Heavy metal monitoring and irrigational suitability of water in the midland Paddy fields - A case study in South India

Mohan Meethu* and Jaya D.S.
Department of Environmental Sciences, University of Kerala, Thiruvananthapuram, Kerala, INDIA
*meethuvijayamohan@gmail.com

Abstract
A detailed study was performed to monitor the heavy metals and the irrigation suitability of water in the midland paddy fields of Kerala during the summer season of the year 2017. The water from the Ithikkara River was used for irrigating the midland paddy fields of the study area. Five water samples were collected from the irrigation water channels, arising from the Ithikkara River including one water sample from the river. The water samples were analyzed for the physicochemical variables and heavy metals like chromium, zinc, iron, lead, cadmium and copper. Irrigational suitability indices and the water quality criteria for irrigation were determined.

Results showed that heavy metals like chromium and copper exceeded the maximum recommended concentration for agriculture. This is due to the application of chemical fertilizers like urea, muriate of potash and calcium phosphate in the paddy fields prior to sowing during cultivation. Kelly's index values of the water samples in the study sites are below one suggesting not suitable for irrigation. However, some indices like sodium percentage, permeability index and magnesium hazard allow the water for use in irrigation purposes.

Keywords: Paddy field, Irrigation water, Heavy metal, Sodium adsorption ratio.

Introduction

The three primary natural resources that determine the flourishing growth of crop plants are climate, soil and water. Climate determines the availability of water and the nature of crops to be cultivated in a region. Soil contributes storehouse of water and nutrients needed for the growth of plants. Water is indispensable for all life processes and nothing can substitute it.

The higher demand for water for industry, domestic work, sanitation and recreational activities mostly affects the availability of water for agriculture. Intermittently occurring drought and flood may cause immense damage to crop growth and production processes[19]. Irrigation plays an elemental role in increasing the productivity of crops.

Author for Correspondence

The significant factors influencing the irrigation development facility are soil, climate, topography, water source, crops to be cultivated, economic factors, environmental factors and socio-economic factors. For the adequate growth of plants, they need water as one of the main components. The water in the soil meets the demand for water by crops with the aid of the root system[1].

Rice is the second largest crop consumed by the people globally, first being wheat. The traditional system for irrigating the rice is by maintaining flooded water in the field[18]. It favours the condition for land preparation and crop transplanting initially. Continuous flooding supplies water and nutrients under the anaerobic growth conditions. Sustained rice production is attained only by the increased yield from high water productivity[6]. Water scarcity is a pertinent factor that determines the rice production. This will reduce the rice yield by 77% during the growth stages viz. vegetative, panicle initiation and reproductive stages[12].

In India, freshwater is needed for irrigating the agricultural fields. The natural availability of fresh water is very less, especially by precipitation in arid and semi-arid regions. The different levels of pollution limit the quality and quantity of water employed for irrigation in the country[22].

The present study aims to assess the heavy metal content and quality of water used for irrigating the selected midland paddy fields in Chathanoor panchayat, Kollam, Kerala. The study computes the physico-chemical attributes of water samples, estimates the heavy metal content in the water samples, evaluates the water quality criteria for irrigation and calculates the agricultural parameters such as Soluble Sodium percentage (SSP), Permeability Index (PI), Kelly's ratio (KR) and Magnesium Hazard (MH).

Material and Methods

Description of the study area: The present study was conducted in the selected midland paddy fields (Kurungal paddy sector) of Chathannoor in Kollam district, Kerala. Chathannoor is about 14 km away from Kollam Railway station in Kerala and is on the banks of the Ithikkara river. Ithikkara river (56 km length) originates from the Kulathoopuzha hills in the Western Ghats and flows through the Kollam District, finally emptying into Paravur Kayal.

The water from the Ithikkara river is used for irrigation of the paddy fields in this area. The average temperature during the study period is 30˚C. The average elevation is 14m.

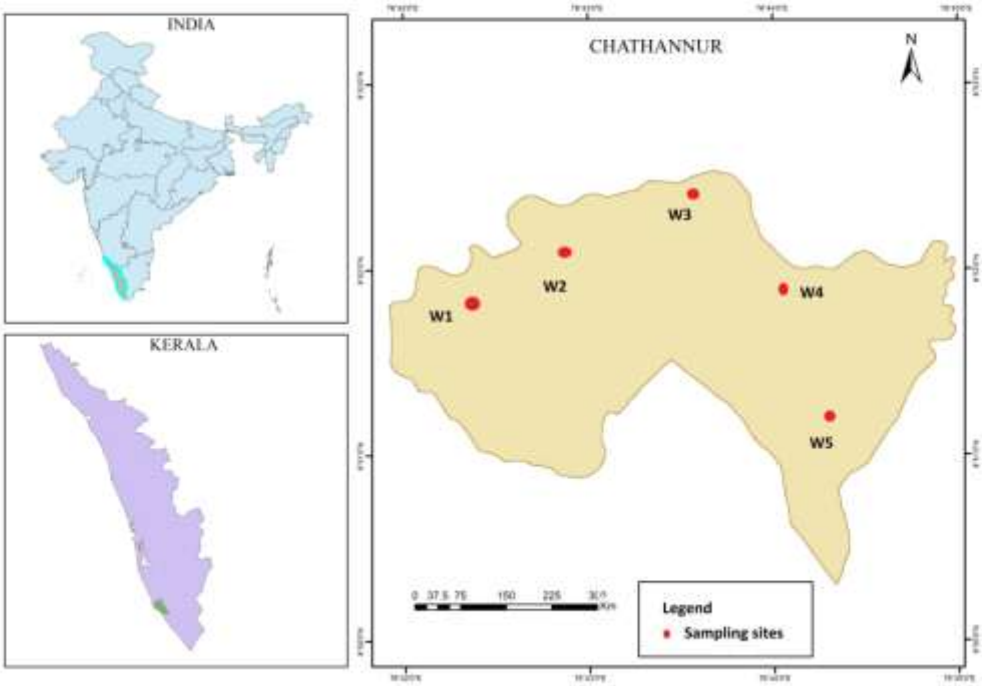

Fig. 1: Location map of the study area showing sampling sites

The exact location of the study sites is marked by using the Global Positioning System (Garmin, USA). The location map of the study area is given in fig. 1. Chathannoor is bound on the north and west by the Ithikkara river. Kaolinite or china clay is the primary mineral found in Chathannoor[17]. The inhabitants of the study area mainly depend on agriculture.

Paddy (*Oryza sativa*), coconut (*Cocos nucifera*), areca nut (*Areca catechu*), pepper (*Piper nigrum*), cashew nut (*Anacardium occidentale*) are the major crops cultivated in the study area.

Sampling and analytical procedure: The water samples were collected from Ithikkara river and water channels arising from the river to the paddy fields during the summer season of the year 2017. The water samples were collected from five sampling sites in clean polypropylene bottles (manufactured by Tarson, India) and labelled appropriately. Four water samples from the channels are arising from the river to the paddy fields and one river water sample (W3). The sampling sites were fixed based on the deviation from the Ithikkara river to the paddy fields, depending upon the geographic condition and ease of access. Global Positioning System was used for recording the coordinates of the sampling sites. After collecting the samples, they were brought to the laboratory for further analysis.

Physico-chemical characteristics of irrigation water: The physico-chemical characteristics in the irrigation water samples (pH, electrical conductivity, turbidity, alkalinity, bicarbonates, chlorides, sodium, potassium, calcium, magnesium and boron) were determined by following the standard procedures[2]. The micronutrient boron in the water samples was estimated following the procedures by Azomethine H method[5].

Heavy metal analysis in irrigation water: Water samples were subjected to nitric acid digestion for metal analysis[2]. To 500ml sample, 5ml of concentrated nitric acid was added and digested in the digestion chamber. Afterwards, the sample was made up to 50ml volume and filtered using 0.45µm membrane filter paper. Filtered samples were analyzed for heavy metals Cr, Zn, Cd, Fe, Cu and Pb using Atomic Absorption Spectrophotometer (Pinnacle 500, Perkin Elmer, Singapore). Hollow cathode lamps and EDL lamps at specific wavelengths (Zn-213.56, Pb-283.31, Cr-357.87, Cu-324.75, Cd-N9300107 and Fe-248.33) were used.

For calibration of Atomic Absorption Spectrophotometer, the standards of the heavy metals Cd, Cr, Pb, Cu, Zn and Fe were prepared. Working standards were prepared from stock standard solutions (Pure grade Perkin Elmer standards of Cu-N9300114, Zn- N9300168, Cr-N9300112, Pb-N9300128 and Fe-N9300126) by dilution of 1000 mg/L stock solutions. The calibration curve for each heavy metal was linear and a correlation coefficient of 0.995 was obtained. All standards solutions were prepared by double distilled water. A reagent blank was also made in the same manner for sample preparation. The heavy metal content in irrigation water was expressed in mg/L.

Water quality criteria for irrigation: The following chemical properties determine the water quality criteria for irrigation (Table 1). They are (1) Total salt concentration (2) Sodium Adsorption Ratio (3) Residual Sodium Carbonate and (4) Boron content[7].

Table 1
Water quality criteria for irrigation

Class	SAR √(millimole/litre)	RSC (meq/litre)	Range of EC (micromhos/cm)	Boron content (ppm)
Low	Below 10	Below 1.5	Below 1500	Below 1.0
Medium	10-18	1.5 – 3.0	1500-3000	1.0-2.0
High	18-26	3.0 – 6.0	3000-6000	2.0-4.0
Very high	Above 26	Above 6.0	Above 6000	Above 4.0

(1) Total salt concentration: It is an expression of electrical conductivity. Concerning the hazardous effects of electrical conductivity, irrigation water can be classified into four groups.

(2) Sodium Adsorption Ratio: The equation for calculating Sodium Adsorption Ratio is:

$$\text{SAR}=\frac{\text{Na}}{\sqrt{(\text{Ca+Mg})/2}}$$

(3) Residual Sodium Carbonate: Residual Sodium Carbonate can be calculated by the equation:

$$\text{RSC} = (\text{Carbonate} + \text{Bicarbonate}) - (\text{Ca} + \text{Mg})$$

(4) Boron content: Boron, the micronutrient becomes toxic if it exceeds a particular level.

Indices to assess the suitability of water for agriculture: The various indices determining the suitability of water for agriculture are Permeability Index, Kelly's Index, Soluble sodium percentage and Magnesium Hazard

(1) Permeability Index: Permeability Index (PI) is for assessing the suitability of water for agriculture[8]. The permeability of soil is affected by a high concentration of sodium, calcium, magnesium and bicarbonate ions and can be calculated by the formula[23]:

$$\text{PI} = \frac{\{(\text{Na} + \sqrt{\text{Bicarbonate}}) \times 100\}}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})}$$

If PI is >75%, it is suitable for irrigation; 25-75% - moderately suitable and <25%, unsuitable for irrigation.

(2) Kelly's Index: In Kelly's Index (KI), sodium is measured against calcium and magnesium[16] from the following equation:

$$\text{KI} = \frac{\text{Na}}{\text{Ca} + \text{Mg}}$$

If KI is <1, suitable for irrigation; and >1, it is unsuitable.

(3) Soluble Sodium Percentage: Percentage of sodium (SSP) is also a factor determining the suitability of water for agriculture[27].The equation for calculating SSP is:

$$\text{Na\%} = \frac{(\text{Na} \times 100)}{(\text{Ca} + \text{Mg} + \text{Na} + \text{K})}$$

If SSP is <60%, the water is safe for irrigation; >60%, it is unsafe.

(4) Magnesium Hazard: Calcium and magnesium continue to be in a state of equilibrium in most natural waters. A high concentration of magnesium ions present in water adversely affects the soil quality, results in the alkaline condition of the soil, thereby affects the crop yield[15,25]. The magnesium hazard (MH) was calculated using the formula. The concentrations of Ca and Mg are expressed in meq/l. If MH is <50%, water is safe for irrigation; >50%, it is unsafe.

$$\text{MH}=\left(\frac{\text{Mg}}{\text{Ca+Mg}}\right)\times 100$$

Results and Discussion

The result of the study depicts the major physico-chemical parameters (Table 2), heavy metal content (Table 3) water quality criteria for irrigation (Table 4) and irrigational suitability indices (Table 5) of the water used for irrigating the selected midland paddy fields of Kerala.

Physico-chemical characteristics of irrigation water: The pH of irrigation water samples in the study area varied from 6.8 (W5) to 7.3(W3), with mean value 7.06, which comes under neutral to slightly alkaline category (Table 6). It is within the normal range of water for irrigation[4]. The temperature variation of the irrigation water samples around the study area ranged from 30 to 32°C. The electrical conductivity of the water samples was found to vary from 100.8 (W5) to 210.7µScm^{-1} (W3).

The average electrical conductivity of samples is 141.34µScm^{-1}. The turbidity values of the water samples were observed from 5.1 (W5) to 16.8NTU (W3) with an average of 9.42 NTU. The turbid nature of water is due to the presence of suspended solids and silts. Alkalinity of the water samples ranged from 50 to 100mg/L with an average of 80mg/L and chloride values varied from 0.011 to 0.022meq/L (W3), having mean value 0.018meq/L.

According to the classification of chlorides in irrigation water, the irrigation water samples of the study area come under "Low category - <4meq/L.[4]" Bicarbonates value of irrigation water samples ranged from 0.98 to 1.26meq/L.

The average concentration of bicarbonates is 1.57meq/L which comes under the "Low category<1.5meq/L[4]". Sodium values in the irrigation water ranged from 1.65 (W1) to 2.66meq/L (W2), with the mean value 2.16meq/L. It also comes under the "Low category - <3meq/L[4].

Potassium concentrations in the irrigation water samples varied from 3.6 to 6.9mg/L with an average concentration of 4.94mg/L. This is within the usual range (0 to 2 mg/L[4]. Calcium and magnesium concentrations in the irrigation water samples were also estimated (Table 2). The concentration of calcium in water samples ranged from 8.01 to 12.02 mg/L with an average of 10.41mg/L. Magnesium in the irrigation water samples was observed from 4.87 to 9.74mg/L, with a mean value 7.79mg/L. Boron is a micronutrient which is observed in the irrigation water samples in the range 0.61 (W3) to 0.98mg/L (W1) with a mean value of 0.80mg/L (Table 2).

Heavy metal content in irrigation water: All trace elements are not considered toxic and some are beneficial in smaller quantities for the growth of plants. The concentration of heavy metals chromium, zinc, iron, lead, copper and cadmium was estimated in the irrigation water samples of the study area (Table 3).

Chromium is a non-essential element for the growth of plants. The recommended maximum concentration of Cr in irrigation water is 0.10 mg/L.[4] The concentration of Cr in the irrigation water samples was found to vary from 0.0031 to 0.0129 mg/L, which exceeds the recommended maximum concentration. Maximum concentration was observed in site W3, the river water sample. The excessive concentration of Cr detected in one site clues the use of pesticides in plantation or agricultural land.[12] Cr can bind to solids that have negatively charged silicates and organic materials.[9]

Zinc is toxic to many plants and crops at widely varying concentrations. In fine-textured or organic soils, having a pH greater than 6, the toxicity is reduced. The concentration of Zn in the irrigation water sample ranged from 0.46 to 0.74 mg/L. The recommended maximum concentration of zinc for irrigation is 2 mg/L.[4] The concentration of zinc in all the sites is within the recommended concentration. High concentrations of soluble zinc are present under the well oxidized condition and pH 5 to 6.5.[10]

The metal iron is non-toxic to plants in aerated soils but can cause soil acidification and loss of availability of essential phosphorus and molybdenum. Overhead sprinkling may result in unsightly deposits on plants, equipment and buildings. The maximum recommended concentration of iron in water for irrigation is 5 mg/L.[4] The range of Fe content varies from 1.69 to 3.18 mg/L in which all the sites are within the recommended limits.

Table 2
Descriptive statistics of various physico-chemical parameters

Parameters	**Max**	**Min**	**Mean**	**SD***
pH	7.3	6.8	7.06	0.207
EC (μScm^{-1})	210.7	100.8	141.34	46.06
Turbidity (NTU)	16.8	5.1	9.42	4.39
Chlorides (mg/L)	82.5	42.6	56.26	19.14
Alkalinity (mg/L)	100	50	80	7.38
Bicarbonate (mg/L)	122	61	47.6	33.41
Sodium (mg/L)	61.3	38.1	49.72	9.18
Potassium (mg/L)	6.9	3.6	4.94	1.24
Calcium (mg/L)	12.02	8.01	10.41	2.19
Magnesium (mg/L)	9.74	4.87	7.79	2.66
Boron (mg/L)	0.987	0.61	0.80	0.14

SD* - Standard Deviation

Table 3
Heavy metal content in irrigation water

Heavy metals (mg/L)	**Max**	**Min**	**Mean**	**SD***
Chromium	0.0129	0.0031	0.0084	0..0035
Zinc	0.74	0.46	0.62	0.11
Iron	3.18	1.69	2.56	0.58
Lead	0.059	0.031	0.043	0.01
Copper	1.04	0.029	0.24	0.44
Cadmium	0.05	0.02	0.03	0.008

SD* - Standard deviation

The studies on the metal pollution in groundwater near the sewage farm in Thiruvananthapuram, Kerala reported that a high concentration of Fe in water could be either due to the discharge of domestic wastewater or by the leaching of wastewater from the sewage farms or houses.[26] The excess deposition of Fe in the organs of humans leads to shrinkage of the liver followed by fibrosis and cirrhosis. The Fe content in water samples also occurs from geologic attributes like the presence of weathered magmatic rocks.[11]

In the present study the Pb content in irrigation water varies from 0.031 to 0.059 mg/L with a mean concentration of 0.043 mg/L. The maximum recommended concentration of Pb for irrigation is 5.0mg/L.[4] Current results showed that the concentration of Pb in all the irrigation water samples is within the recommended maximum concentration. Gasoline, paint, pesticides and ammunitions are the common anthropogenic sources of lead. Leaded gasoline releases organo-metallic lead compounds which reach the surface water polluting it. Lead can inhibit plant cell growth at very high concentrations.

The mean concentration of copper in irrigation water recorded was 0.24 mg/L that exceeds the recommended maximum concentration of copper (0.2 mg/L).[4] The concentration of Cu in the irrigation water samples ranged from 0.029 to 1.04mg/L. At higher concentrations, Cu is toxic to aquatic microorganisms and plants.[24] The traditional application of Cu in the form of Bordeaux mixture poses a serious threat in increasing the concentration of Cu in all sites. Also, the application of Fycol 8 in rubber plantations of Kerala is responsible for the high Cu levels.[21]

Cadmium is the non-essential element for the growth of plants by which high concentration is toxic to many vegetables such as beans, beetroots and turnips. The concentration of Cd in the irrigation water samples ranged from 0.02 to 0.05mg/L, with an average concentration of 0.03mg/L. The maximum recommended concentration of Cd in the irrigation water samples is 0.01mg/L[4]. The water samples collected from all study sites exceeded the maximum recommended concentration, which could not be safe for long-term irrigation. The vegetables and crops irrigated with the water having toxic metals will ultimately result in lead and cadmium-induced diseases, renal failure and disorder of the nervous system with impairment of the immune system. The primary source of cadmium in agricultural soils is the over-application of chemical fertilizers like urea, muriate of potash.[20]

Water quality criteria for irrigation: The water quality criteria for irrigation were put forward by Bureau of Indian Standards[7]. Here, the quality of water used for irrigating the paddy fields of the study area was determined by the estimation of EC, SAR, RSC and Boron content (Table 4). Electrical conductivity which signifies the salt concentration in water, is an essential factor assessing the suitability of water for irrigation. The electrical conductivity of the irrigation water samples ranged from 100.8 to 210.7micromhos/cm.

The water samples from all the sites have EC values < 1500micromhos/cm indicating low concentration which is suitable for irrigation. SAR values are considered as an essential index for determining the suitability of water used for irrigation[23]. The SAR of irrigation water samples of the study area was found to vary from 1.97 to 4.21(√ millimole/litre). The elevated levels of salinity interfere with the osmotic pressure and reduce the absorption of water and nutrients from the soil. Thus, plant metabolism is prevented.[3]

The SAR level of the water samples in all the study sites was found below 10 of low category. Residual sodium carbonate is the quantity of carbonate and bicarbonate above alkaline earth metals calcium and magnesium.[22] The RSC levels of the water samples varied from -0.41 to 0.61meq/L. The recorded value of RSC in the irrigation water samples of the study area is below 1.5, low category.[7] Boron in the irrigation water samples ranged from 0.61 to 0.98ppm. It is the micronutrient responsible for toxicity issues if exceeded the standard concentration. The concentration of boron in all the sampling sites of the study area is less than 1ppm and was found low.[7]

Suitability indices for irrigation water: The suitability of water for irrigation purpose always depends on its physical and chemical properties. It was mainly assessed in terms of dissolved salts and plant nutrients.[14] The irrigational suitability indices of water used for the irrigation of paddy fields are given in table 5.

Permeability Index (PI) is one of the major factors determining the suitability of irrigation water. PI values of the irrigation water samples were found to vary from 84.05 to 148.9, which is rated greater than 75%, comes under "Class I, suitable" for irrigation. Kelly's Index (KI) measures sodium against calcium and magnesium. It is an indication of excess sodium in water. The KI values of irrigation water samples of the study area varied from 1.18 to 3.33meq/L, found to be unsuitable for irrigation, as the KI values are greater than 1. Soluble sodium percentage or % Na is also a function of sodium. High sodium content reduces the permeability of nutrients[25].

Based on sodium percentage, the water can be categorized into safe or unsafe for irrigation. The %Na values of the irrigation water samples in the study area ranged from 52.59 to 74.59%. The water samples (W1 and W4) come under the safe category, as the %Na values are less than 60%. The other irrigation water samples (W2, W3 and W5) come under the unsafe category, as the sodium percentage is greater than 60%. Calcium and magnesium ions maintain a state of equilibrium in most natural water[15]. The high concentration of Mg ion in water harmfully affects the soil quality, making the soil alkaline and low crop yield results.

Table 4
Water quality criteria for irrigation in the study area

Sites	EC (micromhos/cm)	SAR √(millimole/litre)	RSC (meq/L)	Broron (ppm)
W1	129.8	1.97	0.58	0.987
W2	103.1	4.21	-0.41	0.739
W3	210.7	2.88	-0.79	0.61
W4	162.3	2.58	0.54	0.791
W5	100.8	3.01	0.61	0.917

Table 5
Suitability indices for irrigation water in the study area

Sites	PI (%)	KI (meq/L)	SSP (%)	MH (%)
W1	84.05	1.18	52.59	57.2
W2	102.3	3.33	74.59	50.06
W3	95.59	1.72	60.52	57.22
W4	96.46	1.54	58.52	57.2
W5	148.9	2.38	67.34	50.06

MH values of the irrigation water samples were found to vary from 50.06 to 57.2% and considered safe for irrigation (Table 5).

Conclusion

The study concluded that most of the water samples used for irrigating the midland paddy fields are contaminated with metals like Cr and Cd. The study suggests that both natural and anthropogenic activities control the metals distribution in the water channels and river.

The presence of these metals is due to the leachates from sewage and from the application of agrochemicals during the cultivation in order to increase crop production. The presence of Cr in the study area may be of geological origin.

Application of chemical fertilizers (urea, muriate of potash, calcium super phosphate) in paddy fields, fungicides (Fycol8) in the rubber plantations and plantain cultivation significantly contributes to heavy metal pollution in the river water used for irrigation of paddy fields in the study area. The heavy metal accumulation will occur in the paddy on continuous irrigation with heavy metal contaminated water which will affect the health of the consumers. The study suggests that care should be taken for maintaining sufficient water flow to reduce the accumulation of contaminants in the water channels.

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