Domestic three stage water-treatment option for harvested rainwater in water-stressed communities

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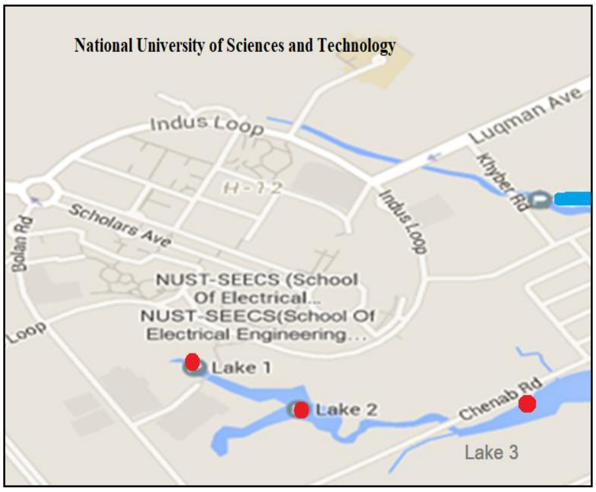
Abstract. Rainwater harvesting (RWH) practice can be traced back millennia, the degree of its modern implementation varies greatly across the world. And is the best option for water-stressed communities. A harvested rainwater quality monitoring study was undertaken at 3 lakes constructed in NUST Islamabad, Pakistan for a period of 10 months over two seasons i.e. wet and dry periods. Overall, harvested rainwater was of good quality, falling within the recreational water quality as per WHO standards with the exceptions for pH, color, turbidity, total coliforms and total bacterial count. A large number of samples tested positive for the total bacterial count and total coliforms, showing that disinfection of harvested rainwater is mandatory prior to use and its direct consumption without treatment may pose a health risk. For its treatment, an indigenously designed (SwissPak) water filter employing physicochemical methods were tested for making harvested rainwater fit for potable use. This filter contains silica sand for pre-filtration, granulated chlorine for disinfection and charcoal for removal of taste, odor and dissolved organic while alum was used as coagulant initially. This filter successfully improved the harvested rainwater quality and proved itself a suitable option for water treatment.
Keywords: Rainwater harvesting, water quality, physicochemical water treatment

1. Introduction

Human health, livelihood, and continuous development is directly and indirectly linked to the provision of safe drinking water [1]. The ratio between total water withdrawals and available renewable surface water at a sub-catchment level is termed as water stressed defined by World Water Resources Institute, it also highlights the alarming situation that Pakistan will have to face being a most water-stressed country in the region by the year 2040.Recent conditions threatening Pakistan and making it 23rd most water-stressed country in the world, if not tried to implement water conservation strategies [2]. Pakistan being a victim of water stress, facing poor water availability, in villages ponds are a source of water for animal and human beings as well. As considerable predictions open the gate for alternatives especially in developing countries where water withdrawal will increase by 50 % as compared to 18 % in developed countries. This will directly push almost 800 million people into absolute water scarcity [3]. About 44 % of Pakistan's population is lacking the safe water resources reported by Pakistan Council of Research in Water Resources (PCRWR). The surface and groundwater use has reached the upper limits in most parts of the country. Rainwater harvesting is the answer to mitigate the upcoming challenges linked with rapid economic growth and population burden. Mostly rainwater is pure from extensive contamination, easily treatable which makes it eye-catching option in the water-stressed condition [4, 5]. But health risks are also associated with the consumption of untreated rainwater [6, 7]. Recent study was designed to examine low-cost, indigenously designed water filter integrated coagulation, flocculation, filtration and disinfection water treatment system for harvested rainwater.

2. Methods and material

Lakes of New campus of National University of Sciences and Technology Islamabad, Pakistan were taken as the study site where rainwater harvesting is in practice (figure 1). These lakes 1, 2 and 3 have area 1.5, 2 and 2.25 acre with height 25, 16 – 20 and 25 feet respectively. And they have a storage volume of 0.17, 0.16 and 0.74 GL respectively. Composite water samples were collected from all three lakes of NUST. It was done with seasonal variation before and after the rain (figure 2). All the sampling and preservation methods carried out for the quality analysis in water samples were in the light of Standard Methods for the Examination of Water and Wastewater [8].



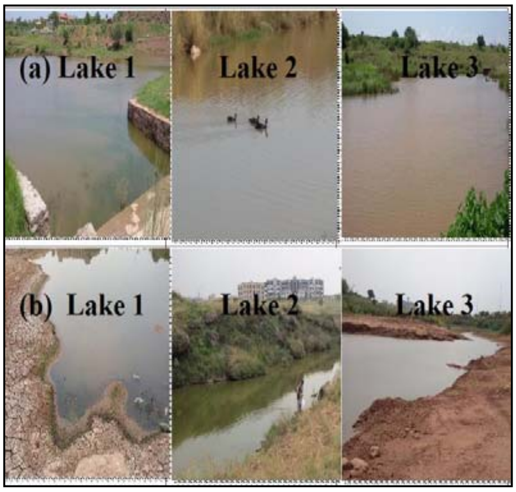


Figure 1. Red circles showing location of NUST Lakes. **Figure 2.** (a) Lakes in wet, (b) Lakes in dry season.

Table.1 shows water quality parameters associated with units and methods of analysis. The temperature of water samples was measured at the sampling points by a mercury thermometer. In the laboratory, all the samples were analyzed for different physicochemical and biological parameters. pH, electrical conductivity (EC), dissolved oxygen (DO) and turbidity was measured by pH, EC, DO and turbidimeters respectively. TDS were determined gravimetrically at 180 °C. EDTA complexometry titration, with indicator Eriochrome Black T for total hardness. Chlorides were determined by the argentometric method. The total alkalinity was measured by titration, with indicators phenolphthalein and methyl orange. Colour, phosphorus and nitrates were measured by using a spectrophotometer. Total bacterial count was done by spread plate count and T. Coliform by membrane filter technique.

2.1. Treatment methodology

Water treatment methodology is shown in (figure.3). Composite water samples were collected from all the three lakes, and coagulation was done by alum stick (1 turn of alum stick/L of water). Coagulation involves adding a chemical, which has a positive charge. This chemical binds (flocculation) with the negative charged dissolved and suspended particle in raw water and neutralize these. Two hours were given for flocculation. Then this water was improved by pouring it into the three-stage SwissPak portable water filter. It is simple, portable, reliable, lightweight and low-cost household water treatment option. This point of use water filter is specifically designed for rural households for treating turbid and biological contaminated water. It is based on modern filtration technologies of large filter plants that are simplified for use by rural household level. It is robust and has a high output flow. It keeps water cool and fresh without using energy. It improves the filtration process and significantly prolongs the life of replaceable filter cartridges. It has provision for coagulating very turbid waters.

Table 1. Water quality parameters associated with abbreviations, units and analytical methods used.

Variables	Abbreviations	Units	Methods
Temperature	Temp	°C	Thermometer
PH	pH	pH unit	pH meter
Turbidity	-	NTU	Nephelometric
Dissolved Oxygen	DO	mg L^{-1}	DO meter
Total dissolved solid	TDS	mg L^{-1}	Gravimetric
Electrical conductivity	EC	µS cm^{-1}	Electrometric
Colour	-	TPC	Spectrometer
Chloride	Cl	mg L^{-1}	Titrimetric
Total Hardness	T.Hard	mg L^{-1}	Titrimetric
Alkalinity	ALKY	mg L^{-1}	Titrimetric
Phosphorus	P	mg L^{-1}	Spectrometer
Nitrates	NO_3	mg L^{-1}	Spectrometer
T. Bacterial Count	TBC	CFU/ml	SPC
T. Coliform	TC	CFU/100ml	MF Technique

Table 2.: Daily range and total monthly rainfall values for Islamabad- Pakistan during the study period (October 2015 to July 2016)

Month/Year	Daily Range (mm)	Total monthly rainfall (mm)
Oct. 2015	0-136	190.2
Nov. 2015	0-10	18.7
Dec. 2015	0-25.8	25.9
Jan. 2016	0-36	54.8
Feb. 2016	0-36	86.9
Mar. 2016	0-72	202.1
Apr. 2016	0-4	12.1
May. 2016	0-17	27.4
Jun. 2016	0-19	47.5
Jul. 2016	0-75.4	368.6

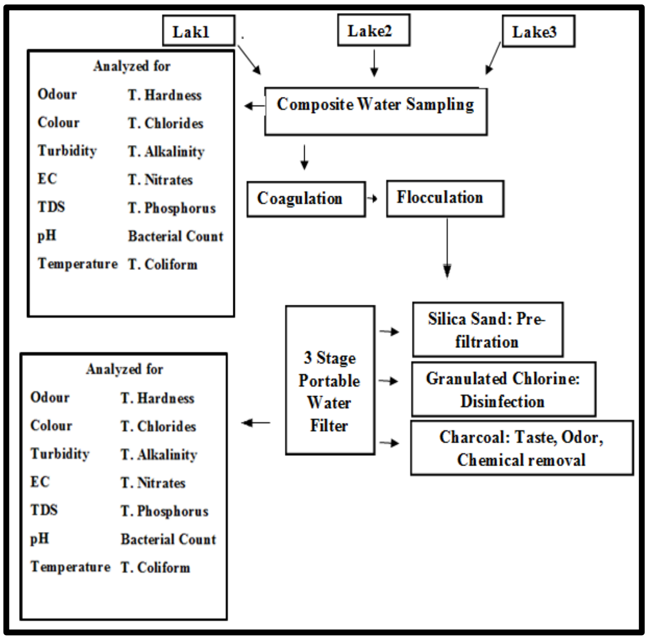


Figure 3. Flow diagram of study

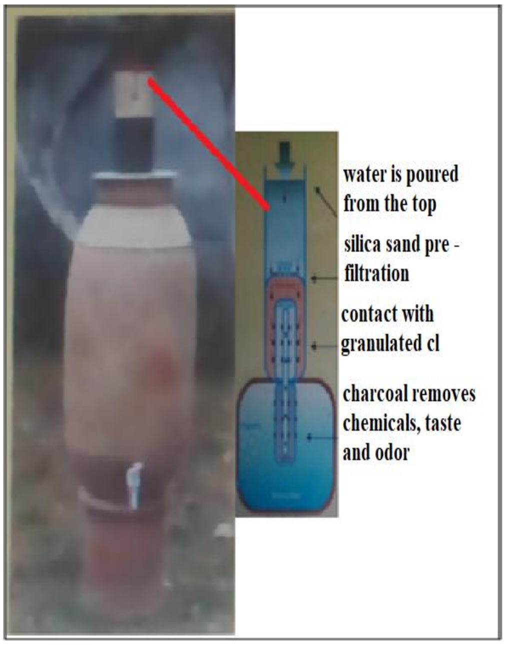


Figure 4. Schematic diagram of three stage portable water filter.

The filter is powered by gravity flow. Its upper part is made of plastic pipe through which water is poured. Its outflow is 3-4 liters per minute. When water is poured from the top, silica sand acts as pre-filtration, and then have contact with the granulated chlorine for disinfection (simple chlorine dosing and dispelling) and carbon block removes the chemical, taste, and odor (figure 4). Its main body is made of mud which can store 30 liters of water. Physicochemical and biological analysis (Total Bacterial Count, Total Coliform, Colour, Odour, Turbidity, DO, TDS, pH, EC, Total Hardness, Chloride, Alkalinity, Phosphorous and Nitrates) of water was done before and after treatment. The daily rainfall range and the total monthly rainfall values for each month of the study are presented in table 2. The total monthly rainfall varied from month to month and ranged from 12.1 mm to 368.6 mm. The values reflected the rainfall pattern of rainy and dry seasons in the year. July 2016 had the highest monthly total rainfall of 368.6 mm followed by March 2016. November 15, April, May and June 16 were typically dry months with very low amounts of rainfall. Water sampling was done Oct 15 to July 16, all the data regarding rainfall, the pattern of rainy and dry seasons in the year is shown in table 2. Monthly rainfall ranged from 12.1 mm to 368.6 mm. Highest monthly rainfall was recorded 368.6 mm in July 2016 followed by March 2016. Low amount of rainfall was recorded in dry months of November 15, April, May and June 16.

3. Results and discussion

Harvested rainwater quality found reliable when compared with drinking water guidelines except for color, turbidity, pH, Bacterial count and T Coliform in dry and wet season table 3 and 4. The analytical result of physicochemical and biological water quality parameters before and after treatment was significantly different for all the three lakes. And the efficiency of the three-stage portable water filter was evaluated based on the 14 water parameters and will be represented in the form of graphs for each parameter. Quality of rainwater samples was already under the guidelines for most of the parameters, so water filter was tested for academic purposes while considering the removal of turbidity, color, bacterial count and T. coliform.

Presence of microorganisms in water is directly linked with its temperature [9]. Bacterial growth rate, the decay of the disinfection residual is affected by water temperature [10]. More than 25 °C temperature can be a problem and change the taste, odor, and color. The temperature of raw water ranged before treatment 21.3 – 21.7°C and 27- 28 °C in wet and dry seasons respectively. After treatment, a decrease in temperature was found as its body is designed with mud texture which keeps water cool and fresh without using energy. It is said that pH should range from 6.5 to 8.5. As it does not cause any harm when intake. pH of lake water samples was from 7.3 – 7.6 and 8.1 – 8.2 in wet and dry seasons respectively. These recorded values indicating that rain from studies area is not acidic in nature [11]. Another study reported similar pH values 7.63 – 8.80 from harvested rainwater [12]. After treatment, a slight decrease in pH was found. It means chemical did play a minor role in changing pH. It was recorded that lake water had EC 227 – 254 and 571 – 1100 µs/cm in a wet and dry season respectively (figure 5a). Similarly, the low range of EC is reported from harvested rain water [12]. And 20 – 30 percent removal was achieved by three-stage portable water filter treatment. The physicochemical quality of harvested rainwater in Spain appeared to be better than the average quality found in the literature review [10].

These lakes were originated from outside and inside of NUST and bring both point and non-point source pollution from surrounding sectors. These sources add turbidity as well. It was also found that the value of turbidity increases every time after precipitation due to the water turbulence and soil erosion. The turbidity of water samples ranged 14-30 and 8.9-25 NTU in a wet and dry season respectively (figure 5b). The used water filter is specifically designed for rural household. The SwissPak treatment proved very efficient for the removal of turbidity 92-94 percent. So, it has provision for coagulating very turbid waters. DO is affected by temperature level in a water body and found to be critical for the survival of aquatic organisms for aerobic respiration. A relation between DO and temperature was found, when the low temperature in lakes DO was more and less DO was recorded in higher temperature. It was found that DO remained the same, as before the treatment 9.2-9.3 and 8.3-8.5 mg/L respectively in wet and dry weather (figure 5c). Electrical conductivity increases an amount of dissolved salts, showing a direct relationship

[13]. Total dissolved solids were 116-161 and 296-563 mg /L in a wet and dry season respectively (figure 5d).

Table 3. Descriptive statistics of rainwater quality of lakes in dry season along with national standards of drinking water quality*

Parameters	Site No	Observations	Minimum	Maximum	Mean	SD	*NSDWQ
Color(TCU)	1	7	75	258	163	105	15
	2	7	64	295	123	90	15
	3	7	43	240	99	74	15
Turbidity(NTU)	1	7	10.2	33.5	24	8	5
	2	7	9.1	35.7	10.4	10	5
	3	7	7.5	33.7	15.8	8.9	5
DO (mg/L)	1	7	7.5	10	8.87	1.02	-
	2	7	7.6	10	8.9	1.02	-
	3	7	7.5	10	8.87	1.04	-
EC (µs/cm)	1	7	392	1233	15.8	8.9	-
	2	7	380	1121	719	313	-
	3	7	306	684	536	133	-
TDS (mg/L)	1	7	170	655	419	198	1000
	2	7	185	570	371	158	1000
	3	7	142	382	274	82	1000
pH	1	7	7.5	8.4	7.89	0.41	6.5-8.5
	2	7	7.3	8.3	7.84	0.42	6.5-8.5
	3	7	7.2	8.7	7.84	0.59	6.5-8.5
Temperature (◦C)	1	7	16.17	30.3	23	5.84	25
	2	7	16.5	30.4	22.99	5.85	25
	3	7	15.8	30.2	22.99	6.1	25
Hardness (mg/L)	1	7	151	337	252	70.2	500
	2	7	145	299	228	59	500
	3	7	133	271	206	56	500
Chlorides (mg/L)	1	7	39	129	90.14	34.26	250
	2	7	33	125	79.43	32.91	250
	3	7	29	115	68	29.31	250
Alkalinity (mg/L)	1	7	109	345	208.71	101.97	1000
	2	7	102	281	189.71	82.45	1000
	3	7	102	192	144.57	42.17	1000
Phosphorus(mg/L)	1	7	4.22	5.9	4.88	0.6	-
	2	7	2.17	5.7	3.92	1.37	-
	3	7	1.32	3.51	2.09	0.7	-
Nitrates (mg/L)	1	7	6.8	28.97	16.22	9.09	50
	2	7	10.2	28.02	21.07	8.3	50
	3	7	3.75	31.5	13.74	9.58	50
Bacterial count/ml	1	7	90000	227000	15551	51074	0
	2	7	89000	286000	154000	70114	0
	3	7	71000	150000	102428	24905	0
T Coliform100ml	1	7	20200	29800	25871	3926	0
	2	7	20000	28100	23557	3463.07	0
	3	7	16900	22600	19328	1949.97	0

The SwissPak treatment removed 19-37 percent TDS. Color of raw water ranged from 34-55 and 43-173 TCU in wet and dry seasons respectively (figure 5e). Mostly this color was due to the algae present in it. It was found that the color of the raw water was low every time after precipitation. And found higher in all the study months, exceeding the permissible limits. Efficient results were found by SwissPak treatment. Color removal was 94 – 97 percent. Total alkalinity of raw water ranged from 89 – 142 and 192 – 290 mg/L in a wet and dry season respectively (figure 5f). By SwissPak treatment, alkalinity removal was 22 – 32 percent in both types of water samples. Total hardness of raw water ranged from 109 – 131 and 269 – 301 mg/L in a wet and dry season respectively (figure. 5g). And another study reported hardness in harvested rainwater, where the highest value was found 74mg/L [12]. By SwissPak treatment 29 – 43 percent hardness removal was achieved. Total chlorides of water ranged from 21 – 27 and 69 – 122 mg/L in a wet and dry season respectively (figure 5h). In a SwissPak treatment 22 – 34 percent removal was achieved. Total nitrates of water ranged from 3.72 – 11.43 and 3.16 – 29.08 mg/L in a wet and dry season respectively (figure 5i). In SwissPak treatments nitrates removal was 67 – 97 percent from both types of samples. Total phosphorus of water ranged from 2.01 – 2.62 and 1.32 – 5.23 mg/L in a wet and dry season respectively (figure 5j). It was found that SwissPak treatment improved the water quality by removing 42 – 64 percent phosphorus. Water used for drinking purpose must follow the standards which state bacteria should be absent from 1mL of water [14]. However, all the tested water samples confirmed the presence of bacteria. Harvested rainwater quality is dependent on the location and the distance from pollution source [15]. If harvested, rainwater is surrounded by vegetation, plantation, trees and other types of vegetation it provides a suitable environment for a variety of avian, mammal and reptiles fauna [16]. As bacterial count and coliform were high is lake water clearly suggesting the source of pollution was of animal residing in or near lakes and human feces. This analysis clearly suggested the need for water disinfection for making it suitable for use.

There are a number of treatment methods according to the type of raw water [17]. The microbiological quality of harvested rainwater was assessed in terms of total bacterial count and T coliform and tested positive. The high bacterial count and total coliforms was attributed to wastewater coming from outside, groundwater seeping into the porous, as soil act as the medium for bacterial contamination [18]. Similar results were found from harvested rainwater in Jordan, one of the water pollution indicator fecal coliform tested positive [19]. One of the studies regarding domestic rainwater harvesting quality revealed that water born disease risk was associated with the use of water [20].

In Greece, rainwater samples were tested in terms of chemical and biological parameters. Water sound chemically safe from any impurity but total coliforms, *Escherichia coli* and enterococci were detected in 80.3%, 40.9% and 28.8% of the rainwater samples showing pollution [12]. Bacterial count ranged 50,000 – 108,000 and 90,000 – 127,000/ml in wet and dry season respectively (figure 5k). The improving efficiency of lakes water by three-stage portable water filter was successfully determined by before and after treatment analysis of water. In dry season water pollution was higher as compared to wet after precipitation. Similar results are recorded from harvested rainwater with seasonal variation [12].

The results of study matched with previous studies [22, 23] in which microbial contamination was linked with season and weather condition. Number of similar studies have been conducted in different countries [11, 22, 24-27]. But filter was found efficient to improve the quality of lakes by 100 percent removal. Similar results were found for T Coliform, it ranged from 13900 – 21000 and 20100 – 24800/ 100ml in wet and dry conditions respectively (figure 5l). Used treatment proved efficient by removing 100 percent coliform and making water clean and suitable for drinking. Similarly, efficient results were found, while using mineral pot filter in removing bacteria and water turbidity [21].

Table 4. Descriptive statistics of rainwater quality of lakes in rainy season along with national standards of drinking water quality (NSDWQ)*

Parameters	Site No	Observations	Minimum	Maximum	Mean	SD	*NSDWQ
Color(TCU)	1	4	35	88	58	36.55	15
	2	4	32	88	52	37.87	15
	3	4	21	35	41	32.58	15
Turbidity(NTU)	1	4	15.7	37.5	24.8	15.48	5
	2	4	19	210.6	82.68	109.72	5
	3	4	14.2	64.8	43.05	35.81	5
DO (mg/L)	1	7	7.5	10	8.87	1.02	-
	2	7	7.6	10	8.9	1.02	-
	3	7	7.5	10	8.87	1.04	-
EC (µs/cm)	1	4	289	582	365	236	-
	2	4	232	524	317	217	-
	3	4	220	372	277	140	-
TDS (mg/L)	1	4	129	288	186.5	116.39	1000
	2	4	128	261	186.25	105.16	1000
	3	4	116	165	134.5	56.49	1000
pH	1	4	7.2	8.7	7.8	2.67	6.5-8.5
	2	4	7.2	8.7	7.9	265	6.5-8.5
	3	4	7.2	8.1	7.7	2.35	6.5-8.5
Temperature(◦C)	1	4	15	33.6	25.4	15.02	25
	2	4	15.02	33.2	25.26	14.89	25
	3	4	15.05	33.2	25.23	14.89	25
Hardness(mg/L)	1	4	115	178	137.5	62.19	500
	2	4	120	138	125.75	39.7	500
	3	4	98	128	112.25	40.51	500
Chlorides(mg/L)	1	4	6.6	105	42.7	53.66	250
	2	4	8.5	95	37.88	48.26	250
	3	4	16.8	42	24.95	17.74	250
Alkalinity (mg/L)	1	4	92	180	120.8	70.3	1000
	2	4	82	159	108.75	62.8	1000
	3	4	48	108	78.75	52.93	1000
Phosphorus(mg/L)	1	4	2.12	11.2	6.5	6.72	-
	2	4	1.7	14.36	7.85	8.58	-
	3	4	2.01	16.84	8.25	9.51	-
Nitrates (mg/L)	1	4	3.16	10.5	6.7	4.91	50
	2	4	5.79	25.87	13.92	12.32	50
	3	4	3.29	29.02	17.07	15.59	50
Bacterial count/ml	1	4	108000	300000	183500	138871	0
	2	4	64000	236000	96375	119957	0
	3	4	50000	155000	93500	73631	0
T Coliform100/ml	1	4	11800	28800	21150	12344	0
	2	4	10200	26700	17200	11203	0
	3	4	5900	21500	13875	1949	0

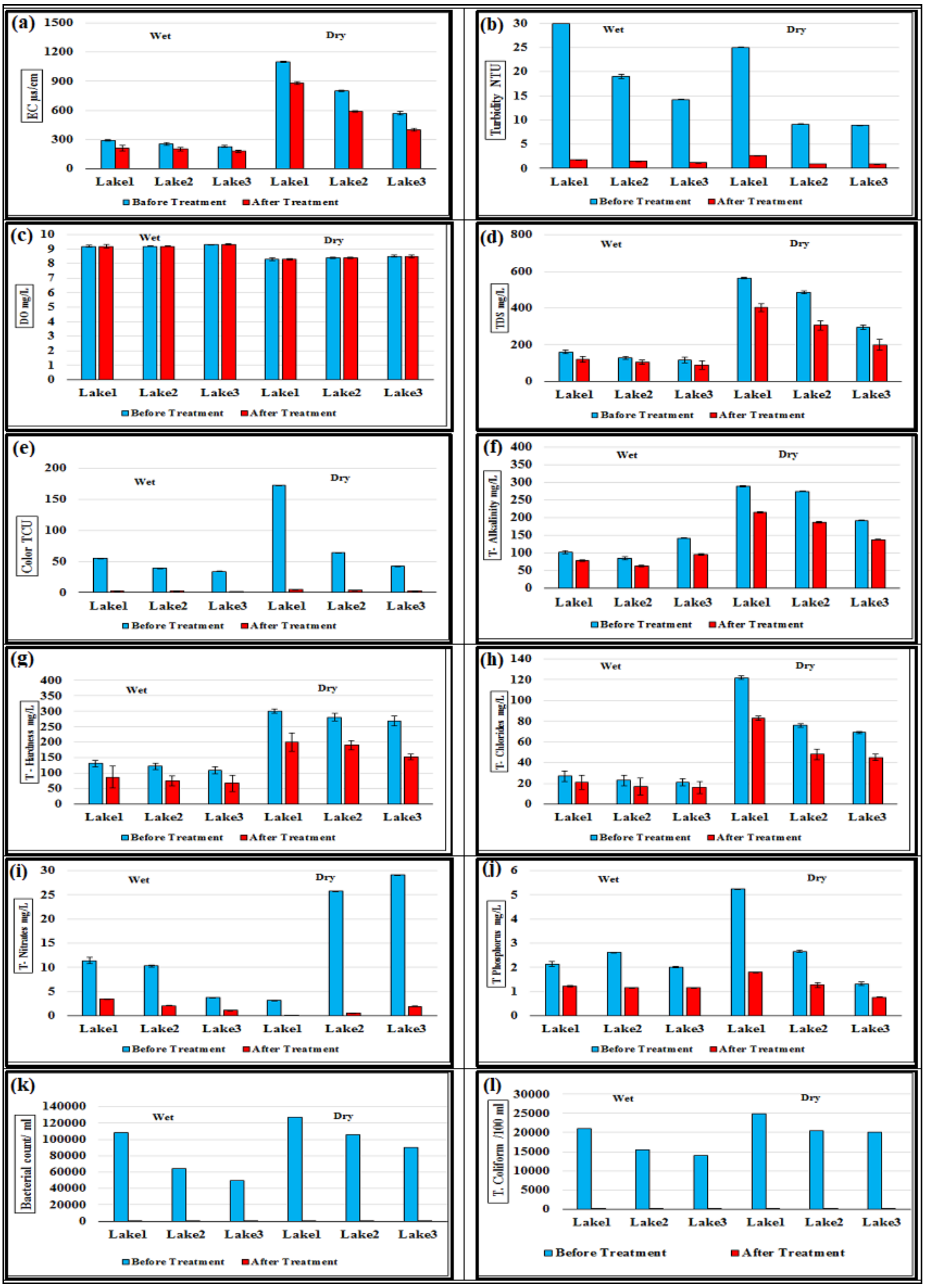


Figure 5. (a-l) SwissPak treatment of harvested rainwater in dry and wet season.

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4. Conclusions

Rainwater harvesting becomes the suitable solution in the absence of fresh water for the livings. Quality of harvested rainwater in Islamabad is satisfied in terms of physicochemical accept microbiological parameters. So this harvested water need some treatment before use. Three stage portable water filter is an efficient option. This water filter is specifically designed for rural households for treating turbid and biological contaminated water. Therefore, rainwater harvesting should be in practice to overcome the water shortage in areas like Islamabad, where water shortage becomes the prominent problem in summers. And three stage portable water filter should be used to overcome the shortage of safe water. In dry areas, rainwater harvesting is one of the options for overcoming the need of water for survival, so three-stage water treatment filter can be successfully applied in any remote, dry lands like Thar, Thal, and Balochistan, and in other arid sites in rainy days. Because it is simple, reliable, lightweight and low-cost household water treatment option. This can also be the best option in flooded condition to provide drinking water.

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