

## RISK ASSESSMENT OF HEAVY METALS IN POTABLE WATER OF COASTAL AREA OF TALUKA JATI, SINDH, PAKISTAN

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DOI:(<https://doi.org/10.71146/kjmr816>)

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### Abstract

This study evaluates the level in mg/L and health risk assessment of heavy metals in drinking water across several sampling sites from coastal area of Taluka Jati (JT-50 to JT-84). The ranges of Heavy metals were observed as Cd (0.001 - 0.012), Cr (0.03 - 0.06), Cu (0.01 - 0.05), Co (0.03 - 0.18), Mn (0.00 - 0.50), Fe (0.09 - 0.26), Ni (0.01 - 0.04), Zn (0.01 - 0.05), Na (118.0 - 279.0), Ca (23.2 - 97.1), Mg (23.67 - 81.67) and K (1.53 - 6.43) mg/L. The assessment also focused on the Average Daily Dose (ADD), Hazard Quotient (HQ), Hazard Index (HI), and Total Cancer Risk (TCR) for metals including Cadmium (Cd), Chromium (Cr), Copper (Cu), Cobalt (Co), Manganese (Mn), Iron (Fe), Nickel (Ni), and Zinc (Zn). The results indicated that the cumulative non-carcinogenic risk, represented by the Hazard Index (HI), exceeded the safety threshold of 1.0 at multiple locations, with the highest values observed at sites JT-76 (1.260) and JT-59 (1.240). Furthermore, the Total Cancer Risk (TCR) for almost all sites fell within the range of  $10^{-4}$  to  $10^{-3}$ , which exceeds the USEPA's generally acceptable risk limit of  $1 \times 10^{-4}$ . Chromium and Nickel were identified as the primary contributors to both carcinogenic and non-carcinogenic risks. These findings suggest that the drinking water in the studied areas poses a significant health threat to the local population, necessitating immediate environmental intervention and water quality management.

**Keywords:** Heavy Metals, Taluka Jati, Hazard Index (HI), Total Cancer Risk (TCR).

## Introduction

In various countries of the world, the main source of freshwater supply is served by coastal aquifers [1]. The freshwater in the coastal areas is required in large amounts because of these areas are densely populated all over the world [1]. The freshwater depletion as well as local water table depression is observed because of severe withdrawal of groundwater from coastal aquifers, resulting seawater to travel inland and mounting towards the wells causing dropping the quality of groundwater [2-4]. Seawater intrusion may be caused by various reasons like, coastal areas occupied by growth in population [5,6].

Water is basic to all outlines of environmental services comprising maintenance, demanding, cultural and provisioning; although polluted water also plays as core mediums for morbidity as well as mortality all over the globe [7]. The recharge capacity of groundwater withdrawal from the majority of the aquifers of the world has been surpassed, leading unfavorable ecological outcomes due to disappearing water table at severe level which has deteriorated quality of water [8]. Reports reveal that quality as well as quantity of groundwater is affected directly or indirectly along the aquifers of coastal areas because of rapid urbanizations [9, 10]. The appropriate consideration on the hydrochemistry of an area is required for the procedure of measuring the appropriateness of groundwater. Moreover, it is significant to recognize the water-rock contact which affects the quality of groundwater [11]. Usually, it is natural process of intrusion of salt water in coastal regions; however, when coastal aquifers are used as water sources it (salt water) may become exasperated [12]. Besides the groundwater's natural salinity, water quality may be considerably worsened due to some anthropogenic actions [13] which may cause heart diseases [14].

In Pakistan, canal water and groundwater is broadly utilized for drinking purpose particularly in rural areas and towns [15]. The Arabian Sea coast and southern districts of Sindh province are connected at Karachi. The water quality of Indus basin is not constant, closer to sources of recharge it is non-saline, whereas progressively becomes salty by increasing the distance of recharge source [16, 17]. Groundwater withdrawal at large extent may produce differential zones by moving lateral as well as vertical flow of salt water causing fresh water zones saline. Due to the unique properties of heavy metals cause environmental contamination and may accumulate in organs and tissues for instance, bones, liver and kidneys causing harmful diseases. Each metal show particular symptoms and signs of toxicity. For example, Hg, As, Cr, Cd and Pb may cause diarrhea, stomatitis, gastrointestinal disorders, hemoglobinuria, ataxia, paralysis, vomiting, convulsion, pneumonia and depression [18, 19].

## Heavy Metal Contamination of Drinking Water in Pakistan

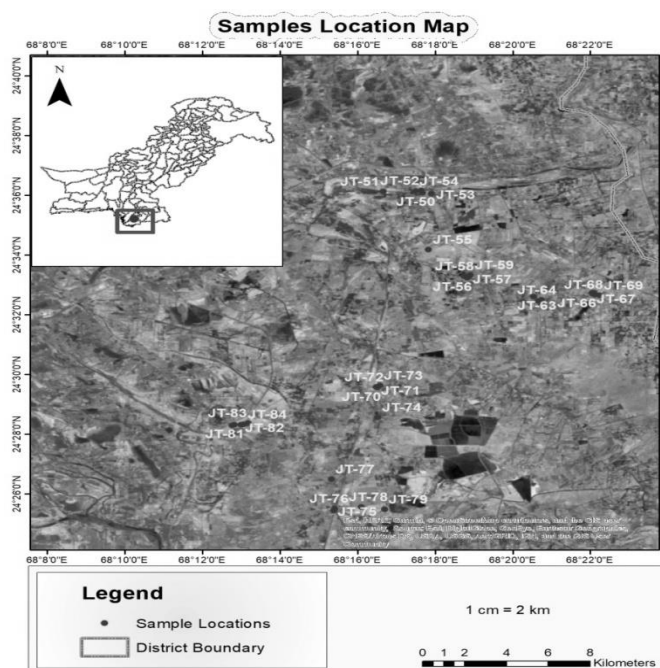
Feeding demands of a living body are satisfied when all kinds of micro and macro nutrients provided in combination [20]. Important role is played by trace elements in enzymatic, catalytic, metabolic, biochemical, biological and chemical reactions in living cells of humans, animals and plants [20, 21]. Heavy metals are highly toxic for plants, animals and humans because of their solubility in water is major environmental issue [22–24]. The reason of consuming contaminated drinking water is limited access to clean drinking water in

developing countries [25, 26]. People of Azad Jammu and Kashmir are suffering from diseases out of which 80% are due to consumption of contaminated drinking water [27]. Reports reveal that water borne diseases cause yearly national revenue loss of 25 to 58 billion rupees and contaminated drinking water is the reason of 250,000 deaths of children every year while, 20-40% of the beds of hospitals are full by patients suffering from water borne diseases [25, 26]. Clean potable water is accessed only to 25.61% of the population of Pakistan [26]. For major municipalities, groundwater is the only source of water supply which contributes about 1/3<sup>rd</sup> in total water resources of Pakistan [25, 28]. Water pollution is worsened and broadened by carrying industrial effluents, urban wastes, farm wastes and municipal sewage through canals and drains to rivers [29–31].

Various other types of diseases are also observed due to cadmium intoxication for instance, itai-itai disease, skeletal damage, kidney damage, and pulmonary damage [32, 33]. The highest permissible limit of 0.003 mg/L of cadmium in drinking water is given by WHO [34, 30]. The sources through which nickel causes various diseases including cancer may be percutaneous absorption, inhalation, water and nickel contaminated food [35, 36].

### Study Area

Study area is one of the Taluka of District Sujawal closer to coastal zone; its coordinates are 24°36'23" of North and 68°4'19" of East. Indus River one of the largest rivers of Pakistan flows to northeast. Population of the Taluka Jati according to census of 2017 was recorded as 202,299. Its climate is under the influence of monsoon and is dry tropical. The range of temperature is found as 23.8 °C and 28.7 °C. The normal yearly rainfall on the study area is 220 mm (Fig.1).



**Figure 1** Map of sample locations at Taluka Jati

## Materials and Methods

All samples of drinking water were collected in triplicate from each location in which different water sources were fitted by villagers. Usually hand pumps and motor pumps were fitted by villagers to get groundwater for drinking cooking and washing purposes. In total 35 samples of drinking water were collected in 1.5 L capacity of plastic bottles from Taluka Jati of Coastal Area of Sindh. Before taking samples, all plastic bottles were washed with and rinsed with 0.02M Nitric Acid for maintenance of pH, changing in physical and chemical characteristic, evaporation and precipitation. Samples in triplicate were collected randomly by means of acidified plastic bottles and mixed.

Chemicals used throughout the work were of high purity A.R grade reagents; Hydrochloric acid (35 – 38%, Blulux, Laboratory reagent, U.K), Nitric Acid and (69% LR, Breckland Scientific Supplies, U.K), all standards of Cd, Cr, Cu, Co, Mn, Fe, Ni Zn, Na, Ca, Mg, and K were prepared from their salts in 2% HNO<sub>3</sub> and were bought from Fluka and Merck, Germany. De-ionized as well as double distilled water was used throughout the experimental work for preparation of stock and standard solutions. Stock standard solutions of 1000 mg/L were prepared and then dilute solutions by successive dilutions were made. Glassware of different sizes was used throughout the research work including test tubes, funnels, measuring flasks, measuring cylinders, beakers, Erlenmeyer flasks to perform experiments. Though, micropipettes, electric hotplates, magnetic stirrers, thermometers, plastic bottles for prepared sample storage, stop watch and filter papers No: 42 were also used to continue the practical work.

Digital analytical balance was used for all measurements of chemicals. Atomic Absorption Spectrophotometer was used to determine the concentration of metals such as, Cadmium, Chromium, Copper, Cobalt, Iron, Manganese, Nickel, Zinc, Sodium, Calcium, Magnesium and Potassium from prepared water sample solutions of Taluka Jati. To measure the concentration of metals under study, the hollow cathode lamps were employed and to produce flame mixture of air/acetylene was used.

## Risk Assessment

In human health risk assessments for contaminated drinking water, the process is divided into two main categories: non-carcinogenic hazards (systemic toxicity) and carcinogenic risks (cancer probability). Both rely on calculating the Average Daily Dose (ADD) [37].

## Calculating the Exposure Dose

Before determining risk, how much of the contaminant a person is actually ingesting was calculated by using the formula of Average Daily Dose (ADD):

$$ADD = \frac{C \times IR \times EF \times ED}{BW \times AT}$$

Table: 1 Parameters for Calculating Average Daily Dose (ADD) via Water Ingestion

| Variable | Description   | Standard Units     |
|----------|---|--------------------|
| C        | Concentration of contaminant in water                   | mg/L               |
| IR       | Ingestion Rate (amount of water drunk per day)          | 2.0 L/day          |
| EF       | Exposure Frequency (days per year)                      | 365 days/year      |
| ED       | Exposure Duration (total years of exposure)             | 30 years           |
| BW       | Body Weight   | 70kg               |
| AT       | Averaging Time (period over which exposure is averaged) | AT = ED × 365 days |

### Non-Carcinogenic Risk (Hazard Quotient)

Non-carcinogenic risk assumes there is a “threshold” below which no ill effects occur. This was measured using the Hazard Quotient (HQ).

$$HQ = \frac{ADD}{RfD}$$

If multiple contaminants are present, the Hazard Index (HI) is the sum of all individual HQs which was measured using the following equation:

$$HI = \sum HQ_i$$

### Carcinogenic Risk (Cancer Probability)

Cancer risk is treated as “non-threshold,” meaning any exposure carries some level of risk. It is expressed as the probability of developing cancer over a lifetime.

$$\text{Risk} = \text{LADD} \times \text{CSF}$$

**LADD (Lifetime Average Daily Dose):** The daily intake averaged over a 70-year lifetime.

## Results and Discussion

### *Heavy Metals Analysis*

Analytical studies show Samples containing cadmium content less than or equal to 0.003 mg/L include JT-53, JT-54, JT-68, JT-69, JT-74 and JT-75. However, samples in which higher level of Cd than 0.005 mg/L was reported were labeled as, JT-51, JT-52, JT-58, JT-59, JT-62, JT-64, JT-65, JT-66, JT-67, JT-70, JT-73, JT-76, JT-77, JT-79, JT-80, JT-81, JT-82, JT-83 and JT-84. Results are given in (Table: 2). Maximum Contaminant level of Cr specified by various guidelines like World Health Organization, European Union, China and Canada is 0.05 mg/L, while United States has recognized its MCL as 0.1 mg/L. Greater contents of Cr

than 0.05 mg/L were determined in drinking water of samples of Taluka Jati were regarded as, JT-66, JT-68, JT-71, JT-72, JT-76 and JT-80. Since, all the remaining samples showed Cr concentration within safe limit. The uppermost and the lowermost Cr content of 0.06 and 0.03 mg/L were detected in samples JT-73 and JT-80 respectively. (Table: 1). Minimum and maximum content of Cu measured were 0.01 and 0.05 mg/L in samples JT-61 and JT-59 respectively. No guideline is fixed for Cobalt in drinking water by any Water Quality Directives. Only one sample labeled as JT-64 showed the highest content of 0.176 mg/L of Co. The lowest Co content of 0.03 mg/L was displayed by the sample JT-67 (Table.1). Samples showing higher concentration of Mn than prescribed limit of 0.05 mg/L were tagged as JT-50, JT-53, JT-54, JT-55 and JT-56, while all the other samples displayed the Mn content within safe limit. European Union has specified the MCL for Fe as 0.2 mg/L and 0.300 mg/L is specified by Canada. The lowest and highest Fe amount of 0.09 and 0.26 mg/L was observed in samples JT-61 & JT-59 and JT-80 respectively. Samples in which higher Fe content than 0.20 mg/L was determined were found JT-79, JT-81, JT-82 and JT-83. Samples which displayed higher Ni content than (0.02 mg/L) Maximum Contaminant Level (MCL) were characterized as JT-55, JT-56, JT-57, JT-59, JT-60, JT-61, JT-63, JT-64, JT-67, JT-68, JT-73, JT-77 and JT-79. However, minimum and maximum nickel levels of 0.01 and 0.04 mg/L were observed (Table: 1). All samples of the study area showed lower limit of Zn as compared to guideline value of 3.00 – 5.00 mg/L. whereas, greater and lesser limit of Zn were declared as 0.05 and 0.01 mg/L [Table: 2, Fig: (a) – (h)].

**Table: 2**Determination of concentration of heavy metals (mg/L) from Coastal Area of Taluka Jati

| Code No: | Cd                              | Cr                             | Cu                            | Co                              | Mn                             | Fe                            | Ni                             | Zn                            |
|----------|---------------------------------|--------------------------------|-------------------------------|---------------------------------|--------------------------------|-------------------------------|--------------------------------|-------------------------------|
|          | WHO<br>Limit =<br>0.003<br>mg/L | WHO<br>Limit =<br>0.05<br>mg/L | WHO<br>Limit =<br>2.0<br>mg/L | WHO<br>Limit =<br>Not<br>listed | WHO<br>Limit =<br>0.05<br>mg/L | WHO<br>Limit =<br>0.3<br>mg/L | WHO<br>Limit =<br>0.02<br>mg/L | WHO<br>Limit =<br>3.0<br>mg/L |
| JT-50    | 0.005                           | 0.033                          | 0.014                         | 0.055                           | 0.500                          | 0.11                          | 0.019                          | 0.0089                        |
| JT-51    | 0.008                           | 0.042                          | 0.021                         | 0.064                           | 0.028                          | 0.13                          | 0.013                          | 0.0109                        |
| JT-52    | 0.006                           | 0.035                          | 0.023                         | 0.050                           | 0.001                          | 0.11                          | 0.017                          | 0.0137                        |
| JT-53    | 0.002                           | 0.047                          | 0.047                         | 0.043                           | 0.147                          | 0.13                          | 0.016                          | 0.0069                        |
| JT-54    | 0.003                           | 0.047                          | 0.041                         | 0.080                           | 0.152                          | 0.1                           | 0.013                          | 0.0126                        |
| JT-55    | 0.004                           | 0.046                          | 0.023                         | 0.068                           | 0.054                          | 0.12                          | 0.021                          | 0.0426                        |
| JT-56    | 0.004                           | 0.042                          | 0.036                         | 0.066                           | 0.079                          | 0.13                          | 0.036                          | 0.0096                        |
| JT-57    | 0.005                           | 0.040                          | 0.036                         | 0.043                           | 0.010                          | 0.14                          | 0.024                          | 0.0124                        |
| JT-58    | 0.010                           | 0.046                          | 0.018                         | 0.080                           | 0.092                          | 0.14                          | 0.014                          | 0.0084                        |
| JT-59    | 0.011                           | 0.050                          | 0.048                         | 0.068                           | 0.001                          | 0.090                         | 0.022                          | 0.0094                        |
| JT-60    | 0.004                           | 0.049                          | 0.041                         | 0.066                           | 0.012                          | 0.10                          | 0.031                          | 0.0089                        |

|              |       |       |       |       |       |      |       |        |
|--------------|-------|-------|-------|-------|-------|------|-------|--------|
| <b>JT-61</b> | 0.004 | 0.036 | 0.010 | 0.063 | 0.018 | 0.09 | 0.021 | 0.0073 |
| <b>JT-62</b> | 0.011 | 0.035 | 0.023 | 0.064 | 0.004 | 0.10 | 0.020 | 0.012  |
| <b>JT-63</b> | 0.004 | 0.038 | 0.010 | 0.037 | 0.071 | 0.11 | 0.038 | 0.0087 |
| <b>JT-64</b> | 0.007 | 0.037 | 0.022 | 0.176 | 0.145 | 0.11 | 0.039 | 0.0476 |
| <b>JT-65</b> | 0.012 | 0.040 | 0.035 | 0.064 | 0.020 | 0.12 | 0.013 | 0.0149 |
| <b>JT-66</b> | 0.007 | 0.054 | 0.027 | 0.043 | 0.189 | 0.12 | 0.017 | 0.0078 |
| <b>JT-67</b> | 0.007 | 0.036 | 0.014 | 0.026 | 0.205 | 0.12 | 0.022 | 0.0093 |
| <b>JT-68</b> | 0.003 | 0.057 | 0.021 | 0.039 | 0.145 | 0.12 | 0.036 | 0.0153 |
| <b>JT-69</b> | 0.002 | 0.038 | 0.022 | 0.069 | 0.205 | 0.13 | 0.018 | 0.0057 |
| <b>JT-70</b> | 0.009 | 0.045 | 0.021 | 0.064 | 0.093 | 0.14 | 0.016 | 0.011  |
| <b>JT-71</b> | 0.005 | 0.053 | 0.008 | 0.065 | 0.205 | 0.14 | 0.016 | 0.009  |
| <b>JT-72</b> | 0.004 | 0.057 | 0.023 | 0.048 | 0.234 | 0.15 | 0.016 | 0.011  |
| <b>JT-73</b> | 0.007 | 0.030 | 0.016 | 0.053 | 0.039 | 0.14 | 0.024 | 0.007  |
| <b>JT-74</b> | 0.001 | 0.047 | 0.013 | 0.048 | 0.047 | 0.11 | 0.015 | 0.01   |
| <b>JT-75</b> | 0.003 | 0.038 | 0.027 | 0.037 | 0.040 | 0.11 | 0.017 | 0.017  |
| <b>JT-76</b> | 0.010 | 0.057 | 0.043 | 0.063 | 0.139 | 0.13 | 0.014 | 0.012  |
| <b>JT-77</b> | 0.006 | 0.050 | 0.029 | 0.064 | 0.001 | 0.12 | 0.036 | 0.008  |
| <b>JT-78</b> | 0.004 | 0.041 | 0.018 | 0.037 | 0.012 | 0.11 | 0.013 | 0.009  |
| <b>JT-79</b> | 0.012 | 0.038 | 0.020 | 0.055 | 0.018 | 0.23 | 0.022 | 0.009  |
| <b>JT-80</b> | 0.009 | 0.058 | 0.025 | 0.064 | 0.004 | 0.26 | 0.011 | 0.008  |
| <b>JT-81</b> | 0.010 | 0.048 | 0.040 | 0.050 | 0.071 | 0.23 | 0.018 | 0.011  |
| <b>JT-82</b> | 0.012 | 0.034 | 0.019 | 0.043 | 0.126 | 0.21 | 0.017 | 0.007  |
| <b>JT-83</b> | 0.008 | 0.038 | 0.018 | 0.086 | 0.180 | 0.23 | 0.015 | 0.007  |
| <b>JT-84</b> | 0.007 | 0.045 | 0.034 | 0.042 | 0.018 | 0.19 | 0.016 | 0.011  |

### Macro Elements (Metals) Analysis:

According to Canada permissible limit for calcium in drinking water is given as 200 mg/L. All samples of Taluka Jati posed Ca content below than permissible level. However, Samples in which Sodium (Na) content was found higher are; JT-50, JT-51, JT-52, JT-53, JT-54, JT-60, JT-61, JT-62, JT-63, JT-66, JT-69, JT-70, JT-71, JT-73 and JT-80. Uppermost and lowermost contents were observed as 279.0 and 118.0 mg/L. (Table: 2). Studies shows higher concentrations of Mg was found than Canadian water quality guideline of 50.0 mg/L are; JT-50, JT-51, JT-52, JT-53, JT-54, JT-57, JT-59, JT-60, JT-63, JT-66, JT-68, JT-69, JT-70, JT-71, JT-72, JT-73, JT-79, JT-80, JT-82, and JT-8. However minimum and maximum

concentration of Potassium is given as 1.53 and 7.0 mg/L in samples JT-60 and JT-74. [Table: 3 & Fig: (i) – (l)].

**Table: 3** Determination Of concentration (mg/L) of macro elements (metals) from Coastal Area of Taluka Jati

|          | Na                   | Ca                   | Mg                  | K                      |          | Na                   | Ca                   | Mg                  | K                      |
|----------|----------------------|----------------------|---------------------|------------------------|----------|----------------------|----------------------|---------------------|------------------------|
| Code No: | WHO Limit = 200 mg/L | WHO Limit = 200 mg/L | WHO Limit = 50 mg/L | WHO Limit = Not Listed | Code No: | WHO Limit = 200 mg/L | WHO Limit = 200 mg/L | WHO Limit = 50 mg/L | WHO Limit = Not Listed |
| JT-50    | 233                  | 155                  | 54                  | 3                      | JT-68    | 178                  | 122                  | 55                  | 4                      |
| JT-51    | 277                  | 144                  | 55                  | 3                      | JT-69    | 212                  | 81                   | 79                  | 2                      |
| JT-52    | 246                  | 135                  | 55                  | 3                      | JT-70    | 218                  | 88                   | 82                  | 3                      |
| JT-53    | 251                  | 149                  | 57                  | 2                      | JT-71    | 207                  | 77                   | 71                  | 2                      |
| JT-54    | 247                  | 163                  | 53                  | 4                      | JT-72    | 200                  | 122                  | 76                  | 3                      |
| JT-55    | 199                  | 99                   | 43                  | 5                      | JT-73    | 210                  | 133                  | 63                  | 2                      |
| JT-56    | 158                  | 76                   | 41                  | 5                      | JT-74    | 155                  | 112                  | 45                  | 7                      |
| JT-57    | 167                  | 67                   | 53                  | 4                      | JT-75    | 133                  | 87                   | 30                  | 2                      |
| JT-58    | 188                  | 99                   | 45                  | 5                      | JT-76    | 187                  | 112                  | 44                  | 3                      |
| JT-59    | 178                  | 132                  | 76                  | 4                      | JT-77    | 215                  | 117                  | 34                  | 2                      |
| JT-60    | 256                  | 145                  | 75                  | 4                      | JT-78    | 169                  | 112                  | 44                  | 2                      |
| JT-61    | 244                  | 82                   | 50                  | 5                      | JT-79    | 187                  | 82                   | 70                  | 4                      |
| JT-62    | 211                  | 122                  | 51                  | 6                      | JT-80    | 213                  | 110                  | 84                  | 5                      |
| JT-63    | 231                  | 122                  | 51                  | 5                      | JT-81    | 194                  | 99                   | 45                  | 4                      |
| JT-64    | 148                  | 67                   | 41                  | 2                      | JT-82    | 184                  | 99                   | 63                  | 4                      |
| JT-65    | 188                  | 99                   | 40                  | 3                      | JT-83    | 187                  | 112                  | 70                  | 4                      |
| JT-66    | 223                  | 76                   | 55                  | 2                      | JT-84    | 189                  | 97                   | 34                  | 5                      |
| JT-67    | 167                  | 89                   | 50                  | 2.3                    | ---      | ---                  | ---                  | ---                 | ---                    |

## NON-CARCINOGENIC RISK

### *Average Daily Dose (ADD)*

The Average Daily Dose (ADD) values presented in the table for Taluka Jati provide a quantitative measure of the daily intake of heavy metals through drinking water relative to the body weight of the consumer. When evaluating these values against the provided Oral Reference Dose (RfD), it is evident that for every single metal listed—Cadmium, Chromium, Copper, Cobalt, Manganese, Iron, Nickel, and Zinc—the calculated ADD is lower than its respective RfD. This specific relationship indicates that, based on current toxicological standards, the individual daily exposure to any one of these metals is not expected to cause immediate or chronic non-carcinogenic health effects.

Compared to metals like zinc or iron, where the gap between the dose and the limit is much wider, the ADD for chromium, which ranges roughly from  $8.57 \times 10^{-4}$  to  $1.66 \times 10^{-3}$ , is still below the threshold of 0.003 but represents a sizable portion of the allowable daily limit. Manganese exhibits significant variation among the JT codes; some values, such as  $1.43 \times 10^{-2}$  in JT-50, are significantly higher than others, but even these peaks are still an order of magnitude below the RfD of 0.14. Because their ADD values are so small compared to their allowable daily intake levels, iron and zinc consistently exhibit the lowest risk profiles in the dosage table.

While the ADD values themselves suggest safety for individual non-carcinogenic endpoints, the interpretation for the coastal area of Jati must account for the fact that these dosages occur simultaneously. In environmental toxicology, while each ADD is below the limit, the additive effect of consuming multiple metals at these levels every day for thirty years or more is what typically drives the overall risk index higher. The presence of Cadmium and Nickel at these dosage levels is particularly noteworthy for a coastal deltaic region, as these are often mobilized by increasing salinity and seawater intrusion, making even these "sub-limit" doses a critical factor in long-term public health monitoring for the local community (Table: 4).

Table: 4 Estimated Average Daily Dose (ADD) of Heavy Metals via Drinking Water Ingestion by Sampling Site

| Code No      | Cd                    | Cr                    | Cu                    | Co                    | Mn                    | Fe                    | Ni                    | Zn                    |
|--------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>RfD</b>   | <b>0.0005</b>         | <b>0.003</b>          | <b>0.04</b>           | <b>0.03</b>           | <b>0.14</b>           | <b>0.7</b>            | <b>0.02</b>           | <b>0.3</b>            |
| <b>JT-50</b> | $1.43 \times 10^{-4}$ | $9.43 \times 10^{-4}$ | $4.00 \times 10^{-4}$ | $1.57 \times 10^{-3}$ | $1.43 \times 10^{-2}$ | $3.14 \times 10^{-3}$ | $5.43 \times 10^{-4}$ | $2.54 \times 10^{-4}$ |
| <b>JT-51</b> | $2.29 \times 10^{-4}$ | $1.20 \times 10^{-3}$ | $6.00 \times 10^{-4}$ | $1.83 \times 10^{-3}$ | $8.00 \times 10^{-4}$ | $3.71 \times 10^{-3}$ | $3.71 \times 10^{-4}$ | $3.11 \times 10^{-4}$ |
| <b>JT-52</b> | $1.71 \times 10^{-4}$ | $1.00 \times 10^{-3}$ | $6.57 \times 10^{-4}$ | $1.43 \times 10^{-3}$ | $2.86 \times 10^{-5}$ | $3.14 \times 10^{-3}$ | $4.86 \times 10^{-4}$ | $3.91 \times 10^{-4}$ |
| <b>JT-53</b> | $5.71 \times 10^{-5}$ | $1.34 \times 10^{-3}$ | $1.34 \times 10^{-3}$ | $1.23 \times 10^{-3}$ | $4.20 \times 10^{-3}$ | $3.71 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $1.97 \times 10^{-4}$ |
| <b>JT-54</b> | $8.57 \times 10^{-5}$ | $1.34 \times 10^{-3}$ | $1.17 \times 10^{-3}$ | $2.29 \times 10^{-3}$ | $4.34 \times 10^{-3}$ | $2.86 \times 10^{-3}$ | $3.71 \times 10^{-4}$ | $3.60 \times 10^{-4}$ |
| <b>JT-55</b> | $1.14 \times 10^{-4}$ | $1.31 \times 10^{-3}$ | $6.57 \times 10^{-4}$ | $1.94 \times 10^{-3}$ | $1.54 \times 10^{-3}$ | $3.43 \times 10^{-3}$ | $6.00 \times 10^{-4}$ | $1.22 \times 10^{-3}$ |

|              |                       |                       |                       |                       |                       |                       |                       |                       |
|--------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>JT-56</b> | $1.14 \times 10^{-4}$ | $1.20 \times 10^{-3}$ | $1.03 \times 10^{-3}$ | $1.89 \times 10^{-3}$ | $2.26 \times 10^{-3}$ | $3.71 \times 10^{-3}$ | $1.03 \times 10^{-3}$ | $2.74 \times 10^{-4}$ |
| <b>JT-57</b> | $1.43 \times 10^{-4}$ | $1.14 \times 10^{-3}$ | $1.03 \times 10^{-3}$ | $1.23 \times 10^{-3}$ | $2.86 \times 10^{-4}$ | $4.00 \times 10^{-3}$ | $6.86 \times 10^{-4}$ | $3.54 \times 10^{-4}$ |
| <b>JT-58</b> | $2.86 \times 10^{-4}$ | $1.31 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $2.29 \times 10^{-3}$ | $2.63 \times 10^{-3}$ | $4.00 \times 10^{-3}$ | $4.00 \times 10^{-4}$ | $2.40 \times 10^{-4}$ |
| <b>JT-59</b> | $3.14 \times 10^{-4}$ | $1.43 \times 10^{-3}$ | $1.37 \times 10^{-3}$ | $1.94 \times 10^{-3}$ | $2.86 \times 10^{-5}$ | $2.57 \times 10^{-3}$ | $6.29 \times 10^{-4}$ | $2.69 \times 10^{-4}$ |
| <b>JT-60</b> | $1.14 \times 10^{-4}$ | $1.40 \times 10^{-3}$ | $1.17 \times 10^{-3}$ | $1.89 \times 10^{-3}$ | $3.43 \times 10^{-4}$ | $2.86 \times 10^{-3}$ | $8.86 \times 10^{-4}$ | $2.54 \times 10^{-4}$ |
| <b>JT-61</b> | $1.14 \times 10^{-4}$ | $1.03 \times 10^{-3}$ | $2.86 \times 10^{-4}$ | $1.80 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $2.57 \times 10^{-3}$ | $6.00 \times 10^{-4}$ | $2.09 \times 10^{-4}$ |
| <b>JT-62</b> | $3.14 \times 10^{-4}$ | $1.00 \times 10^{-3}$ | $6.57 \times 10^{-4}$ | $1.83 \times 10^{-3}$ | $1.14 \times 10^{-4}$ | $2.86 \times 10^{-3}$ | $5.71 \times 10^{-4}$ | $3.43 \times 10^{-4}$ |
| <b>JT-63</b> | $1.14 \times 10^{-4}$ | $1.09 \times 10^{-3}$ | $2.86 \times 10^{-4}$ | $1.06 \times 10^{-3}$ | $2.03 \times 10^{-3}$ | $3.14 \times 10^{-3}$ | $1.09 \times 10^{-3}$ | $2.49 \times 10^{-4}$ |
| <b>JT-64</b> | $2.00 \times 10^{-4}$ | $1.06 \times 10^{-3}$ | $6.29 \times 10^{-4}$ | $5.03 \times 10^{-3}$ | $4.14 \times 10^{-3}$ | $3.14 \times 10^{-3}$ | $1.11 \times 10^{-3}$ | $1.36 \times 10^{-3}$ |
| <b>JT-65</b> | $3.43 \times 10^{-4}$ | $1.14 \times 10^{-3}$ | $1.00 \times 10^{-3}$ | $1.83 \times 10^{-3}$ | $5.71 \times 10^{-4}$ | $3.43 \times 10^{-3}$ | $3.71 \times 10^{-4}$ | $4.26 \times 10^{-4}$ |
| <b>JT-66</b> | $2.00 \times 10^{-4}$ | $1.54 \times 10^{-3}$ | $7.71 \times 10^{-4}$ | $1.23 \times 10^{-3}$ | $5.40 \times 10^{-3}$ | $3.43 \times 10^{-3}$ | $4.86 \times 10^{-4}$ | $2.23 \times 10^{-4}$ |
| <b>JT-67</b> | $2.00 \times 10^{-4}$ | $1.03 \times 10^{-3}$ | $4.00 \times 10^{-4}$ | $7.43 \times 10^{-4}$ | $5.86 \times 10^{-3}$ | $3.43 \times 10^{-3}$ | $6.29 \times 10^{-4}$ | $2.66 \times 10^{-4}$ |
| <b>JT-68</b> | $8.57 \times 10^{-5}$ | $1.63 \times 10^{-3}$ | $6.00 \times 10^{-4}$ | $1.11 \times 10^{-3}$ | $4.14 \times 10^{-3}$ | $3.43 \times 10^{-3}$ | $1.03 \times 10^{-3}$ | $4.37 \times 10^{-4}$ |
| <b>JT-69</b> | $5.71 \times 10^{-5}$ | $1.09 \times 10^{-3}$ | $6.29 \times 10^{-4}$ | $1.97 \times 10^{-3}$ | $5.86 \times 10^{-3}$ | $3.71 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $1.63 \times 10^{-4}$ |
| <b>JT-70</b> | $2.57 \times 10^{-4}$ | $1.29 \times 10^{-3}$ | $6.00 \times 10^{-4}$ | $1.83 \times 10^{-3}$ | $2.66 \times 10^{-3}$ | $4.00 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $3.14 \times 10^{-4}$ |
| <b>JT-71</b> | $1.43 \times 10^{-4}$ | $1.51 \times 10^{-3}$ | $2.29 \times 10^{-4}$ | $1.86 \times 10^{-3}$ | $5.86 \times 10^{-3}$ | $4.00 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $2.57 \times 10^{-4}$ |
| <b>JT-72</b> | $1.14 \times 10^{-4}$ | $1.63 \times 10^{-3}$ | $6.57 \times 10^{-4}$ | $1.37 \times 10^{-3}$ | $6.69 \times 10^{-3}$ | $4.29 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $3.14 \times 10^{-4}$ |
| <b>JT-73</b> | $2.00 \times 10^{-4}$ | $8.57 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $1.51 \times 10^{-3}$ | $1.11 \times 10^{-3}$ | $4.00 \times 10^{-3}$ | $6.86 \times 10^{-4}$ | $2.00 \times 10^{-4}$ |
| <b>JT-74</b> | $2.86 \times 10^{-5}$ | $1.34 \times 10^{-3}$ | $3.71 \times 10^{-4}$ | $1.37 \times 10^{-3}$ | $1.34 \times 10^{-3}$ | $3.14 \times 10^{-3}$ | $4.29 \times 10^{-4}$ | $2.86 \times 10^{-4}$ |
| <b>JT-75</b> | $8.57 \times 10^{-5}$ | $1.09 \times 10^{-3}$ | $7.71 \times 10^{-4}$ | $1.06 \times 10^{-3}$ | $1.14 \times 10^{-3}$ | $3.14 \times 10^{-3}$ | $4.86 \times 10^{-4}$ | $4.86 \times 10^{-4}$ |
| <b>JT-76</b> | $2.86 \times 10^{-4}$ | $1.63 \times 10^{-3}$ | $1.23 \times 10^{-3}$ | $1.80 \times 10^{-3}$ | $3.97 \times 10^{-3}$ | $3.71 \times 10^{-3}$ | $4.00 \times 10^{-4}$ | $3.43 \times 10^{-4}$ |
| <b>JT-77</b> | $1.71 \times 10^{-4}$ | $1.43 \times 10^{-3}$ | $8.29 \times 10^{-4}$ | $1.83 \times 10^{-3}$ | $2.86 \times 10^{-5}$ | $3.43 \times 10^{-3}$ | $1.03 \times 10^{-3}$ | $2.29 \times 10^{-4}$ |
| <b>JT-78</b> | $1.14 \times 10^{-4}$ | $1.17 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $1.06 \times 10^{-3}$ | $3.43 \times 10^{-4}$ | $3.14 \times 10^{-3}$ | $3.71 \times 10^{-4}$ | $2.57 \times 10^{-4}$ |
| <b>JT-79</b> | $3.43 \times 10^{-4}$ | $1.09 \times 10^{-3}$ | $5.71 \times 10^{-4}$ | $1.57 \times 10^{-3}$ | $5.14 \times 10^{-3}$ | $6.57 \times 10^{-3}$ | $6.29 \times 10^{-4}$ | $2.57 \times 10^{-4}$ |
| <b>JT-80</b> | $2.57 \times 10^{-4}$ | $1.66 \times 10^{-3}$ | $7.14 \times 10^{-4}$ | $1.83 \times 10^{-3}$ | $1.14 \times 10^{-4}$ | $7.43 \times 10^{-3}$ | $3.14 \times 10^{-4}$ | $2.29 \times 10^{-4}$ |
| <b>JT-81</b> | $2.86 \times 10^{-4}$ | $1.37 \times 10^{-3}$ | $1.14 \times 10^{-3}$ | $1.43 \times 10^{-3}$ | $2.03 \times 10^{-3}$ | $6.57 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $3.14 \times 10^{-4}$ |
| <b>JT-82</b> | $3.43 \times 10^{-4}$ | $9.71 \times 10^{-3}$ | $5.43 \times 10^{-4}$ | $1.23 \times 10^{-3}$ | $3.60 \times 10^{-3}$ | $6.00 \times 10^{-3}$ | $4.86 \times 10^{-4}$ | $2.00 \times 10^{-4}$ |
| <b>JT-83</b> | $2.29 \times 10^{-4}$ | $1.09 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $2.46 \times 10^{-3}$ | $5.14 \times 10^{-3}$ | $6.57 \times 10^{-3}$ | $4.29 \times 10^{-4}$ | $2.00 \times 10^{-4}$ |
| <b>JT-84</b> | $2.00 \times 10^{-4}$ | $1.29 \times 10^{-3}$ | $9.71 \times 10^{-4}$ | $1.20 \times 10^{-3}$ | $5.14 \times 10^{-4}$ | $5.43 \times 10^{-3}$ | $4.57 \times 10^{-4}$ | $3.14 \times 10^{-4}$ |

### *Hazard Quotient (HQ)*

The main metrics used to evaluate the non-carcinogenic health risks related to heavy metal consumption in the Taluka Jati coastal region are the Hazard Quotient (HQ) and Hazard Index (HI).

### *Hazard Quotient (HQ) Analysis*

The HQ reflects the ratio of a metal's exposure dosage to its reference dose. A value of HQ greater than one indicates that a single metal offers a possible health danger. All individual HQ values for metals such as copper (Cu), cobalt (Co), manganese (Mn), iron (Fe), nickel (Ni), and zinc (Zn) are much lower than the threshold of 1.0 in the data supplied. However, Cadmium (Cd) and Chromium (Cr) regularly have the highest HQ values, frequently reaching 0.5. While no single element exceeds the 1.0 limit on its own, Cd and Cr have significant levels, indicating that they are the primary contributors to the toxicological profile of the water in this location.

The Hazard Index (HI) is the total of the HQs for each metal evaluated in a sample. It offers a picture of the overall non-cancerous risk. Several samples (JT-58, JT-59, JT-62, JT-64, JT-65, JT-66, JT-70, JT-76, JT-79, JT-80, JT-81, and JT-82) show an  $HI > 1$ . This is an important discovery since an HI larger than unity suggests that the combined effect of these metals may constitute a chronic health risk to the local people throughout the course of their intake.

The shift from safe individual HQs to harmful cumulative HI values emphasizes the risk of "cocktail effects" in polluted water. Even if each metal is within its individual limit, its presence in Jati's coastal groundwater produces a high-risk environment. The samples with  $HI > 1$  are predominantly driven by the interaction of Cadmium and Chromium. This shows that the water in these specific places is unfit for long-term consumption unless properly filtered or treated to lower heavy metal levels (Table 5).

Table: 5 Hazard Quotient (HQ) and Hazard Index (HI) for Heavy Metal Exposure via Drinking Water

| Code         | Cd    | Cr    | Cu    | Co    | Mn    | Fe    | Ni    | Zn    | HI           |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------|
| <b>JT-50</b> | 0.286 | 0.314 | 0.010 | 0.052 | 0.102 | 0.004 | 0.027 | 0.001 | <b>0.797</b> |
| <b>JT-51</b> | 0.457 | 0.400 | 0.015 | 0.061 | 0.006 | 0.005 | 0.019 | 0.001 | <b>0.964</b> |
| <b>JT-52</b> | 0.343 | 0.333 | 0.016 | 0.048 | 0.000 | 0.004 | 0.024 | 0.001 | <b>0.771</b> |
| <b>JT-53</b> | 0.114 | 0.448 | 0.034 | 0.041 | 0.030 | 0.005 | 0.023 | 0.001 | <b>0.695</b> |
| <b>JT-54</b> | 0.171 | 0.448 | 0.029 | 0.076 | 0.031 | 0.004 | 0.019 | 0.001 | <b>0.779</b> |

|              |       |       |       |       |       |       |       |       |              |
|--------------|-------|-------|-------|-------|-------|-------|-------|-------|--------------|
| <b>JT-55</b> | 0.229 | 0.438 | 0.016 | 0.065 | 0.011 | 0.005 | 0.030 | 0.004 | <b>0.798</b> |
| <b>JT-56</b> | 0.229 | 0.400 | 0.026 | 0.063 | 0.016 | 0.005 | 0.051 | 0.001 | <b>0.791</b> |
| <b>JT-57</b> | 0.286 | 0.381 | 0.026 | 0.041 | 0.002 | 0.006 | 0.034 | 0.001 | <b>0.777</b> |
| <b>JT-58</b> | 0.571 | 0.438 | 0.013 | 0.076 | 0.019 | 0.006 | 0.020 | 0.001 | <b>1.144</b> |
| <b>JT-59</b> | 0.629 | 0.476 | 0.034 | 0.065 | 0.000 | 0.004 | 0.031 | 0.001 | <b>1.240</b> |
| <b>JT-60</b> | 0.229 | 0.467 | 0.029 | 0.063 | 0.002 | 0.004 | 0.044 | 0.001 | <b>0.839</b> |
| <b>JT-61</b> | 0.229 | 0.343 | 0.007 | 0.060 | 0.004 | 0.004 | 0.030 | 0.001 | <b>0.677</b> |
| <b>JT-62</b> | 0.629 | 0.333 | 0.016 | 0.061 | 0.001 | 0.004 | 0.029 | 0.001 | <b>1.074</b> |
| <b>JT-63</b> | 0.229 | 0.362 | 0.007 | 0.035 | 0.014 | 0.004 | 0.054 | 0.001 | <b>0.707</b> |
| <b>JT-64</b> | 0.400 | 0.352 | 0.016 | 0.168 | 0.030 | 0.004 | 0.056 | 0.005 | <b>1.031</b> |
| <b>JT-65</b> | 0.686 | 0.381 | 0.025 | 0.061 | 0.004 | 0.005 | 0.019 | 0.001 | <b>1.182</b> |
| <b>JT-66</b> | 0.400 | 0.514 | 0.019 | 0.041 | 0.039 | 0.005 | 0.024 | 0.001 | <b>1.043</b> |
| <b>JT-67</b> | 0.400 | 0.343 | 0.010 | 0.025 | 0.042 | 0.005 | 0.031 | 0.001 | <b>0.857</b> |
| <b>JT-68</b> | 0.171 | 0.543 | 0.015 | 0.037 | 0.030 | 0.005 | 0.051 | 0.001 | <b>0.854</b> |
| <b>JT-69</b> | 0.114 | 0.362 | 0.016 | 0.066 | 0.042 | 0.005 | 0.026 | 0.001 | <b>0.632</b> |
| <b>JT-70</b> | 0.514 | 0.429 | 0.015 | 0.061 | 0.019 | 0.006 | 0.023 | 0.001 | <b>1.068</b> |
| <b>JT-71</b> | 0.286 | 0.505 | 0.006 | 0.062 | 0.042 | 0.006 | 0.023 | 0.001 | <b>0.930</b> |
| <b>JT-72</b> | 0.229 | 0.543 | 0.016 | 0.046 | 0.048 | 0.006 | 0.023 | 0.001 | <b>0.912</b> |
| <b>JT-73</b> | 0.400 | 0.286 | 0.011 | 0.050 | 0.008 | 0.006 | 0.034 | 0.001 | <b>0.796</b> |
| <b>JT-74</b> | 0.057 | 0.448 | 0.009 | 0.046 | 0.010 | 0.004 | 0.021 | 0.001 | <b>0.596</b> |
| <b>JT-75</b> | 0.171 | 0.362 | 0.019 | 0.035 | 0.008 | 0.004 | 0.024 | 0.002 | <b>0.626</b> |
| <b>JT-76</b> | 0.571 | 0.543 | 0.031 | 0.060 | 0.028 | 0.005 | 0.020 | 0.001 | <b>1.260</b> |
| <b>JT-77</b> | 0.343 | 0.476 | 0.021 | 0.061 | 0.000 | 0.005 | 0.051 | 0.001 | <b>0.958</b> |
| <b>JT-78</b> | 0.229 | 0.390 | 0.013 | 0.035 | 0.002 | 0.004 | 0.019 | 0.001 | <b>0.694</b> |
| <b>JT-79</b> | 0.686 | 0.362 | 0.014 | 0.052 | 0.004 | 0.009 | 0.031 | 0.001 | <b>1.160</b> |
| <b>JT-80</b> | 0.514 | 0.552 | 0.018 | 0.061 | 0.001 | 0.011 | 0.016 | 0.001 | <b>1.154</b> |
| <b>JT-81</b> | 0.571 | 0.457 | 0.029 | 0.048 | 0.014 | 0.009 | 0.026 | 0.001 | <b>1.156</b> |
| <b>JT-82</b> | 0.686 | 0.324 | 0.014 | 0.041 | 0.026 | 0.009 | 0.024 | 0.001 | <b>1.124</b> |
| <b>JT-83</b> | 0.457 | 0.362 | 0.013 | 0.082 | 0.037 | 0.009 | 0.021 | 0.001 | <b>0.982</b> |
| <b>JT-84</b> | 0.400 | 0.429 | 0.024 | 0.040 | 0.004 | 0.008 | 0.023 | 0.001 | <b>0.929</b> |

## CARCINOGENIC RISK

The carcinogenic risk assessment for the drinking water samples from Taluka Jati focuses on the probability of developing cancer over a lifetime due to exposure to Chromium (Cr), Cadmium (Cd), and Nickel (Ni). According to the table, the risk values for individual metals are expressed in scientific notation, where  $10^{-4}$  represents a 1 in 10,000 chance and  $10^{-3}$  represents a 1 in 1,000 chance. Nickel and Chromium emerge as the most significant contributors to the overall risk profile across all sampling locations. For example, in sample JT-68, the risk from Nickel alone is  $7.50 \times 10^{-4}$  and Chromium contribute  $3.50 \times 10^{-4}$ , leading to one of the highest total risks in the dataset. The total cancer risk (TCR) is calculated by adding these individual probabilities. The tolerable minimum risk range, as defined by the US EPA, is normally between  $10^{-6}$  (1 in 1,000,000) and  $10^{-4}$  (1 in 10,000). TCR values from JT-

50 to JT-84 consistently above the  $1.00 \times 10^{-4}$  threshold. The values vary from  $5.41 \times 10^{-4}$  at JT-78 to  $1.11 \times 10^{-3}$  at JT-68.

Because every sample had a TCR more than the allowed limit of  $10^{-4}$ , the findings suggest that long-term intake of this water offers a serious carcinogenic risk to the local people. Specifically, a TCR of  $1.11 \times 10^{-3}$  implies that for every 1,000 people drinking this water over a 70-year lifetime, approximately one additional case of cancer could occur due to these heavy metals. This data underscores an urgent need for water management strategies in these coastal areas to mitigate the concentrations of Nickel and Chromium in the drinking supply (Table: 6).

Table: 6 Estimated Incremental Lifetime Cancer Risk (ILCR) and Total Cancer Risk (TCR) via Drinking Water Ingestion

| Code         | Risk (Cr)             | Risk (Cd)             | Risk (Ni)             | Total Cancer Risk (TCR)                 |
|--------------|-----------------------|-----------------------|-----------------------|---|
| <b>JT-50</b> | $2.02 \times 10^{-4}$ | $2.33 \times 10^{-5}$ | $3.96 \times 10^{-4}$ | <b><math>6.21 \times 10^{-4}</math></b> |
| <b>JT-51</b> | $2.57 \times 10^{-4}$ | $3.73 \times 10^{-5}$ | $2.71 \times 10^{-4}$ | <b><math>5.65 \times 10^{-4}</math></b> |
| <b>JT-52</b> | $2.14 \times 10^{-4}$ | $2.80 \times 10^{-5}$ | $3.54 \times 10^{-4}$ | <b><math>5.96 \times 10^{-4}</math></b> |
| <b>JT-53</b> | $2.88 \times 10^{-4}$ | $9.33 \times 10^{-6}$ | $3.33 \times 10^{-4}$ | <b><math>6.30 \times 10^{-4}</math></b> |
| <b>JT-54</b> | $2.88 \times 10^{-4}$ | $1.40 \times 10^{-5}$ | $2.71 \times 10^{-4}$ | <b><math>5.72 \times 10^{-4}</math></b> |
| <b>JT-55</b> | $2.82 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $4.37 \times 10^{-4}$ | <b><math>7.38 \times 10^{-4}</math></b> |
| <b>JT-56</b> | $2.57 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $7.50 \times 10^{-4}$ | <b><math>1.03 \times 10^{-3}</math></b> |
| <b>JT-57</b> | $2.45 \times 10^{-4}$ | $2.33 \times 10^{-5}$ | $5.00 \times 10^{-4}$ | <b><math>7.68 \times 10^{-4}</math></b> |
| <b>JT-58</b> | $2.82 \times 10^{-4}$ | $4.66 \times 10^{-5}$ | $2.92 \times 10^{-4}$ | <b><math>6.20 \times 10^{-4}</math></b> |
| <b>JT-59</b> | $3.07 \times 10^{-4}$ | $5.13 \times 10^{-5}$ | $4.58 \times 10^{-4}$ | <b><math>8.16 \times 10^{-4}</math></b> |
| <b>JT-60</b> | $3.00 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $6.46 \times 10^{-4}$ | <b><math>9.65 \times 10^{-4}</math></b> |
| <b>JT-61</b> | $2.21 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $4.37 \times 10^{-4}$ | <b><math>6.77 \times 10^{-4}</math></b> |
| <b>JT-62</b> | $2.14 \times 10^{-4}$ | $5.13 \times 10^{-5}$ | $4.17 \times 10^{-4}$ | <b><math>6.82 \times 10^{-4}</math></b> |
| <b>JT-63</b> | $2.33 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $7.91 \times 10^{-4}$ | <b><math>1.04 \times 10^{-3}</math></b> |
| <b>JT-64</b> | $2.27 \times 10^{-4}$ | $3.26 \times 10^{-5}$ | $8.12 \times 10^{-4}$ | <b><math>1.07 \times 10^{-3}</math></b> |
| <b>JT-65</b> | $2.45 \times 10^{-4}$ | $5.59 \times 10^{-5}$ | $2.71 \times 10^{-4}$ | <b><math>5.72 \times 10^{-4}</math></b> |
| <b>JT-66</b> | $3.31 \times 10^{-4}$ | $3.26 \times 10^{-5}$ | $3.54 \times 10^{-4}$ | <b><math>7.18 \times 10^{-4}</math></b> |

|              |                       |                       |                       |                       |
|--------------|-----------------------|-----------------------|-----------------------|-----------------------|
| <b>JT-67</b> | $2.21 \times 10^{-4}$ | $3.26 \times 10^{-5}$ | $4.58 \times 10^{-4}$ | $7.11 \times 10^{-4}$ |
| <b>JT-68</b> | $3.50 \times 10^{-4}$ | $1.40 \times 10^{-5}$ | $7.50 \times 10^{-4}$ | $1.11 \times 10^{-3}$ |
| <b>JT-69</b> | $2.33 \times 10^{-4}$ | $9.33 \times 10^{-6}$ | $3.75 \times 10^{-4}$ | $6.17 \times 10^{-4}$ |
| <b>JT-70</b> | $2.76 \times 10^{-4}$ | $4.20 \times 10^{-5}$ | $3.33 \times 10^{-4}$ | $6.51 \times 10^{-4}$ |
| <b>JT-71</b> | $3.25 \times 10^{-4}$ | $2.33 \times 10^{-5}$ | $3.33 \times 10^{-4}$ | $6.81 \times 10^{-4}$ |
| <b>JT-72</b> | $3.50 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $3.33 \times 10^{-4}$ | $7.01 \times 10^{-4}$ |
| <b>JT-73</b> | $1.84 \times 10^{-4}$ | $3.26 \times 10^{-5}$ | $5.00 \times 10^{-4}$ | $7.16 \times 10^{-4}$ |
| <b>JT-74</b> | $2.88 \times 10^{-4}$ | $4.66 \times 10^{-6}$ | $3.12 \times 10^{-4}$ | $6.05 \times 10^{-4}$ |
| <b>JT-75</b> | $2.33 \times 10^{-4}$ | $1.40 \times 10^{-5}$ | $3.54 \times 10^{-4}$ | $6.01 \times 10^{-4}$ |
| <b>JT-76</b> | $3.50 \times 10^{-4}$ | $4.66 \times 10^{-5}$ | $2.92 \times 10^{-4}$ | $6.88 \times 10^{-4}$ |
| <b>JT-77</b> | $3.07 \times 10^{-4}$ | $2.80 \times 10^{-5}$ | $7.50 \times 10^{-4}$ | $1.08 \times 10^{-3}$ |
| <b>JT-78</b> | $2.51 \times 10^{-4}$ | $1.86 \times 10^{-5}$ | $2.71 \times 10^{-4}$ | $5.41 \times 10^{-4}$ |
| <b>JT-79</b> | $2.33 \times 10^{-4}$ | $5.59 \times 10^{-5}$ | $4.58 \times 10^{-4}$ | $7.47 \times 10^{-4}$ |
| <b>JT-80</b> | $3.56 \times 10^{-4}$ | $4.20 \times 10^{-5}$ | $2.29 \times 10^{-4}$ | $6.27 \times 10^{-4}$ |
| <b>JT-81</b> | $2.94 \times 10^{-4}$ | $4.66 \times 10^{-5}$ | $3.75 \times 10^{-4}$ | $7.16 \times 10^{-4}$ |
| <b>JT-82</b> | $2.08 \times 10^{-4}$ | $5.59 \times 10^{-5}$ | $3.54 \times 10^{-4}$ | $6.18 \times 10^{-4}$ |
| <b>JT-83</b> | $2.33 \times 10^{-4}$ | $3.73 \times 10^{-5}$ | $3.12 \times 10^{-4}$ | $5.83 \times 10^{-4}$ |
| <b>JT-84</b> | $2.76 \times 10^{-4}$ | $3.26 \times 10^{-5}$ | $3.33 \times 10^{-4}$ | $6.42 \times 10^{-4}$ |

### STATISTICAL ANALYSIS OF CHEMICAL PARAMETERS

Mean values of Cadmium (Cd), Manganese (Mn) and Nickel (Ni) were found higher than permissible level suggested by WHO or EU. Heavy metals were also correlated with each other which showed that Cu and Cr are weakly positively correlated, Fe and Cd are weakly positively correlated and Zn and Co are also positively correlated with each other, however their correlation was little bit strong at significant level of  $p < 0.01$  and  $p < 0.05$ . Calcium was positively correlated with sodium ( $0.602^{**}$ ), whereas magnesium and sodium ( $0.535^{**}$ ) also positively correlated with each other. Strong positive correlation of Magnesium and calcium was observed ( $0.849^{**}$ ) at significant level of 0.000. Positive correlation shows that the source of contamination of water due to heavy metals may be the same (Table: 7 & 8).

**Table: 7** Correlation Coefficient among heavy metals

| Parameter | Cd      | Cr     | Cu         | Co      | Mn         | Fe         | Ni   | Zn |
|-----------|---------|--------|------------|---------|------------|------------|------|----|
| <b>Cd</b> | 1       |        |            |         |            |            |      |    |
| <b>Cr</b> | -0.085  | 1      |            |         |            |            |      |    |
| <b>Cu</b> | 0.118   | 0.372* | 1          |         |            |            |      |    |
| <b>Co</b> | 0.145   | -0.059 | 0.038      | 1       |            |            |      |    |
| <b>Mn</b> | -0.21   | -0.002 | -<br>0.234 | 0.056   | 1          |            |      |    |
| <b>Fe</b> | 0.447** | 0.112  | -<br>0.017 | -0.056  | -0.04      | 1          |      |    |
| <b>Ni</b> | -0.214  | -0.102 | -<br>0.028 | 0.243   | -<br>0.071 | -<br>0.275 | 1    |    |
| <b>Zn</b> | -0.066  | -0.035 | 0.006      | 0.611** | -<br>0.033 | -<br>0.201 | 0.28 | 1  |

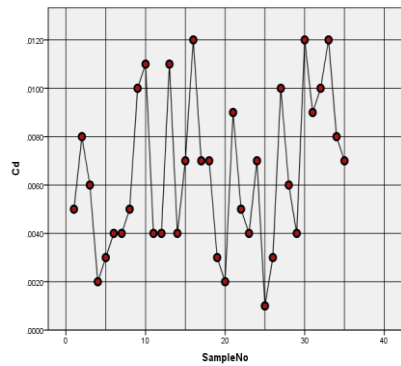
\*\* . Correlation is significant at the 0.01 level (2-tailed).

\* . Correlation is significant at the 0.05 level (2-tailed).

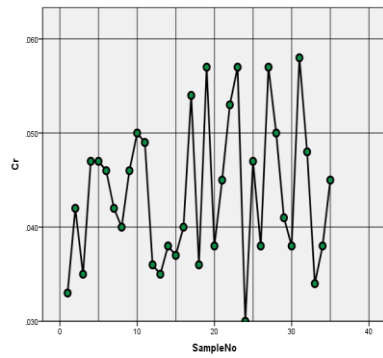
**Table: 8** Correlation co-efficient among macro elements (metals) in the groundwater of Taluka Jati

|                       | Sodium (Na) | Calcium (Ca) | Magnesium (Mg) | Potassium (K) |
|-----------------------|-------------|--------------|----------------|---------------|
| <b>Sodium (Na)</b>    | 1.000       |              |                |               |
| <b>Calcium (Ca)</b>   | 0.602**     | 1.000        |                |               |
| <b>Magnesium (Mg)</b> | 0.535**     | 0.849**      | 1.000          |               |
| <b>Potassium (K)</b>  | 0.248       | 0.214        | 0.175          | 1.000         |

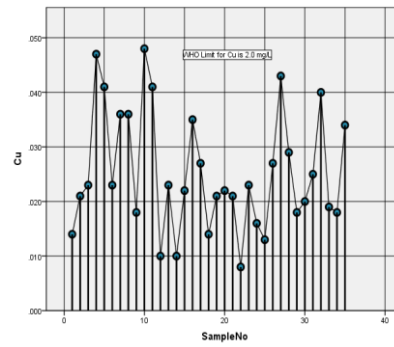
\*\* . Correlation is significant at the 0.01 level (2-tailed).



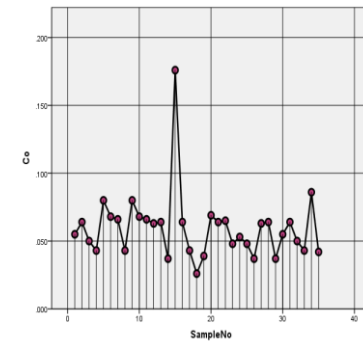
(a)



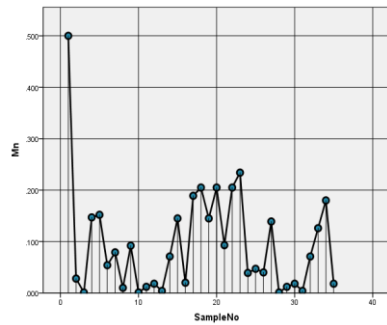
(b)



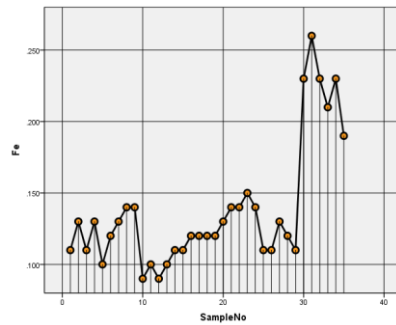
(c)



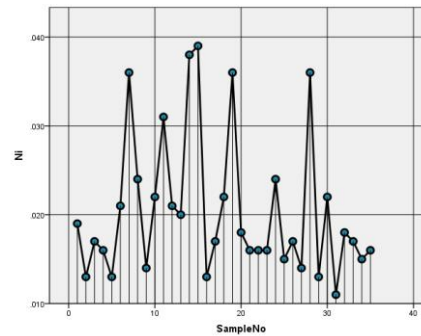
(d)



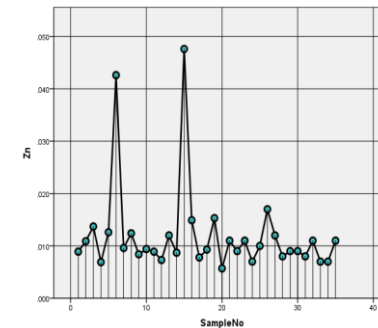
(e)



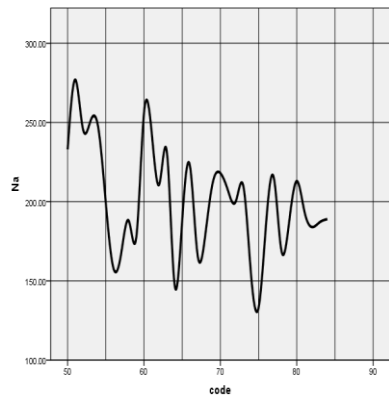
(f)



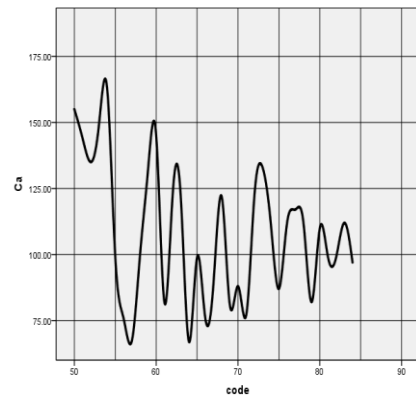
(g)



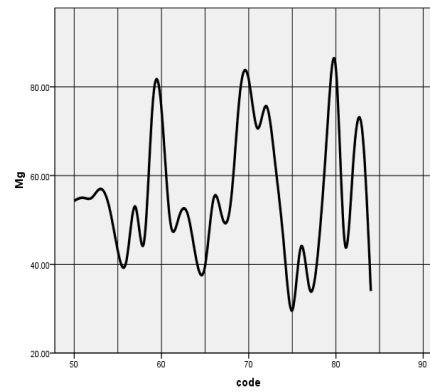
(h)



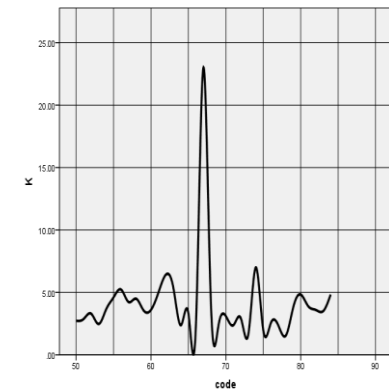
(i)



(j)



(k)



(l)

**Figure 2:** Variations in concentrations of Arsenic and heavy metals in different ground water samples of Taluka Jati. Figure(a) Cadmium (b) Chromium (c) Copper (d) Cobalt (e) Manganese (f) Iron (g) Nickel (h) Zinc (i) Sodium (j) Calcium (k) Magnesium (l) Potassium Concentrations

## Conclusions

A risk assessment of heavy metals in drinking water across Taluka Jati reveals significant contamination. Cadmium (Cd) concentrations exceeded WHO permissible limits in 82.7% of samples, while Cobalt (Co), Nickel (Ni), and Manganese (Mn) exceeded limits in 60%, 54.3%, and 37.1% of samples, respectively. Sodium (Na) and Magnesium (Mg) also surpassed safety thresholds in 42.8% and 60% of cases, though Calcium (Ca) and Potassium (K) remained within safe levels. The non-carcinogenic Hazard Index (HI) exceeded the safety threshold ( $HI > 1$ ) at 35% of sites, primarily driven by Cadmium and Chromium. Furthermore, the Total Cancer Risk (TCR) surpassed the acceptable limit ( $1 \times 10^{-4}$ ) at nearly all locations, peaking at  $1.11 \times 10^{-3}$  at site JT-68. This suggests a high lifetime probability of cancer for the exposed population. The study concludes that these water sources are unsafe for long-term consumption without treatment. Immediate intervention is required to identify contamination sources—likely industrial or geological—and to implement effective filtration and remediation strategies to safeguard public health in the region.

## Author Contribution

Abdul Raheem Shar conceptualized, collected samples, designed experiments, Dr. Liaquat Ali Shar and Seema Sarwar Ghumro collected data and prepared the draft of the article, Rabia Parveen Memon and Ammat - ur - Rehman Soomro interpreted the data Farzana Mangrio, performed water analysis, all authors read, revised, and approved the final version of the manuscript.

## Acknowledgements

The authors acknowledge the facilities provided by the Institute of Chemistry, Shah Abdul Latif University Khairpur and also technical support provided by department of water quality laboratory Pakistan Council of Research in water resources.

## Conflict of Interest

The authors declare no conflict of interest

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