Effects of Selective Meteorological Parameters on Water Quality of Wastewater Treatment Systems

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Abstract

Rapid expansion in urbanization and industrialization is continuously exerting pressure on limited resources of the planet, particularly fresh water resources. Inadequate approach to clean water and hygiene has turned into one of the most persistent issues afflicting public throughout the developing world. Pakistan is now designated as the third most water-stressed country globally because its per capita yearly water availability is 1,017 m^3. In order to cope with the water crises, effective water management strategies should be adopted to reuse wastewater in a sustainable way. Phytoremediation system (PS) and Membrane bioreactors (MBRs) are the important biological and biomechanical systems for the treatment of wastewater. The study was undertaken to compare the performance efficiencies of PS and MBR system in terms of effluent water quality and effects of meteorological parameters (Wind Speed, Global Horizontal Irradiance and Air Pressure) on water quality. Dissolved oxygen and Chemical Oxygen Demand COD of PS and MBR system exhibited the negative correlation with Global horizontal irradiance while COD, pH and turbidity of both systems showed the positive correlation with Air pressure. Enzymatic and microbial degradation pathway studies of the bacterial community can be examined in detail further for better performance efficiency of the systems.

Introduction

Water is considered as an invaluable finite resource, which should be properly managed and used in a most sustainable way. Reuse of wastewater offers additional opportunities for enhancing the recycling process. Rising and increasing demand of water for agriculture, industrial and other sectors is increasing the competition for the allocation of the fresh water resources which are already too limited (Grant et al., 2012).

A vast quantity of wastewater is being produced by the human beings and that wastewater is creating sustainability challenges and ecosystem health is being severely affected by it. There should be the proper management of Wastewater and maximum efforts should be put in to reutilize that water in an effectual and sustainable way (Levine & Asano, 2004). Source control is the first and foremost way to avoid pollution and reuse that for the agricultural purposes especially in the arid regions which are being severely affected by the climate change (Muga & Mihelcic, 2008).

Over the last two decades, sustainable wastewater management is the issue that was discussed at various conferences. First international conference of "Ecological engineering of wastewater treatment" was held in 1991 at Sweden (Etnier & Guterstam, 1991). Sustainable sanitation alliance (SSA, 2007) was formed by the United Nations to promote the sustainable wastewater system.

Sustainable development goals set by the United Nations emphasized on improving water quality by reducing pollution, eliminating, dumping and minimizing the release of hazardous chemicals and materials and to achieve sustainable water for all. Reuse of wastewater by the use of efficient wastewater treatment technologies will greatly help to achieve these goals (Griggs, 2007). Water pollution has resulted in many problems all over the world which include drinking water supplies, sanitation supplies and survival of species (Shah et al., 2014).

Phytoremediation makes use of natural plant systems and can be used to clean up agricultural soils, industrial sites, and water that contain toxic pollutants or to recover food chain security (Pandey et al.,

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2015). It is environment-friendly technology that target removal, degradation or control of harmful constituents (Witters et al., 2013).

A study conducted in China on parallel horizontal subsurface flow planted with three plant species (Phragmites australis, Typha latifolia and Scirpus planiculmis). The plant removal efficiencies under saline condition were assessed. The major parameters measured in the effluent were chemical oxygen demand (COD), biological oxygen demand (BOD), total nitrogen (TN), and total phosphorus (TP). The increasing order of metal accumulations in CWs was K>Ca>Na>Mg>Zn>Cu. More than 80 % of metals were concentrated in the root part of Pistia australis. Typha latifolia had the best performance of pollutant removal, with an average removal of 49.96 and 39.45 % for COD and TN respectively. The effluent water quality is in accordance with the water standards set by China (Xu et al., 2017).

High strength wastewaters can be successfully treated by MBR which have typically very high concentrations of COD and BOD. By monitoring and maintaining parameters such as HRT, SRT, TMP, MLSS and Flux to an optimum condition, the finest performance of MBR can be achieved and also membrane fouling can be controlled. For wastewater with very high loading, it has to be treated before entering MBR to avoid membrane fouling. Some physiological characteristics (EPS, SMP, organic and inorganic matters and MLSS concentration) are difficult to control and result in membrane fouling. However, some methods are there to reduce the fouling problems and enhance the performance of MBR to yield high quality effluents (Mutamim et al., 2013).

A study was conducted by Shin and his coworkers to check the performance efficiency of pilot scale MBR system that was operated continuously for 485 days, treated domestic wastewater with temperature maintained between 8 and 30° C and hydraulic retention time was maintained between 4.6 to 8 hours. During the winter season, average removal efficiency of COD and BOD was 81 and 85% respectively at 8-15°C. However, in summers under more acclimatized conditions the removal efficiency of COD and BOD was 94 and 98 % respectively and the average effluent COD value was not higher than 24 mg/l and BOD value not higher than 9 mg/l. Operational energy requirements were about 23 kWh/m^3 (Shin et al., 2014).

Effects of meteorological parameters on water quality parameters were acknowledged in very few studies and substantial correlations were recognized. Zhang and his colleagues explored the correlation among several physicochemical factors (total dissolved solids and suspended solids) with climatic parameters in a reservoir in China. A regression method was used to study the correlations among eleven physicochemical parameters and three meteorological factors (wind speed, rain fall and solar radiation). They conclusion of the study was that three climatic parameters were positively associated with suspended solids. Moreover, substantial correlations among many water quality elements such as BOD, COD, TDS, total phosphorus, total phosphorus and EC and climatic factors were revealed (Zhang et al., 2017).

A study was conducted in Poland to check the impacts of weather conditions on the physicochemical composition of surface water of kettle ponds and found notable impacts of weather parameters on the ionic concentration of water of two hydrologically and geographically distinct regions. The variation was attributed to the vertical exchange of air due to influence of various meteorological factors (Major and Cieśliński, 2017).

The present study was conducted to at NUST H-12 sector Islamabad to identify the impacts of meteorological factors (Global Horizontal Irradiance, Wind Speed, and Air pressure) on the water quality of Membrane bioreactors and Phytoremediation system over a six month period.

Methodology

Study Site

The wastewater treatment systems studied were the urban facilities used in NUST, H-12 sector Islamabad for the treatment of wastewater from residential apartments, academic blocks, schools, institutes and hostels. Wetland project was completed by the funding of UNESCO and is being maintained by NUST Research and development funds while funding agency for MBR plant was NUST

R&D funds and Samsung Corporation Korea. The total population of NUST is around 6000 and it covers an area of 1000 acres. The total volume of sewage generated by NUST is about 200,000 US gallons per day and the flow into the treatment facility is maintained at 75000 US gallons per day at the inlet of PS and about 7925 US gallons of wastewater is directed towards the inlet of MBR system. Aerial view of treatment systems at NUST is represented in Figure 1.

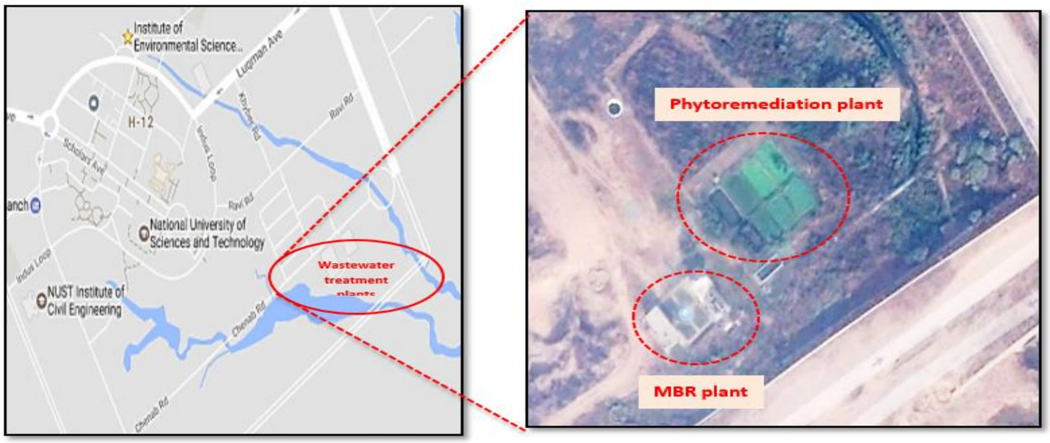


Figure 1: Aerial view of Phytoremediation and MBR plant

Sampling

Sampling was done weekly from August to October 2016 from inlet and outlets of each selected systems. All methods for the collection, transport and storage of samples were carried out under the standard method for the examination of water and wastewater (APHA, 2012).

Water quality was assessed by measuring the Physicochemical and Biological parameters. Physicochemical analysis included pH, Temperature, Electrical conductivity, Turbidity, Total suspended solids, Total dissolved solids, Chemical oxygen demand and Dissolved oxygen. Biological parameters include the Fecal coliform and Total coliform tests. Table 1 characterizes methods and instruments used for the analysis of Physicochemical parameters

Table 1: Methods and instruments for physicochemical parameters

Parameters	Equipment used	Method of analysis
pH	pH meter	Potentiometric method
Temp(˚C)	HACH session 1	Laboratory method
EC(μS/cm)	Conductivity meter	Potentiometric method
Total dissolved solids (mg/L)	Conductivity meter	Potentiometric method
Total suspended solids (mg/L)	Analytical balance	Gravimetric dried method
Chemical oxygen demand (mg/L)	Through titration	Closed reflux method
Dissolved oxygen	DO meter	Potentiometric method

Biological parameters were also analyzed in the study and those were Fecal coliforms and Total Coliform. Membrane filtration technique was used for the analysis and the media used were Eosin Methylene Blue Agar media and the measuring unit was CFU/100 mL.

Acquisition of Meteorological Data

Daily mean data of Air Pressure and Global Horizontal Irradiance were acquired from August 2016 to January 2017 from US-Pak Center for Advanced Studies in Energy (US-CASE), NUST.

Statistical Analysis

Results were analyzed by using graphical tools in Microsoft Excel 2016. The correlation was applied by using Microsoft Excel data analysis tool to test the significant and non-significant effects of climatic parameters on physicochemical and biological parameters.

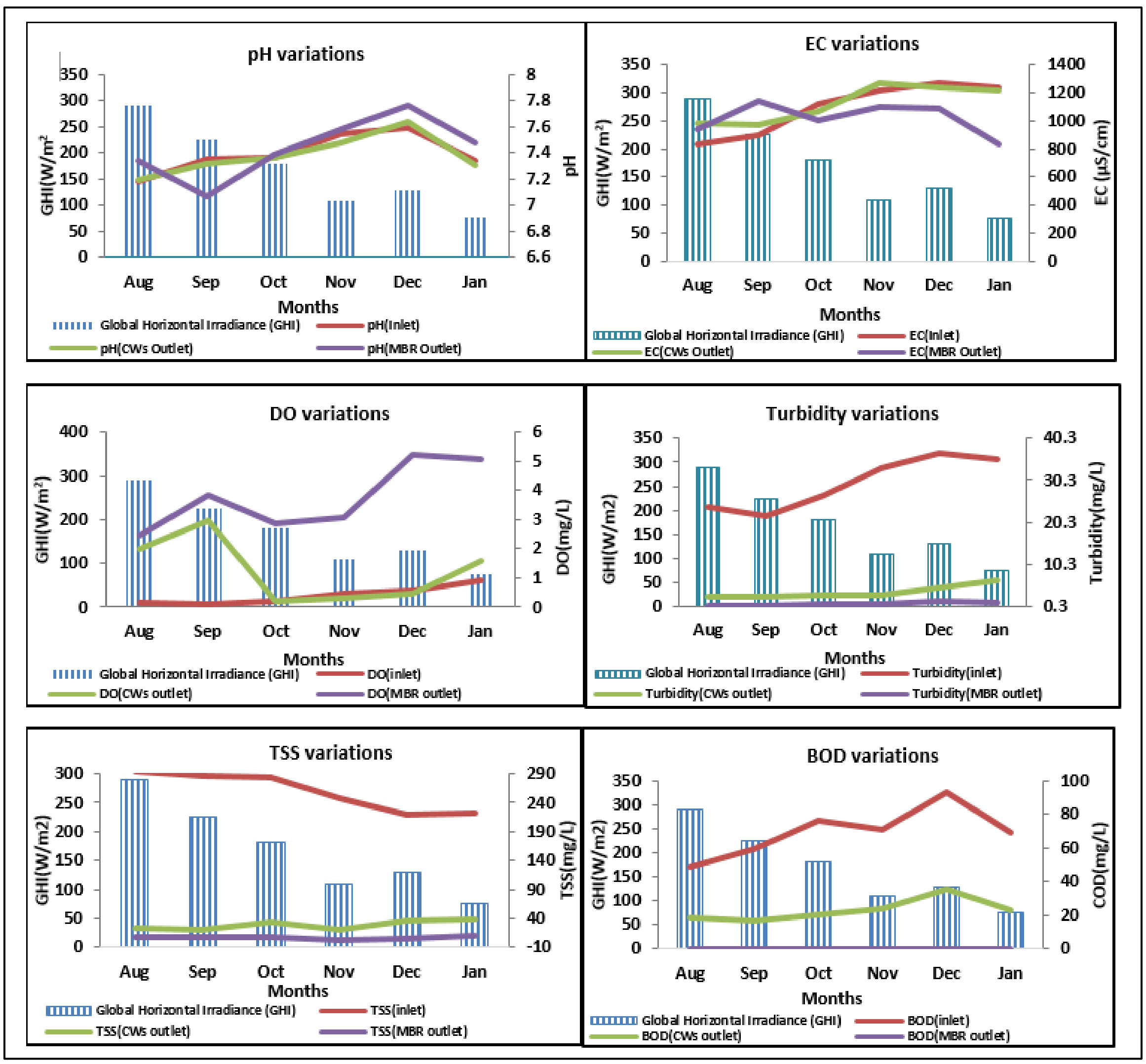
Results and Discussion

In this study, performance efficiency of Phytoremediation system and Membrane bioreactor system was assessed in terms of pH, EC, Turbidity, TSS, COD, BOD and Total coliform (TC). Impact of meteorological parameters (Global Horizontal Irradiance, Wind Speed and Air Pressure) on the concentrations of pollutants at inlet and outlets of systems were also analyzed. Bacterial community dynamics in both systems was followed through PCR and 16S rRNA sequencing.

Monthly Variations in Water Quality Parameters with Global Horizontal Irradiance (W/m^2)

Global horizontal irradiance is the total amount of direct normal irradiation (DNI) and diffused horizontal irradiance (DIF). It is the sum of shortwave radiation received by horizontal surface of the earth (Lave et al., 2015).

A negative correlation was noted between GHI and pH of influents and effluents of both systems (r = -0.37 for inlet, r = -0.36 for PS outlet and r = -0.44 for MBR outlet). Increase in the GHI resulted in better photosynthetic activity by plants which in turn resulted in more uptake of nutrients and lesser release of decaying organic matter, hence increase in GHI resulted in a decrease in the value of pH for the phytoremediation system (Herrera, 2015). The same trend was observed for MBR system as depicted in Figure 2.



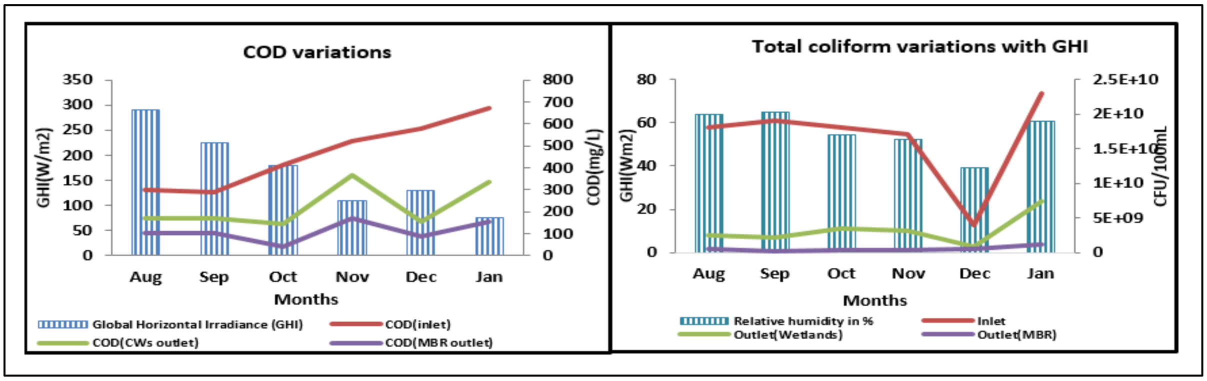


Figure 2: Variations in Water Quality Parameters with Global Horizontal Irradiance (GHI).

Significant negative correlation of EC and GHI was noted for inlet and outlet samples of phytoremediation system (r = -0.99 for inlet and r = -0.90 for outlet) while slightly positive correlation of outlet of PS and DO and was observed (r = 0.59) because at lower radiations, less growth of plants hence lesser release of oxygen by the phytoremediation system overall. In case of MBR system a slight influence of GHI on EC was noted (r = -0.16) however slightly negative correlation was observed between GHI and DO (r = -0.64) as represented in Figure 2

Significant negative correlation was observed between GHI and turbidity of influent and effluent samples of both systems (r = -0.87 for inlet, r = -0.75 for PS outlet and r = -0.67 for MBR outlet) while TSS of inlets showed significant positive correlation with GHI (r = -0.87). Outlets of both systems have showed non-significant correlation with both turbidity and TSS (Figure 2). Turbidity and TSS shows the inverse relation in the system because TSS consists of minerals, clay, organic and inorganic matter which affect the transparency of water (Yang et al., 2015). While turbidity of water depends upon other factors like suspended particles, the morphology of surface area which has an effect on the absorption and reflection of light (Mustapha et al., 2013). Similar negative correlation inclinations were observed in water systems (Lagomarsino et al., 2015).

Increase in GHI resulted in a decrease in the concentrations of COD and BOD of the inlet (r = -0.93 for COD and r = -0.6 for BOD). However, no significant impact was observed in the outlet concentrations of COD and BOD of both treatment systems (Figure 2).

The strong positive correlation was observed between GHI and total coliform concentration in the inlet (r = 0.92). However, concerning outlet of phytoremediation and MBR system non-significant impact was observed (r = 0.23 for PS outlet and r = 0.12 for MBR outlet).

Monthly Variations in Water Quality Parameters with Air Pressure (hPa)

Barometric pressure affects the amount of gas that can dissolve in water. More gas, such as oxygen, can dissolve in water under higher barometric pressure than under lower barometric pressure. For instance, more oxygen is dissolved in water at sea level than at high altitudes as described by Henry's law (Sander, 2015).

Significant positive correlation was observed between air pressure and inlet-outlet value of pH of both systems (r = 0.73 for inlet, r = 0.62 for CWs outlet and r = 0.72 for MBR outlet). However, at highest air pressure in January, pH value got lower as depicted in Figure 3.

Significant positive correlation of EC with air pressure was observed at inlet and outlet of phytoremediation system (r = 0.95 for inlet & r = 0.93 for PS outlet) as shown in figure 4.22(b). Slightly negative correlation of EC with air pressure was noted at outlet of MBR system (r = -0.2). Strong positive correlation was observed between air pressure and DO at inlet and outlet of MBR system (r = 0.90 for inlet & r = 0.72 for MBR outlet). However, negative correlation was noted between air pressure and DO of PS outlet (r = -0.6). This is represented in Figure 3.

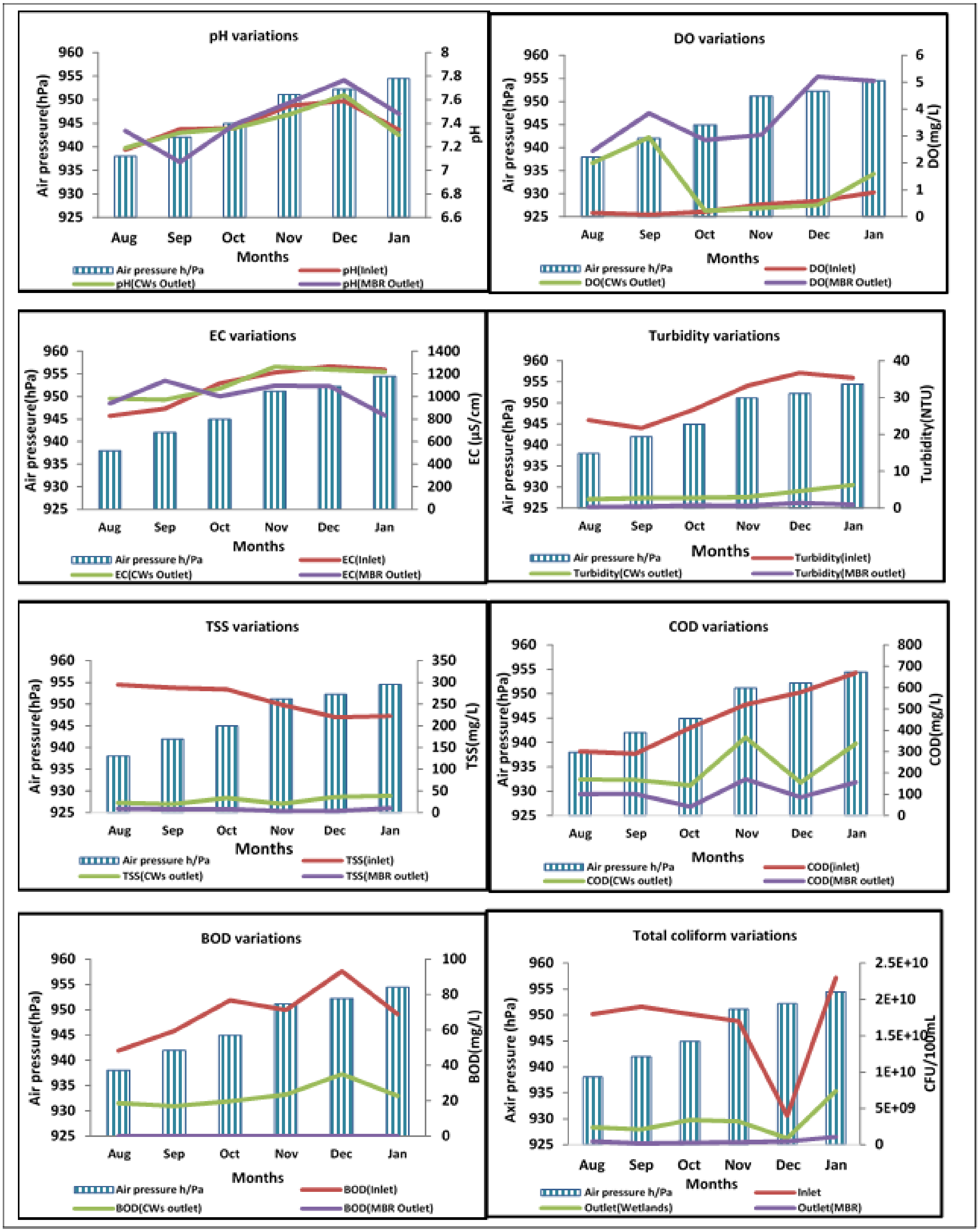


Figure 3: Variations in Water Quality Parameters with Air Pressure.

Significant positive correlation was observed between air pressure and turbidity of inlet and outlet of both treatment systems (r = 0.93 for inlet, r = 0.80 for PS outlet and r = 0.77 for MBR outlet) while significant negative correlation was observed between TSS concentrations of inlet and air pressure (r = -0.94) while in case of correlation with outlets; positive correlation was identified between air pressure and PS outlet (r = 0.66) and non-significant correlation was observed between air pressure and MBR outlet (r = -0.21) as represented in Figure 3. Processes involved in improving water quality in MBR system are filtration and clarification through microfiltration or loose ultrafiltration membranes which is capable of removing suspended solids and microorganisms at higher mixed liquor suspended solids concentrations (Xagoraraki et al., 2014; Chae et al., 2007). Furthermore, the removal of wastewater treatment parameters such as chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), fecal indicator bacteria and pathogens, heavy metals and nutrients by constructed wetlands (CWs) are documented by various researchers (Tanaka et al., 2013; Dan et al., 2011).

Positive correlation of COD and BOD with air pressure was noted. Increase in air pressure resulted in an increase in the values of COD and BOD of inlet and outlet of MBR and Phytoremediation system. Strong positive correlation was observed between air pressure and COD-BOD of inlet (r = 0.96 for COD & r = 0.72 for BOD). COD-BOD concentrations in the outlets of phytoremediation system had slightly positive correlation with air pressure (r = 0.62 for COD & r = 0.67 for BOD). However, not much influence of air pressure on COD-BOD value of outlet of MBR system was observed (r = 0.3 for COD & r = 0 for BOD) as depicted in Figure 3.

Slightly negative correlation of air pressure and total coliform concentration was noted for inlet and phytoremediation system (r = -0.49 for inlet & r = -0.55 for PS outlet) while regarding MBR system no correlation was noted between air pressure and total coliform concentrations as depicted in Figure 3.

Monthly Variations in Water Quality Parameters with Wind Speed (m/s)

Wind is the movement of air from higher pressure areas to lower pressure depending upon the fluctuations in air temperature (Wanninkhof, 2014). Lower wind speed increases the residence time of pollutants and in turn result in lower Dissolved oxygen concentration, hence affect the photosynthesis process. A Study conducted by Wood and Chang in 2006 reported another consequence of wind speed, as lower wind speed results in lower water pollutant dispersal and vice versa which overall effect pollutant removal efficiency of systems.

Increase in wind speed correspondingly increases the values of pH of inlet and outlets of the operating systems for the whole six month periods. Significant positive correlation of pH and wind speed was noted (r = 0.21 for inlet, r = 0.47 for PS outlet & r = 0.39 for MBR outlet) as represented in Figure 4.

Slightly positive correlation was observed between wind speed and electrical conductivity of inlet (r = 0.009) and outlets (r = 0.0053 for PS outlet & r = 0.157 for MBR outlet) of both treatment systems (Figure 4). DO concentrations in the inlet had a slight positive correlation with wind speed (r = 0.042) while the outlet of phytoremediation system had a negative correlation with the wind speed (r = -0.32). The outlet of MBR system had non-significant relation with wind speed as depicted in figure 3. This correlates with the study conducted by Kann and Welch in 2005 where lower wind speed affected the water column stability and positive correlation between wind speed and dissolved oxygen was observed. Lower wind speed in July had resulted in lower DO concentration in the system overall in July-August 2005.

The turbidity of inlet had a slightly positive correlation with wind speed (r = 0.67) while turbidity in outlet of both systems had non-significant correlation with wind speed (Figure 4). Regarding total suspended solids concentrations, positive correlation was noted between TSS of inlet and wind speed (r = 0.43) while non-significant influence of wind speed on TSS concentrations of outlets was observed. This is perfectly in line with the study conducted by Zhang and his coworkers in 2017, where suspended solids (SS) were significantly positively correlated with wind speed and higher wind speed in spring correspondingly increased SS concentrations. Increase in the SS concentration may be attributed to the sediment resuspension as reported in the previous studies (Wu et al., 2014). The wind would induce sediment resuspension, thus leading to the increase in SS concentration. However, despite maximum wind speed in December, not much fluctuations in TSS concentrations were observed (Figure 4)

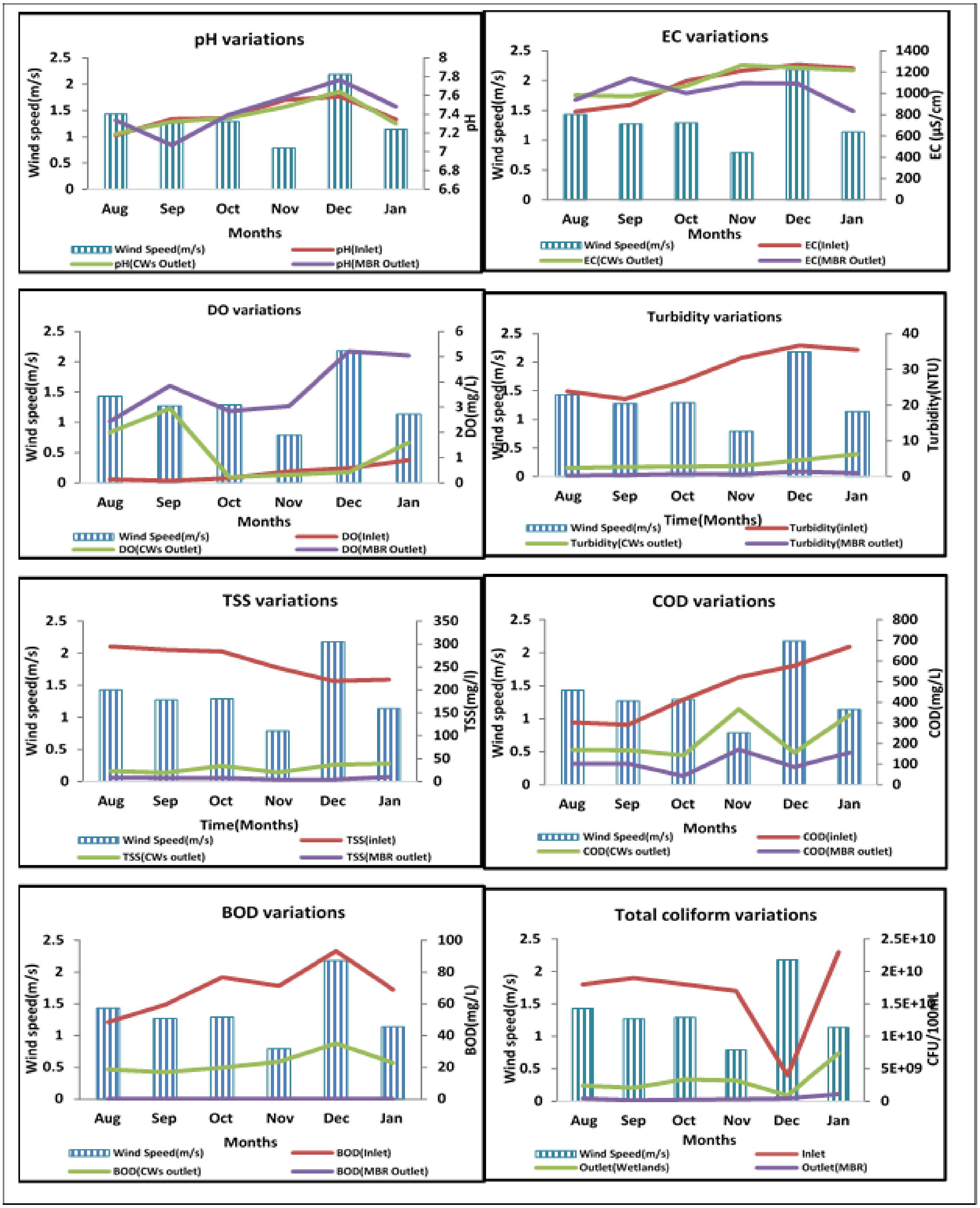


Figure 4: Variations in Water Quality Parameters with Wind Speed.

Increase in wind speed resulted in significant negative fluctuations in COD and BOD concentrations of outlets (r = -0.67 for Phytoremediation system outlet and r = -0.54 for MBR outlet) of both treatment systems under study and non-significant impact of RH (%) on inlet concentration was observed as depicted in Figure 4. However, no impact of wind speed on BOD concentrations of outlets of MBR system was noted.

With the decrease in wind speed, a decrease in coliform concentration in the inlet and outlet of phytoremediation system was observed up to the month of November however in December, maximum wind speed resulted in lowest coliform concentrations in inlet and outlet of phytoremediation system. Concerning MBR system, not much impact of wind speed on total coliform concentration was noted (Figure 4).

Table 2: A wastewater discharge limit for water quality parameters set by WHO.

Climatic parameters	**Water quality parameters (Phytoremediation system)**			**Water quality parameters (MBR system)**	
Global Horizontal Irradiance(GHI)	Turbidity, EC, DO, COD and TSS	pH, BOD, Total coliform		pH, Turbidity, DO, COD	EC, BOD, TSS and Total coliform
Wind speed	pH, Turbidity, EC, DO, TSS, Total coliform	COD	BOD	Turbidity	pH, EC, DO, TSS, Total coliform, COD and BOD
Air pressure	pH, Turbidity, EC COD, BOD, TSS	DO, Total coliform		pH, DO, Turbidity, COD	BOD, Turbidity, EC, TSS

Negative correlation Positive correlation Non-significant correlation

WHO has set a wastewater discharge limit for water quality parameters. The discharge limit for pH is 6-9 and pH of treated water of both systems was found to be fit for agricultural purposes. Concerning Electrical conductivity, the discharge limit set by WHO is 3500 mg/l and it was within the permissible limits in case of both systems. Turbidity level in treated water from both systems is found within the permissible limits set by WHO (5 NTU) to be fit for irrigation purposes. Discharge limit set for TSS is 50 mg/l and throughout the study period, TSS was within the permissible limits for both systems.

Discharge limit set for COD and BOD is 150 and 30 mg/l respectively. In case of MBR system, BOD was within the permissible limit throughout the study period. However, BOD of Phytoremediation system was found to be slightly higher. COD too was within the permissible limits for MBR system while PS have slightly higher COD in the month of November.

Discharge limit for Coliform is 400/100 ml and water discharge from MBR system was within the permissible limits throughout the research period while in case of PS, results showed slightly higher coliform level.

Conclusions and Recommendations

The present study indicated higher proficiency of MBR system as compared to phytoremediation system. Meteorological parameters have proved to have firm positive and negative correlation with water quality factors. Global Horizontal irradiance was negatively correlated with water quality ($r > -0.7$). While wind speed and air pressure are positively correlated with water quality factors ($r > 0.7$).

In conclusions, meteorological parameters do have the effect on the pollutant removal efficiency of both wastewater treatment systems. Likewise, it is suggested that the industrial units would require the consideration of meteorological factors as part of every project proposal relevant to this specific technology and comprehensive development plan.

This research is a useful contribution towards coping with the emerging water stress issues in Pakistan. Reutilization of wastewater for agricultural purposes would be helpful in diverting the fresh water supplies for drinking water utilities. Further, enzymatic and microbial degradation pathway studies of bacterial community may be examined in detail further for better performance efficiency of the systems. Analysis of heavy metal uptake by macrophytes of Phytoremediation system may be carried out by using Atomic absorption spectrophotometer.

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