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Microbiological and Physico-Chemical Quality of Groundwater at a Resettlement Colony, Madanpur Khadar in Delhi, India

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ABSTRACT

Groundwater has been the main source of fresh water supply to a large number of Jhuggi-Jhopri clusters and resettlement colonies in Delhi along the Yamuna River Flood Plains generally referred to as Khadar. One such resettlement colony Madanpur Khadar in South Delhi established in 2001 lacks the most basic amenities like safe drinking water, sanitation and sewage disposal. There are many common complaints of gastroenteritis, diarrhoea, jaundice, skin irritation, eczema and unpalatable quality of water. Hence, the present study was envisaged to assess the microbial and chemical quality of groundwater of the area by analysing it for the presence of coliforms (the indicators of water-borne pathogens), Total Dissolved Solids (TDS), Conductivity, Hardness, Chemical Oxygen Demand (COD), Manganese and Iron, the most probable factors accountable for the above mentioned problems. About one fourth of the water samples contained a high number of coliforms suggesting contamination of aquifers with faecal matter, hence making it unfit for consumption. Similarly, high concentrations of manganese and iron, beyond permissible limits as defined by the Bureau of Indian Standards and World Health Organization, were found in 90% and 33% of water samples, respectively. All the water samples were classified as very hard on the basis of their $CaCO_3$ content, while 52% samples failed the desirable limits of TDS. High content of organic matter, iron, manganese and coliforms of water samples indicates the seepage of sewage from the overflowing drains present in the proximity of the hand pumps and hence are responsible for the unsafe and unpalatable quality of water. The water samples were found to be unfit for consumption without passing through any of the treatment processes of disinfection, oxidation and filtration.

Keywords: Groundwater, Metal related water discoloration, Microbial quality, Physico-chemical parameters, Yamuna Flood Plains, Madanpur Khadar.

INTRODUCTION

Delhi designated as National Capital Territory (NCT) of Delhi in 1991 is spread in a total area of 1483 square kilometres with a population of 16.753 million as per the 2011 Census of India (1). Considering the increase of population at the rate of 1.92 % per annum in Delhi, it is expected to reach 18.069 million in 2015 and 20.264 million in 2021 (2). The current potable water requirement for Delhi's population in 2015, based on 60 Gallons Per Capita Per Day (GPCPD) as per the norms of Central Public Health and Environmental Engineering Organization, Ministry of Urban Development, Government of India would be 1084 Gallons Per Day (GPD). However, the total water treatment capacity and supply in the city since 2012 has been stagnant at 848 GPD including all resources i.e. rivers, canals and under groundwater (2). The fresh water (both treated and untreated) is made available to 81.3 % households by piped water supply system, whereas water to 5.3 and 8.4 % of households is provided by Hand pumps and Tube wells, respectively (1, Figure-I).

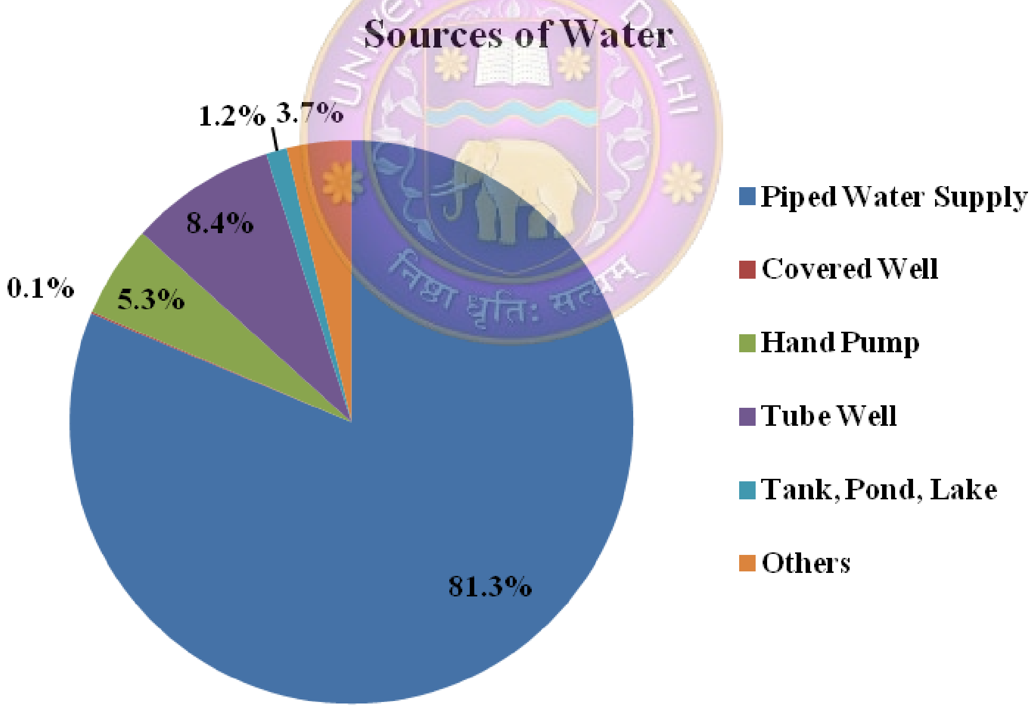

Figure-I. Distribution of households supplied with different sources of water in Delhi. Census of India 2011 (1).

This vast difference in the supply and demand of fresh water has resulted in the unregulated overexploitation of groundwater aquifers affecting the groundwater level and the aquifer's recharge capacity.

Groundwater has been found to be contaminated with a large number of microbial species including viruses (Table-I) which are responsible for gastrointestinal diseases (3).

Table-I: Water-Borne bacterial, viral, protozoan and helminths diseases and their causative agents (3), (5-6).

Agent	Disease
Bacteria	
Shigella spp.	
S. dysenteriae	Bacterial
S. sonnei	Dysentery
S. flexneri	
Salmonella spp.	
S. typhimurium	
S. typhi	
S. paratyphi	Salmonellosis
Escherichia coli	Typhoid fever
(O157:H7)	Paratyphoid fever
Campylobacter	Diarrhoea
jejuni	
Vibrio cholerae	Gastroenteritis
(O139)	Cholera
Yersinia	
enterocolitica	Yersiniosis
Mycobacterium	
spp.	Infections in skin,
M. kansasi	lymph nodes and
M. avium	GI tract.
M. fortuitum	
Aeromonas spp.	Gastroenteritis
A. sobria	
A. hydrophila	
A. caviae	
Legionella	Legionellosis
pneumophila	
Pseudomonas	Blood Infections
aeroginosa	
Helicobacter pylori	Gastric Ulcers
Clostridium	Botulism
botulinum	
Leptospira	Leptospirosis

Agent	Disease
Virus	
Hepatitis A	
Norwalk-like agent	Hepatitis/Jaundice
Virus-like particles	Gastroenteritis
<27 nm	Gastroenteritis
Rotavirus	
Poliovirus	Gastroenteritis
Calcivirus	Poliomyelitis
Hepatitis E	Gastroenteritis
Adenovirus 3	Jaundice
	Pharyngo-
Coronavirus	conjunctival fever
	SARS
Protozoans	
Giardia lamblia	Giardiasis
Entamoeba	Amoebiasis
histolytica	
Cryptosporidium	Cryptosporidiasis
Microsporidium	Microsporidiosis
Balantidium coli	Balantidiasis
Helminthes	
Schistosoma	Schistosomiasis
Fasciola hepatica	Fascioliasis
Cercariae	Cercarial dermatitis
Dracunculus	Dracunculiasis
medinensis	
Ascaris	Ascariasis
lumbricoides	Enterobiasis
Enterobius	
vermicularis	Echinococcosis
Echinococcus	
granulosus	

Cholera, bacterial dysentery, amoebic dysentery, typhoid, diarrhoea and jaundice are some of the examples of water borne diseases. Diarrheal diseases alone are responsible for more than 1.4 million deaths every year globally, out of which, 88% is attributable to poor and unsafe water supply, sanitation and hygiene mainly in the developing countries (4). A number of studies conducted in various parts of India including Delhi have shown the presence of coliforms and faecal coliforms in groundwater samples indicating the contamination of aquifer by faecal matter or sewage (7-15).

The hydrogeochemical processes influence the chemical quality of water in aquifers and are responsible for variations in water characteristics due to rock water interactions and anthropogenic interferences (16). These variations are very much apparent in the four different physiographical regions of Delhi: Newer Alluvium-Yamuna Flood Plains generally referred as Khadar; Older Alluvium – East and West sides of the ridge; Older Alluvium – Chattarpur alluvial basin and Quartzite rock ridge - Extension of Aravali hills from southern part of NCT to Western Banks of Yamuna (16-17). Yamuna Active Flood plain aquifer covers about 35 km along the river Yamuna. The depth of water level in the Newer Alluvium is shallow at 35-70 ft which reduces to 20 ft only during monsoon season and flooding of river Yamuna. The physico-chemical quality of groundwater in flood plains in general reflects the river water quality being classified as fresh water because of river bed recharge (16), (18).

Yamuna Flood Plains on both the east and west sides have been occupied by either unauthorised settlements like Jhuggi-Jhopri (JJ) clusters (21.9 %) or a few authorized resettlement colonies (19). Madanpur Khadar is one such resettlement colony where the basic amenities like safe drinking water and sanitation facilities are lacking (20). The main sources of fresh water in this settlement are the privately installed hand pumps (76.2%), packaged drinking water (13.8%) and MCD water tankers (10%) (20).The water from hand pumps contained high particulate matter and foul odour and turned yellow on storage as reported by residents during a survey conducted by Saini in 2012 (20) and in our study. Some common complaints of ailments like frequent gastric troubles (Gastroenteritis), diarrhoea, jaundice, typhoid, etc. in both children and adults have also been reported from the households who used hand pump water for drinking (22). In view of the above problems of unpalatable water and prevalence of water borne diseases, it becomes pertinent to identify the reasons and sources responsible for such a poor groundwater quality. Therefore, this study was enunciated to determine the microbiological and physico-chemical properties of groundwater used by inhabitants of Madanpur Khadar, a resettlement colony established in Yamuna Flood Plains.

METHODOLOGY

Study Site:

Madanpur Khadar, a resettlement colony, was established in 2001 where people from slums of Nehru Place, Alaknanda, Raj Nagar, etc were relocated by Government of Delhi by allotting houses of 12 to 25 square meter area depending on their length of stay in the slums. This colony is located on the west bank of river Yamuna in South Delhi (Figure-II). It is surrounded by river Yamuna on the East, a NTPC water treatment plant on the South and Agra Canal on the North and the West.

Figure-II. Map of Delhi showing Madanpur Khadar, the site of Groundwater sample collection. Source: Google Maps

Sample Collection:

Hand pumps installed in front of houses were randomly selected from Block A3, A2, A1 and B1 covering almost all the area. Twenty one water samples were collected in two - one litre autoclaved screw capped glass bottles under aseptic conditions after continuously running the hand pumps for about 10 minutes to dispose-off the stored water in the bore well pipes. Water samples in one of the bottles were preserved by adding a few drops of HNO_3. Two samples from water treatment plants (reverse osmosis treatment) maintained by private suppliers were also collected. Samples were stored on ice in ice boxes and transported to the laboratory within 3-4 hours for further analysis.

Microbiological Analysis:

All samples were analysed for the presence of total coliforms and faecal coliforms following the APHA's Standard Methods for the Examination of Water and Wastewater, 2012 (23). Total coliforms were estimated by Multiple Tube Fermentation test (MPN/100ml) and Membrane Filter technique. In the Multiple Tube Fermentation test, water samples in volumes of 10 ml, 1 ml and 0.1 ml were inoculated into tubes containing Lauryl Tryptose Broth (Hi-Media labs) with 0.02 % Bromocresol Purple and inverted Durham's tubes to check for acid and gas production, respectively. The change in colour of broth from purple to yellow or collection of gas in Durham's tube was observed after 48 h of incubation at 37° C. In the filtration method, 100 ml water sample was filtered through 0.45 µm pore size membrane filters (Millipore). Filters entrapping any bacterial cells present in water were transferred to Endo Agar (Hi-Media) plates and incubated at 37°C for 24 h. The typical coliform colonies with red colour and metallic sheen developed on membrane filters were counted. Thermotolerant Faecal coliforms were detected by transferring a loop full of fermented medium from the positive Lauryl Tryptose Broth tubes to Brilliant Green Bile Broth tubes having inverted Durham's tubes. The collection of gas in the Durham's tube in Brilliant Green Bile Broth was observed as positive test after incubation at 44.5° C for 24 h.

Physico-Chemical Analysis:

All samples were analysed for pH, Electrical Conductivity (EC), Total Dissolved Solids (TDS), Total Hardness (TH), Chemical Oxygen Demand (COD), Iron-Fe (II), Manganese-Mn (II) and Salinity. EC, TDS and EC based salinity were measured by a KCl calibrated bench top Conductivity meter (Model TCM-15, TIMPL). COD, Fe and Mn values were determined using Spectroquant cell test kits (Merck Millipore) as per the manufacturer's instructions. Hardness was estimated by EDTA Titration method following APHA 2012 (23).

RESULTS AND DISCUSSION

Groundwater samples collected from hand pumps in Madanpur Khadar were colourless, odourless and without any visible turbidity. However, during storage of these samples in refrigerator, 60% samples developed yellowish brown precipitates while in others white precipitate was generated. Similar details provided by the inhabitants of the study area proved to be of great help in deciding the type of analytical determinants. The results of all analytical parameters along with their comparison with BIS 2009 standards for drinking water (24) have been presented in Table-II.

Table-II. Summary of chemical and microbiological analysis of groundwater samples in comparison with BIS standards, 2009 (24) for drinking water.

Parameters	**Minimum**	**Maximum**	**Average**	**BIS Standard**	**Percentage of samples beyond the permissible limits**
pH	6.7	7.4	7.1	6.5-8.5	Nil
Electrical Conductivity (μmho/cm)	556	982	767	1500	Nil
Total Dissolved Solids (mg/L)	364	643	504	500	52
Hardness (mg$CaCO_3$/L)	416	676	509	200	100
Salinity	0.30	0.48	0.37	0.75	Nil
Chemical Oxygen Demand (mg/L)	UD	114	17	10	24
Mn (mg/L)	0.04	1.04	0.56	0.1	90

Fe (mg/L)	0.01	1.82	0.40	0.3	33
Total Coliform/100 ml	0	1600	79	Absent	24
Faecal Coliforms	-	+	NA	Absent	9.5

The pH of water samples was in the range of 6.7-7.4 with an inclination towards acidic or neutral pH in most of the samples. The pH values were within permissible limits as prescribed by BIS 2009 (24) and WHO 2004 (4). The similar pH values with 7.2-7.3 average of water samples collected from Yamuna flood plains and other parts of NCT Delhi were observed in other studies (16), (25-27) though a wide pH range was seen in these studies. The pH variation of groundwater samples is the result of geochemical equilibration, dissolution of minerals, neighbourhood mining sites and waste contamination (28).

Electrical conductivity accounts for the concentration of ionized substances in water and could directly be related to total dissolved solids. The EC values of water samples varied from 556 to 982 µmho/cm with an average of 767 µmho/cm, much below the permissible limits of 1500 µmho/cm (4). However, in a study conducted by the National Institute of Hydrology, Roorkee in 2000 (25) of Yamuna Flood Plains from Palla area to Okhla Barrage, 70% the water samples both post monsoon and pre monsoon were found to have EC >1000 µmho/cm. In other parts of Delhi particularly Dwarka sub-city and South and South-West of ridge, very high EC values (37,400 µmho/cm) have been observed in some samples (16). EC values of all water samples were compared with TDS values (Figure-III). The correlation between EC and TDS values of all water samples follows the Davis and De Wiest (29) method without any outlier.

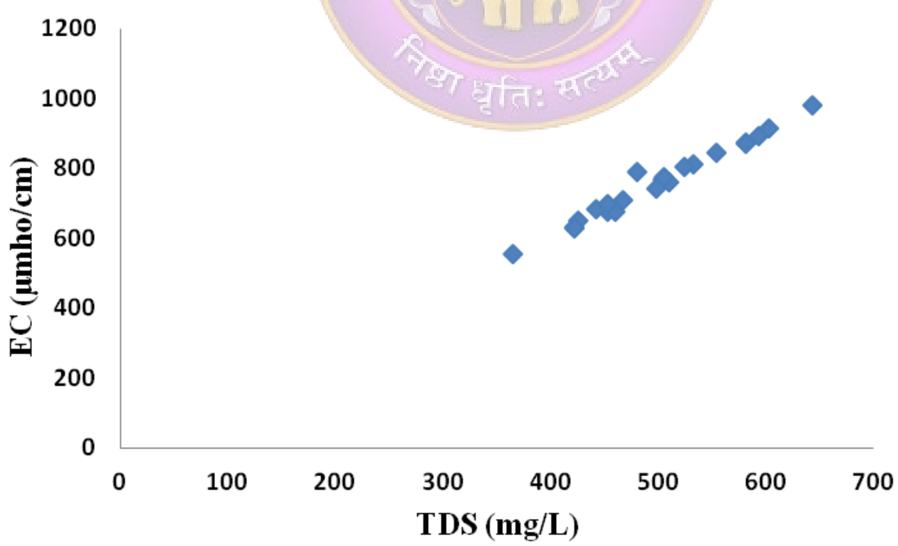

Figure-III. Relationship between Total Dissolved Solids (TDS) and Electrical Conductivity (EC).

Natural waters have been classified on the basis of the concentration of total dissolved solids (TDS) consisting of anions (HCO_3^-, CO_3^-, Cl^-, PO_4^-, NO_3^- and SO_4^{--}), cations (Ca^{++}, Mg^{++}, Na^+, K^+, Fe^{++}, etc.) and small amount of organic matter (29). In the present study, the values of TDS of groundwater samples varied from 364-643 mg/L. 48% of the water samples contained TDS within desirable limits of 500 mg/L for drinking water. However, TDS of all samples tested was within permissible limits (1000 mg/L) for drinking water (Table-III). These TDS values are in contradiction to the TDS values observed in water samples from Yamuna Flood Plains in which only 10% samples had TDS confirming the desirable limit (25). The entire water samples tested in this study were found to be fresh on the basis of Davis and De Wiest (29) classification, indicating the Yamuna River to be the predominant recharge source.

Table-III. Classification of Groundwater based on TDS (29).

Water Suitability	**TDS (mg/L) range**	**Percentage of samples**	**Water Type**	**TDS (mg/L) range**	**Percentage of samples**
Desirable for drinking	<500	48	Fresh	0-1000	100
Permissible for drinking	500-1000	52	Brackish	1001-10,000	Nil
Useful for irrigation	<3000	Nil	Salty	10,001 – 1,00,000	Nil
Unfit for irrigation and drinking	>3000	Nil	Brine	>1,00,000	Nil

The presence of divalent cations like Calcium and Magnesium and their HCO_3 and CO_3 salts makes the water hard and defines the suitability of water for its different applications. All the water samples studied were classified as very hard (Table-IV) on the basis of hardness values which ranged from 416 to 676 mg$CaCO_3$/L much beyond the acceptable limits. Hardness of the two RO treated water samples collected from the area was < 75 mg$CaCO_3$/L allowing these samples as control markers of analysis.

Table-IV. Classification of groundwater samples on the basis of hardness (33).

Total Hardness as $CaCO_3$ (mg/L) range	**Water Type and Quality**	**Percentage of samples**
<75	Soft	Nil
75 - 150	Moderately Hard	Nil
150 - 300	Hard	Nil
>300	Very Hard	100

The use of very hard waters both for domestic and industrial purposes will result into corrosion and scaling on utensils, heat exchangers, metal pipes in the distribution system, etc. Very hard water on regular consumption have also been found to show a temporary change in bowel habits and a laxative effect (diarrhoea) if it contains a very high concentration of magnesium along with sulphate (30). Excess exposure to very hard water has been suggested to exacerbate atopic eczema (31-32). The complaints of skin irritation and eczema among inhabitants of Madanpur Khadar (Survey in this study) could be attributed to the very hard groundwater quality used for washing, bathing and other activities.

The reporting of groundwater samples of the study area turning turbid with yellowish brown or white precipitate by the residents (20), prompted us to check for the load of total organic matter (COD), manganese and iron. These constituents particularly Mn and Fe remain solubilised under anaerobic conditions of groundwater and hence does not show any change in the fresh water characteristics. However, during storage of groundwater Mn and Fe get oxidized, precipitate as white or yellow-brown salts (rust coloured silt) and turn the samples turbid (34-36). COD content determined by potassium dichromate method was found to be very high in 24% of groundwater samples. In these samples COD levels were above 25 mg/L, with 114 mg/L in one of the samples, much above the permissible limits of 10 mg/L. In other samples COD was below the detection limits of the Spectroquant Cell test kits (25 mg/L). Hence, the presence of organic matter in other samples above the permissible limits of 10 mg/L cannot be ruled out. These values for COD in groundwater samples were surprisingly high as even the water samples collected from Yamuna River did not contain COD more than 90 mg/L (37) when tested over a period of one year. This shows that the source of such high organic content in water samples tested cannot be the Yamuna Basin.

In addition to the high COD values, 90% of water samples contained Mn >0.1 mg/L with the highest values of 1.04 mg/L in one of the samples. Similarly, Fe content in 33% of water samples was beyond the permissible limits of 0.3 mg/L with highest concentration up to 1.82 mg/L. At concentration exceeding the permissible limits of 0.1 mg/L, Mn imparts undesirable taste and discoloration (38) and at values as low as 0.02 mg/L, it can form coating on water pipes that sloughs off as black precipitate later (34). High levels of Mn up to 1.3 mg/L and 9.6 mg/L have been found in neutral and acidic groundwater, respectively, in USA (39). Hydrogeological studies of groundwater in Delhi have revealed high concentrations of Mn in the eastern part of Delhi i.e. young alluvial regions attributing it to the anthropogenic activities such as waste discharge from industrial units (16), (26). Though the health risks of human exposure to high amounts of Mn from drinking water are substantially low as most adults consume Mn between 0.7 and 10.9 mg/day in the diet (40), its effects on colour, turbidity and taste of water are much more adverse, making the water unpalatable.

Analogous to high Mn content of water samples studied, high iron concentrations may also result into turbidity and discoloration on storage. Iron levels above 0.3 mg/L in water may stain laundry and plumbing. The chances of any health risk from high iron waters are minimal as the concentrations of iron are too low as compared to the iron intake (10-14 mg/day) from food sources (41).

Total coliform count in 24% of water samples exceeded the prescribed standards which stipulate complete absence of coliforms in drinking water. Faecal coliforms were detected in two water samples indicating a direct correlation between the microbial contamination of groundwater and sewage access to the aquifers. The well fields of Palla area (North Delhi) existing in the Yamuna Flood Plains are being used to extract groundwater for fresh water supply to some parts of Delhi. A study on the microbial quality of water in these wells showed that more wells were contaminated with coliforms during post-monsoon season as compared to pre monsoon period (15). The high water table in the study area makes the shallow groundwater aquifers vulnerable to contamination by sewage percolation from the surface. Significantly high concentrations of total coliforms and faecal coliforms have been reported in waters of Yamuna River at the Agra Canal mid and quarter stream in Delhi which is in close proximity to our study area (37). Sewage overflowing from the unlined drains, septic tanks, pit latrine in the study area closer to groundwater source (20) could presumably be the main reason for contamination as has been observed in other studies (9), (42-43). The presence of high coliform count including faecal coliforms indicates the contamination of hand pump water with water borne microbial species which may be directly attributed to the high frequency of occurrence of water borne diseases like dysentery, diarrhoea, typhoid, jaundice, etc. as observed and reported in this area (21). The highest percentage of morbidity and prevalence of diseases has been reported in slums of Delhi where households have used groundwater for drinking (44).

CONCLUSION

Resettlement colonies along the Yamuna River have been deprived of basic services like safe drinking water and a proper sewage disposal system. After evacuation from slums, these residents are left to the plight of hard living conditions. Being in the close proximity to the Yamuna River, groundwater aquifers have a high recharge potential and hence shallow in nature. The groundwater extracted from hand pumps installed near to the open drains in the present condition is responsible for water borne diseases in the area, therefore, requiring extensive treatment before its usage for any activity. Manganese and iron can be removed by oxidation after addition of chlorine and potassium permanganate to water. These treatment strategies will simultaneously eliminate coliforms and any other water borne pathogens. Organic matter can be removed by passing water through candles containing activated charcoal. However, practicing such procedures will increase the financial burden on the already struggling daily workers. Supply of safe drinking water and maintaining a regulated sewage disposal system is the sole responsibility of the Government of Delhi as it does for other high profile localities.

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