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REVIEW ARTICLE

WASTEWATER IRRIGATION, ITS IMPACT ON ENVIRONMENT AND HEALTH RISK ASSESSMENT IN PERI URBAN AREAS OF PUNJAB PAKISTAN – A REVIEW

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ABSTRACT

Due to water scarcity issues in developing countries, wastewater irrigation has become a viable common practice in majority of the agricultural areas of Pakistan. It has been widely claimed that the use of wastewater for irrigation purpose not only helps in addressing the issues of water scarcity but fulfills the nutritional requirements for the cultivation as well. But the municipal wastewater in urban and peri urban areas of Punjab are carrying excessive pollution loads of untreated industrial wastewater, which is becoming a source of subsurface contamination as well as health hazard, due to carriage of toxic chemicals and heavy metals through the drains, being released from the industries. Industrial areas have equally been spread out all over the province of Punjab, thus the issue of irrigation by using untreated wastewater exists in all the regions of the Punjab. This research work reviews the findings of impact of different significant parameters on soil and groundwater and the uptake of these parameters by the plants and vegetations, along with assessing the health risk of these contaminants on humans after consumption. Based on the review, frame work for the application of municipal wastewater for irrigation purpose in the peri urban areas of Punjab has also been recommended.

KEYWORDS

wastewater irrigation, health risk assessment, subsurface contamination, industrial pollutants, heavy metals

1. INTRODUCTION

Contamination of food products, crops, vegetables and fruits by heavy metals and other hazardous chemicals has been observed throughout the world. It can be due to use of untreated wastewater for irrigation or application of toxic fertilizers, pesticides or insecticides. The toxicity beyond permissible limits and consequent threat to human health by heavy metals such as cadmium (Cd), copper (Cu), lead (Pb), chromium (Cr), zinc (Zn), Nickel (Ni), Arsenic (As), cobalt (Co) and mercury (Hg) are the function of concentration and bioaccumulation [1]. These elements are serious stressors to the environment, representing significant human effects through food chains, water and air pollution [2].

The volume of wastewater generated by domestic, industrial and commercial sources has increased with population increase, urbanization, improved living conditions especially in urban areas, and rapid economic development [3]. In urban areas of many (developing) countries, urban and periurban agriculture depends, at least to some extent, on wastewater as a source of irrigation water. The quality of the water and the conditions under which this water is used vary significantly. In poor countries this water may, in extreme cases, take the form of diluted raw sewage, even if this is considered illegal [4]. However, the quality of the wastewater used and the nature of its end use vary enormously, both between and within countries. In many low-income countries in Africa, Asia, and Latin America, the wastewater tends to be used untreated, while in middle-income countries such as Tunisia and Jordan, treated wastewater is used [5].

The per capita availability of water has dropped from 5,600 m^3 in 1980 to 1,000 m^3 in 2002 [6]. A benchmark stage of 1,000 m^3/p/y is often used as an trademark of water shortage under this rustic in all likelihood to enjoy chronic water shortage on a scale sufficient to obstruct development, damage human fitness and 500 m^3/p/y shows severe water strain.

International Water Management Institute has made a nationwide survey of wastewater use in Pakistan and the effects suggest that 32,500 ha are directly irrigated with wastewater i.e. 26% of the vegetables are being produced using wastewater. A negligible sharing of this wastewater is treated, and no clear guidelines exist on vegetation that can be irrigated with wastewater. Greens vegetables are the maximum commonly irrigated plants, because they fetch excessive expenses inside the close city markets [7].

The common use of urban wastewater for plant grow this especially on those areas which are located around cities [8]. The use of wastewater for irrigation gives good crop yields, as it consists lots of good organic and inorganic elements for growth and development of crops [9]. Heavy Metals in different industrial waste are Cr, Cd, Cu, Pb, Ni, Zn, Co, Mg, Fe and As [10]. Some of the heavy metals are beneficial for proper plant growth within the permissible limits, but the others are not so good after the accumulation in soil that can transfer to the food chain and caused adverse effects [11, 12]. Elements such as Fe, Mn, Co, Cu and Ni are essential, and their permissible limits are very low but in wastewater are present in concentrations above permissible limits and show their toxic effects on the biological system. Heavy metals are dangerous due to their non-biodegradable nature, long biological half-lives and metal enzymes. Among the heavy metals, cadmium shows significant effects on seedling length and dry weight, reduces the activity of photosystem, causes structural change in chloroplasts and therefore reduces photosynthesis availability carbon dioxide, decreased stomatal conductance, reducing total lipids, glycolipids and neutral lipids interfere with the permeability of the membrane and reduces respiration in leaves [13,14].

With rapid increase in industrialization and urbanization, the generation of waste water, residue and gases containing heavy metals has greatly increased. Those heavy metals could deposit in soil and then accumulate in crops, which may possibly cause serious health risks. Thus, it is important to figure out heavy metal pollution situations in the soil and crops. Soil contaminated with metals is a primary route of toxic element exposure to humans. Poisonous metals can enter the human body through intake of contaminated food plants, water or inhalation of dust. The contamination of vegetables with heavy metals poses great risk and safety concern on soil and atmosphere. Food safety problems and capacity fitness risks make such unconventional wastewater as one of the most critical environmental concerns. Vegetables grown on contaminated land may accumulate toxic metals. Prolonged intake of contaminated Food may additionally cause the unceasing accumulation of heavy metals in the liver and kidney of human's ensured disturbance of biochemical processes, such as, liver, kidney, cardiovascular, nervous and bone problems. It has been estimated that greater than 70% of dietary intake of cadmium is contributed by food chain [15].

In this review paper existing situation of soil and groundwater contamination due to wastewater irrigation in entire Punjab region and the health risk assessment due to intake of environmental contaminants, heavy metals in particular, by the crops and vegetables have also been studied. Generalized remedies in order to cope with the health risks and environmental impacts of the contaminants in subsurface have also been provided to develop a frame work for policy making, improving the environmental condition throughout Punjab.

2. MATERIALS AND METHODS

2.1 Research methodology

Major three cities of the province Punjab in Pakistan were selected to obtain data regarding wastewater irrigation and its health risk assessment. These cities include, Lahore, Attock and Faisalabad, thus in the region of Punjab. However, the level of contamination in all these regions is different due to different nature, characteristics and generation rate of wastewater, depending upon the type of industries in each city. The city areas of Punjab that has been included in the study are shown in Figure 1.

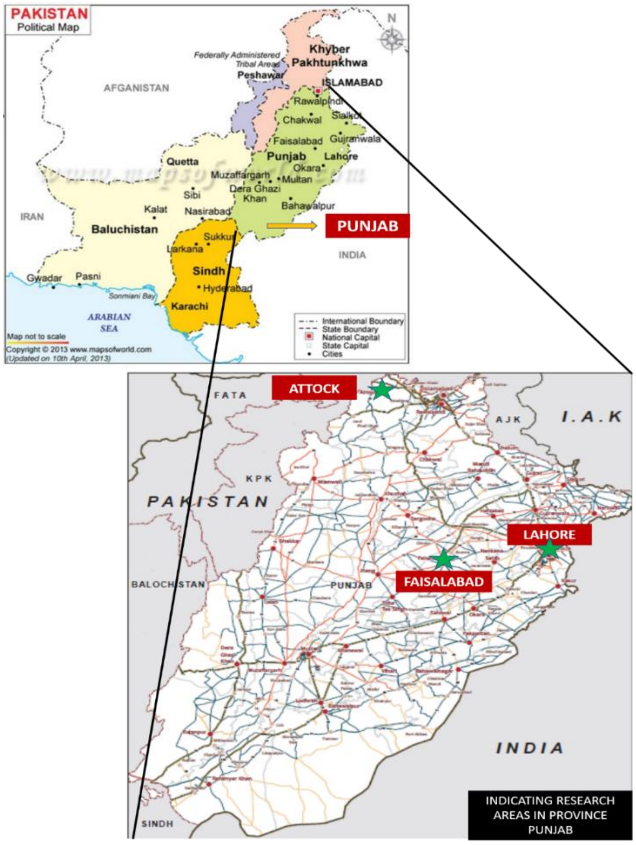

Figure 1: Map of Pakistan and Punjab indicating Study areas (Reproduced by author)

From every research area, different sites were selected for conducting research with the purpose to have wide range of representative data collection in terms of different sampling sources

2.2 Sampling medium and Collection of Data

2.2.1 Soil Sampling and Analysis

From every site in the respective cities as described earlier, soil samples were collected from different depths in order to investigate the presence of contaminants coming from wastewater sources. The sampling depths were not deeper than the root zone of crops usually grown in order to account for the probability of the contaminants being taken by the crops or vegetables. These soil samples were then analyzed for basic chemical parameters as well as heavy metals.

2.2.2 Wastewater and groundwater analysis

The source from which wastewater was drawn and used for irrigation purpose, has been thoroughly investigated in all the researches. Analysis mainly consist of basic chemical parameters along with heavy metals originating from the industrial sources in most of the cases. Groundwater quality has also been investigated to work out the seepage of the contaminants, sourced from the wastewater, into the soil and ultimately contributing to groundwater contamination. In correlation to wastewater all the basic chemical parameters and the heavy metals have been determined.

2.2.3 Vegetation, Crop Analysis

To determine the uptake of contaminants, particularly heavy metals, the vegetables and crops have been investigated in all the studies. It would help in identification of the source of food contamination as well as accumulation or retention concentrations. It will also explain the behavior of contaminant in different soil mediums regarding their uptake tendencies by the crops or vegetables.

2.2.4 Health Risk Data Analysis

Data was analyzed mainly as available in literature [16]. Soil-to-plant transfer quotient was calculated in order to observe the exposure of metals to human beings. Daily intake of metal was calculated and compared with the standard intake of metals to determine the health risks. Health Risk Index was calculated to highlight the exposure of humans to health hazards.

2.2.5 Soil-to-plant transfer Quotient (TF)

As the vegetables are the source of human consumption so soil-to-plant transfer quotient is the main source of human exposure. A suitable way for measuring the relative difference of bioavailability of metal to plant is transfer quotient. In order to determine Health Risk Index (HRI) transfer factor should be known [16]. The higher transfer quotient of heavy metal indicates the stronger accumulation of the respective metal by that vegetable [17]. The soil-to-plant transfer Quotient (TF) was calculated as bellow:

$$TF = C_{PLANT}/C_{SOIL}$$

Where, C Plant is the concentration of heavy metals in plants and C Soil is the concentration of heavy metals in soil.

2.2.6 Daily Intake of Metals (DIM)

As vegetables are contaminated by heavy metals so their daily intake needs to be estimated for comparison as given by US – EPA [18]. Daily intake of metal was calculated by the equation given bellow:

$$DIM = C_{metal} \times C_{factor} \times D_{food\ intake}/B_{average\ weight}$$

C_{metal}, C_{factor}, $D_{food\ intake}$ and $B_{average\ weight}$ represent the heavy metal concentrations in plants (mg kg^{-1}), conversion factor, daily intake of vegetables and average body weight, respectively. Conversion factor was taken as 0.085 [19]. The average daily food intake for adults and children was considered to be 0.345 and 0.232 kg $person^{-1}$ day^{-1}, respectively, while the average adult and child body weights were considered as 73 and 32.7 kg, respectively [20-22].

2.2.7 Health Risk Index (HRI)

By using Daily Intake of Metals (DIM) and reference oral dose we find the health risk index. The following formula is used for the calculation of HRI:

$$HRI = DIM/R\ fd$$

Where DIM represents the daily intake of metals and Rfd represents reference oral dose. Rfd for Cr, Ni, Cu, Pb, Cd, Mn and Zn is 1.5, 0.02, 0.04, 0.004, 0.001, 0.033 and 0.30 (mg/kg bw/day) respectively (US-EPA, 2006) If the value of HRI is less than 1 then the exposed population is said to be safe.

2.2.8 Health Risk Assessment (HQ)

Risk of intake of metal-contaminated vegetables to human health was characterized by Hazard Quotient (HQ). This is a ratio of determined dose to the reference dose (RD). The population will pose no risk if f the ratio is less than 1 and if the ratio is equal or greater than 1 then population will experience health risk. The following equation is used

$$HQ = [W] \times [M] / R_{fD} \times B$$

Where [W] is the dry weight of contaminated plant material consumed (mgd), [M] is concentration of metal in vegetables (mg kg), R_{fD} is the food reference dose for the metal (mgd) and B is the body mass (kg).

3. RESEARCH OUTCOME & DISCUSSION

3.1 Soil Sample Analysis at District Attock Study Areas

In the research conducted in northern Punjab at Attock city, soil samples were collected from two specific areas which were selected for research and furthermore these areas were divided into three zones overall covering length of One (1) kilometer [23]. In total twelve (12) soil samples were collected at the soil depth of 15 cm from two study sites Khour company and Khour City. The pH in Khour company ranged from 6.0 to 7.9, while in Khour City pH ranged from 6.8 to 8.76. Electrical conductivity of soil from Khour Company ranged between 2.27 and 2.53 μS cm^{-1}, while in Khour city it ranged from 3.03 to 3.93 μS cm^{-1}. The average content of moisture in Khour Company ranged between 3.73 and 10.13 while in K. city it ranged between 3.39 and 5.06. In soil samples, the average concentration of heavy metals found in Khour Company ranged from 1.11 to 79.46 while in Khour city the concentration of heavy metals ranged from 0.82-22.74 mg Kg^{-1}. The level of Pb in Khour Company was highest, and Cd was lowest than other heavy metals.

3.2 Soil and Wastewater Sample Analysis at District Lahore Study Areas

In the study selected from District Lahore, two zones were selected, One for Industrial wastewater irrigated Zone (WWZ) while the other on eastern side irrigated by Groundwater (GWZ). Heavy metal concentrations retained in soil for sites irrigated by wastewater WWZ and groundwater GWZ is presented in Table 2. Concentration of Cu was found to be maximum i.e. 18.15 mg/L in water samples of WWZ, followed by the concentration of Ni^{2+}, Cr^{2+}, Cd^{2+}, Pb^{2+}, Mn^{2+}, Co^{2+} and Zn^{2+} compared with the Indian standards while concentration of Zn^{2+} was in the range of permissible limits [24]. Compared with the GWZ; except Cu^{2+}, concentration of heavy metals in water samples were in the range of Indian permissible limits [24]. Soil concentration of heavy metals varied among the sites of WWZ and GWZ. Concentration of heavy metals of soil obtained from different sites of WWZ was found to be significantly high as compared to the soil obtained from various sites of GWZ (Table 2). However, the concentration of heavy metals in WWZ was below the safe limits set by EU and Indian standards except Cd that was 3.15 mg/kg [25]. Concentration of metals among different sites of GWZ was found to be in safe limit [26].

Table 1: Mean Value of heavy metal concentrations in wastewater and groundwater used for Irrigation at Two Study areas in District Lahore (mg/L) [26].

Heavy Metal	WASTEWATER		GROUNDWATER		EU standard	Indian Standard
	Range	Mean value	Range	Mean value		
Cr	11.37 – 33.39	21.01	9.3 - 21.4	14.0	100	NA
Co	4.28 – 13.39	8.04	1.4 – 6.3	3.65	50	60-110
Ni	14.03 – 40.28	28.83	9.9 – 22.1	14.5	50	75-150
Cu	11.28 – 43.53	28.74	6.34 – 26.4	15.3	100	135-270
Pb	8.38 – 21.40	15.38	3.4 – 6.34	7.4	100	250-500
Cd	1.29 – 5.18	3.15	0.16 – 2.2	1.2	3	3-6
Zn	29.12 – 83.28	50.84	23.3 – 45	34.1	300	300-600
Mn	20.48 – 64.19	39.01	9.1 – 36.3	21.2	2000	NA

Table 2: Mean Value of heavy metal concentrations in soil samples irrigated by wastewater and groundwater (mg/kg) [26].

Heavy Metal	SOIL OF WASTEWATER IRRIGATED ZONE		SOIL OF GROUNDWATER IRRIGATED ZONE		Indian Standard
	Range	Mean value	Range	Mean value	
Cr	0.19 – 0.54	0.33	0.03 – 0.44	0.17	0.05
Co	0.023 – 0.12	0.064	0.01 – 0.05	0.03	0.05
Ni	0.91 – 5.94	2.9	0.4 – 1.8	0.93	1.4
Cu	9.28 – 32.7	18.1	2.5 – 11.0	6.3	0.05
Pb	0.26 – 0.7	0.4	0.04 – 0.5	0.21	0.1
Cd	0.18 – 0.37	0.2	0.004 – 0.2	0.01	0.01
Zn	0.34 – 1.4	0.8	0.11 – 0.3	0.17	5.0
Mn	0.19 – 1.13	0.6	0.07 – 0.21	0.13	0.1

Results of the one-way ANOVA revealed that the heavy metal concentration was significantly higher in vegetables grown at WWZ than those grown at GWZ. Concentration of Cr2+, Pb2+ and Cd2+ from vegetables of WWZ exceeded the permissible limits but was in the range of Indian safe limits [24,25]. Continuous wastewater irrigation has changed the soil physicochemical properties and has led to heavy metal uptake by food crops, predominantly vegetables [26]. In the present study metal concentration was greater in the vegetables grown in wastewater, than those grown in groundwater. A variation in the metal concentration may be due to the variable factors like heavy metal concentration in soil wastewater used for irrigation and atmospheric deposition along with the plants capability to uptake and accumulate the heavy metals [27]. One-way ANOVA was used to compare the metal concentration in the vegetables grown in wastewater and those grown in ground water. Results showed significantly higher concentration of Cr2+, Co2+, Ni2+, Cu2+, Pb2+, Mn2+ and Zn2+ in vegetables grown in wastewater as compared to the vegetables grown in ground water.

Similar nature of research work conducted in district Faisalabad, showed similar trend of heavy metal intake by the vegetables. In this regard three (3) different fields were irrigated with waters of varying qualities. These qualities included 100% wastewater, 50% wastewater (conjunctive use of untreated wastewater and regular water / tubewell water) and 100% canal water. The three varying qualities of water for field irrigation were considered as treatments and impacts of their continuous use over several years on groundwater and soils were sought during the present work. Samples of groundwater and soil were gathered from the experimental fields and analyzed to check the groundwater contamination and soil degradation. The variables studied were pH, EC, SAR, RSC, TDS and heavy metals (Mn, Ni, Cr, Pb, Cu, Co, Fe and Zn) [28]. Table 3 represents the heavy metal concentrations retained in the soil receiving varying quality waters.

Table 3: Concentrations of Heavy metals in Soils receiving varying quality waters (mg/kg)

SAMPLE	Sample Depth cm	Mn	Ni	Cr	Pb	Cu	Zn	Fe
100 % WW	0 – 10	477	39.0	24.5	11.0	22.4	57.8	28578
	10 – 20	450	35.5	21.5	9.8	20.6	54.0	26016
	20 – 30	526	41.0	24.5	10.6	22.6	63.0	31499
50 % WW	0 – 10	351	24.3	20.4	7.1	12.4	40.0	18497
	10 – 20	337	23.2	18.9	7.2	12.2	36.8	17872
	20 – 30	287	23.6	17.6	6.2	12.3	35.5	18216
100 % CW	0 – 10	253	18.9	14.6	7.7	13.0	42.4	15561
	10 – 20	252	18.8	14.2	7.4	12.9	39.9	15540
	20 – 30	263	18.4	14.6	5.1	10.3	27.4	15175

CW = Canal water; WW: wastewater [28]

From the soil samples it was concluded that after one-year period pH increased up to 8.6 at depth of 90-cm which shows poor physical condition its mean, soil structure was degraded, and soil salinity was increased considerably in 100%WW and 50%WW treatment of water effluent. From this study it was concluded that untreated wastewater application as a source of irrigation not only degrade the soil structure but also contaminate the groundwater status, so it is more suitable that it should be used by mixing with fresh water.

In another research work conducted in District Faisalabad similar pattern of contaminant uptake, particularly heavy metals were observed. This research was focused on wastewater characterization, determination of heavy metals in the soil and vegetation and finally working out the health risk assessment of these contaminants found in vegetables. Average heavy metal concentrations from four different sites in Faisalabad are shown in Table 4.

Table 4: Concentration of Heavy Metals in Vegetables from Four Selected Sites in Faisalabad [29]

Vegetables	**Cu**	**Ni**	**Pb**	**Zn**	**Cd**	**Cr**	
SITE A	7.6	15.13	3.42	37.21	0.546	9.54	
SITE B	9.54	11.88	1.62	36.94	0.53	9.28	
SITE C	8.10	9.34	1.72	44.37	0.65	8.53	
SITE D	6.83	7.79	0.88	30.65	0.193	4.93	

Heavy metals concentration in soil showed an alarming situation in all sites. In all areas, Zinc (Zn) concentration is truly higher than the standards at floor surface however with the depth, Zn concentration further tends to increase that is a vital state of affairs for vegetables that are grown on this soil. Copper (Cu) concentration need to be 0.50 mg/kg according to the standards. However, in this case, Cu awareness is very excessive from the requirements even at the floor which is more than 5 mg/kg in almost all sites and Cu concentration also increases with intensity. Cadmium (Cd) concentration is almost close the requirements in all places in any respect depths. Lead (Pb) concentration is also very excessive from the requirements in all sites even at floor surface. All areas display equal fashion of growth in Pb awareness with depth. Nickel (Ni) concentration in soil should have to be 8.10 mg/kg with respective to the requirements. However right here effects are confirming a disastrous state of affairs. Zn concentration is highly affected by wastewater than nickel than copper than chromium, lead and lastly cadmium. Chromium (Cr) concentration is excessive from the standard.

Health Risk Assessment related to heavy metals in Spinach vegetable was in the order of Zn>Ni>Cu>Cr>Pb>Cd. Transfer factor for spinach ranges from 0.159 (Zn) to 0.728 (Cr). The trend for DIM in spinach vegetable grown was in the order of Zn > Ni>Cr >Cu>Pb >Cd. HRI was maximum for Pb in spinach (3.72) and Ni (1.20) minimum or out of danger for Cr (0.01) in which HRI for Pb and Ni was maximum or above from the safe limit and HRI for Cu, Cr, Cd and Zn was minimum or in the safe limit. HQ was maximum for nickel, lead and cadmium and harmful for human health. Copper are almost close to the safe limit, zinc and chromium are in the safe limit.

Health risk assessment due to heavy metals in green chilli vegetable was in the order of Zn>Cu>Cr>Ni>Pb>Cd. Transfer factor for green chilli ranges from 0.102 (Pb) to 0.636 (Zn). The trend for DIM in chilli vegetable grown was in the order of Zn > Ni>Cr >Cu>Pb >Cd. HRI was maximum for Pb in chilli (1.41) and minimum or out of danger for Cr (0.01) in which HRI for Pb was maximum or above from the safe limit and HRI for Ni Cu, Cr, Cd and Zn was minimum or in the safe limit. HQ for nickel, lead and cadmium are almost close to the safe limit, copper, zinc and chromium was minimum or in the safe limit.

All wastewater and groundwater samples had EC and TDS above the safe limit. Heavy metals in vegetables had been in the order of Zn>Ni>Cr>Cu>Pb>Cd. Vegetables were also analyzed for transfer factor (TF), daily intake of metals (DIM), health risk index (HRI) and health risk assessment (HQ) were also calculated. While TF was lower for all metals except Cd. HRI was maximum for Pb and Ni in all vegetables. HQ was maximum for Ni, Pb and Cd. Vegetables was observed up taking heavy metals in larger concentrations which when consumed by human beings created a lot of health problems. The vegetables tested were not safe for human use, especially those directly consumed by human beings. Potential health risk of heavy metals to the nearby population through consumption have been predicted [29].

4. CONCLUSION

There is a significant correlation between the concentrations of heavy metals in wastewater, being used for irrigation, and their existence (retention) in soil and accumulation in the crops, vegetables and plants. Therefore, the wastewater irrigation which is beneficial in terms of enrichment of nutrients, poses health risk by the consumption of contaminated crops, vegetables and plants. Particularly as there has been a common practice of disposing the industrial wastewater without primary treatment, the health risk increases by many folds. From the review of similar kind of research work conducted in different regions of the province Punjab, the application of wastewater in comparison to canal water has a gradual trend of contamination accumulation potential in soil and the vegetation ultimately in food chain. As observed from using dilutions of wastewater, there is a gradual decrease in heavy metal retention in soil and vegetables confirming direct association of degree of contamination with the potential health risk in the vegetations and crops. The province Punjab being fertile land with immense water resources, require focusing on developing techniques to harvest additional fresh and safe water source for the irrigation purpose. It may include use of rainwater harvesting techniques, small dams constructions and treatment of municipal wastewater before its use for irrigation purpose.

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