	0.53	0.55
58	24.76345	68.21812	0.65	0.66
59	24.72965	68.32787	0.64	0.66
60	24.65432	68.28771	2.51	2.71
61	24.64482	68.14458	3.42	3.50
62	24.66101	68.13333	0.87	0.89
63	24.64107	68.11746	2.39	2.44
64	24.73024	68.25695	0.65	0.67
65	24.61579	68.29538	0.79	0.85
66	24.5695	68.28629	3.05	3.30
67	24.45614	68.24784	3.65	3.84
68	24.45614	68.26497	3.51	3.58
69	24.38281	68.28498	5.13	5.41
70	24.538	68.38568	3.44	3.65
71	24.47006	68.36367	3.40	3.54
72	24.416	68.30287	3.73	3.95
73	24.34793	68.14664	2.28	2.63
74	24.7009	68.03469	0.78	0.80
75	24.75713	68.107	0.65	0.68
76	24.81922	68.15056	0.63	0.66
77	24.83937	68.13749	0.67	0.69
78	24.83718	68.14835	0.61	0.64
79	24.95801	68.234603	0.62	0.65
80	23.96198	67.444738	6.46	6.81
81	23.80996	67.689438	5.52	5.99
82	24.04869	67.652834	4.74	4.99
83	23.70676	68.156534	5.17	5.45
84	23.69768	68.094115	5.87	6.17
85	24.07021	67.906907	5.67	6.08
86	23.971913	68.258433	4.34	4.55
87	24.06543	68.257611	3.74	4.11
88	23.979707	68.739726	2.75	3.35
89	24.03600	68.495952	3.46	4.22
90	24.13378	68.585026	2.99	3.65
91	24.02655	68.558037	3.20	3.83
92	24.31297	68.248406	3.11	3.80
93	24.11672	68.380785	3.55	4.33
94	24.18671	68.579797	2.92	3.56
95	24.71614	67.93828	0.53	0.64
96	24.18472	67.54237	3.63	4.42
97	24.17608	67.55753	5.52	6.75
98	24.17856	67.58021	7.46	9.12
99	24.16235	67.57672	4.95	6.05
100	24.19256	67.62808	4.28	5.23
101	24.24009	67.60732	6.33	7.74
102	24.43871	67.59344	3.98	4.87

103	24.67599	67.5903	2.72	3.32
104	24.68786	67.5239	2.86	3.51
105	24.48	67.49209	3.30	4.03
106	24.47808	67.53783	2.29	2.80
107	24.47485	67.55866	3.92	4.79
108	24.49855	67.61586	2.90	3.55
109	24.48675	67.64204	5.27	6.44
110	24.47968	67.64774	12.41	15.17
111	24.44987	67.71621	2.94	3.59
112	24.57928	67.89207	1.01	1.23
113	24.52212	67.4856	3.89	4.75
114	24.60749	67.8223	4.60	5.64
115	24.61	67.82021	3.15	3.44
116	24.54891	67.84737	3.97	4.27
117	24.56136	67.83628	7.42	9.07
118	24.57053	67.82518	6.28	7.67
119	24.5769	67.79744	2.98	3.66
120	24.57429	67.78699	3.61	4.41
121	24.55262	67.65233	7.26	8.87
122	24.55262	67.65233	3.05	3.73
123	24.5653	67.62282	5.82	7.10
124	24.61118	67.60271	7.97	9.75
125	24.79717	67.90295	0.54	0.66
126	24.78626	67.863788	2.56	3.27
127	24.78917	67.86977	2.23	2.70
128	24.76284	67.78542	2.37	2.87
129	24.74795	67.77212	0.51	0.62
130	24.74255	67.77383	1.50	1.83
131	24.72345	67.62518	2.11	2.58
132	24.70185	67.66367	1.01	1.24
133	24.69723	67.67353	1.42	1.74
134	24.64548	67.73662	2.48	2.96
135	24.63384	67.7522	13.91	15.32
136	24.7694	67.93874	0.62	0.76
137	24.81108	67.96599	0.57	0.64
138	24.14447	67.45207	4.17	5.08
139	24.71304	67.96167	0.66	0.80
140	24.74666	67.96504	0.65	0.80
141	24.76474	67.96365	0.55	0.67
142	24.78204	67.97162	0.66	0.81
143	24.79421	67.95869	0.55	0.67
144	24.74373	67.8801	0.56	0.69
145	24.27383	67.67395	6.41	6.58
146	24.31082	67.62506	2.02	2.46
147	24.36563	67.74229	2.51	3.07
148	24.37218	67.77356	3.70	4.52
149	24.4015	67.82956	3.41	4.17
150	24.67514	67.93582	3.26	4.01
151	24.72121	67.167543	4.42	5.41
152	23.99865	67.409348	5.58	6.81
153	24.89669	68.160794	0.58	0.71
154	24.87833	68.253086	2.38	2.91
155	24.93953	68.22994	0.60	0.73
156	24.2519	68.31811	2.61	3.19
157	24.25965	68.35145	3.19	3.90
158	24.5307	68.14471	0.71	0.88
159	24.252	68.3181	0.75	0.91
160	24.89669	68.16079	0.59	0.72
161	24.72121	67.167544	3.26	3.99
162	24.71302	67.96168	0.56	0.69
163	24.5651	67.6228	5.20	5.42
164	24.78917	67.86976	2.00	2.45
165	24.57927	67.89206	1.08	1.32

166	24.17855	67.5802	6.85	8.37
167	24.3987	68.07844	3.47	4.23
168	24.61535	48.05258	7.66	9.37
169	24.74665	67.96503	0.82	1.00
170	24.577	67.79743	2.43	2.51
171	24.74374	67.88	0.64	0.78
172	24.35114	67.87632	0.32	0.37
173	24.78626	67.863787	1.40	1.71
174	24.14446	67.45205	2.14	2.62
175	24.5743	67.78698	3.88	4.73
176	24.44988	67.71622	2.60	3.17
177	24.2401	67.60731	6.21	7.59
178	24.62	67.82022	2.93	3.58
179	24.17855	67.5802	5.93	7.23
180	24.49854	67.61587	2.66	3.25