Environmental Impact due to Agricultural runoff containing Heavy Metals – A Review

Hariprasad N. V.*, Dayananda H. S.**

* Research Scholar, Department of Environmental Engineering, Vidyavardhaka college of Engineering, Mysore, Karnataka, India
** Professor, Department of Environmental Engineering, Vidyavardhaka college of Engineering, Mysore, Karnataka, India

Abstract- This paper is a collation and compilation of the research papers pertaining to the heavy metal contents in irrigation water used for agricultural purpose. The uptake of heavy metal by plants through contaminated soil gets accumulated and is a potential threat to animal and human health. The heavy metals in water bodies damage the aquatic organisms and fishes. Excess use of fertilizers and pesticides in agricultural activities to enhance productivity due to rapid population increase and development of technology threaten the groundwater and surface water on a large scale. This shows there is an obvious risk for human in the future. The pesticides used in crop cultivation should be free from heavy metals. Hence this study concentrates on effects of heavy metals present in irrigation water.

Index Terms- Irrigation water, Heavy metals, Agricultural runoff, Fertilizer, Pesticides

I. Background

In India 70% of the total population depends on agriculture. India ranks second in world farming; irrigation has acquired increasing importance in agriculture worldwide. India's irrigation development particularly after independence has seen large number of storage based systems.

Today man is living in a "Chemical sphere" and these chemicals whether, natural or manmade, has the capacity to degrade the delicately balanced ecological system by poisoning air, water and land. Hence, while realizing the need of chemicals, it should be ensured that it will not spoil the environment. Global chemical pollution has been a matter of great concern with increase in public awareness towards environmental problems [17].

In most countries of the world, groundwater and surface water are at a serious risk of pollution due to chemicals used in agricultural activities. During the last two centuries, heavy metals released by human activities have superimposed new pattern of metal distribution on those which are naturally occurring.

The reuse of treated urban wastewater for irrigation is a relatively recent innovation. Although many studies have been carried out on various aspects of the system, knowledge is still limited on the associated heavy metal accumulation in soils. Most studies are done, to know the effects of using treated wastewater with sludge on vegetable crops rather than heavy metal polluted water. Thus, there is an urgent need to be focused on the benefits and limitations of the use of such water for irrigation [41].

II. Sources of Heavy Metal Contamination

Heavy metals are introduced to environment either by natural means or anthropogenic activities.

(a) Natural sources: In nature, excessive levels of trace metals may occur by geographical phenomena like volcanic eruptions, weathering of rocks; leaching into rivers, lakes and oceans due to action of winds.

(b) Anthropogenic sources: In ancient times, heavy metals were released in small amounts while mining and smelting of metal ores in open fires. With the industrial revolution, metals are extracted from natural resources and processed in industries from where heavy metals leak into atmosphere. Similarly, traces of heavy metals get deposited in the environment through discharge; domestic waste, agricultural runoff and automobile exhausts.

The various human activities through which heavy metals reach the environment are i) Smelting or processing of ores of metals, ii) Mining, iii) Burning of fossil fuels such as coal, petrol and kerosene oil, iv) Discharge of agricultural, industrial and domestic waste. v) Auto exhaust, and vi) Pesticides containing compounds of heavy metals.

Heavy metals are also widely used in household appliances, paints, photographic paper, photo chemicals etc., Pollution of ground water and surface water systems through anthropogenic activities is the major environmental problem faced all around the globe [3, 4]. Wastewater from urban area is being used profitably to irrigate crops in the vicinity of cities from the time unknown. Wastewater is still considered rich in plant nutrients and organic matter. However, the situation is changed now because, in many cities and towns the wastewater is sold for secondary use and it is a good source of income to municipalities [16].

Heavy metal is present in diminutive quantities in the water and is further added due to soil erosion and leaching of minerals. However, in the recent past, freshwater pollution due to heavy metals has become a hazard due to discharge of industrial effluents. Heavy metals like Mn, Fe, Ni, Cu, Zn and Cr are essential for the growth of organisms, while Pb, Cd, Hg and Ag are not biologically essential, but definitely toxic. Even the essential heavy metals may be beyond optimum threshold levels, hazardous and toxic. After entering the water, metals may precipitate, gets adsorbed on solid surface, remain suspended in water or taken up by fauna. A very important biological property of metal is its tendency to accumulate [6].

2.1 Contamination through domestic wastewater

The heavy metals like Pb, Cu, Zn and Cd are generally found in wastewater. Copper is one of several heavy metals that are essential to life despite being inherently toxic as non-essential heavy metals exemplified by Pb and Hg [15]. Plants and animals rapidly accumulate it. It is toxic at very low concentration in water and is known to cause brain damage in mammals [11].

Jannapura Lake, a perennial fresh water body located in Bhadravathi town of Karnataka state, India, is used for irrigation purpose. This lake receives untreated domestic wastewater from residential areas. Water samples collected during October 2004 to June 2005 were analyzed using Atomic absorption spectrophotometer for Cu, Zn, Pb, Cd and Ni. The concentration of all the heavy metals of concern in the water exceeded the permissible limits as per WHO Standards. The study indicated that the water of the lake was not suitable for drinking purpose. The concentration of Zn for irrigation and live stock watering are 1.0 mg/L and 0 to 20 mg/L respectively. High concentration of Zn in water is unsuitable for the sustenance of the aquatic life. But could be utilized for irrigation and live stock watering [6]. Although Zn has been found to have low toxicity to human, prolonged consumption of large doses can result in some health complications such as fatigue, dizziness and neutropenia [10].

Water, vegetable and sediment samples collected from Tyume River, South Africa was analyzed for the trace metals Cd, Pb, Co, Zn, Cu and Ni. High levels of Cd (0.044 ± 0.003 mg/L) and Pb (0.035 ± 0.001 mg/L) were found recorded, which may be detrimental to the health of the aquatic ecosystem and indirectly to human since the river water is used to irrigate farmland. The study revealed that open-beaker digestion is still a reliable method for quantitative determination of trace metals in environmental samples. The microwave-assisted digestion method also gives acceptable recoveries and thus applicable for trace metal determination in vegetable samples [31]. The chronic effect of Pb on human includes neurological disorders especially in the fetus and in children. This can lead to behavioral changes and impaired performance in IQ tests [14].

Dissolved trace metals Fe, Mn, Al, Cu, Pb and Cd were quantified for samples collected from Umtata River, South Africa. High level of Al, Cd, Pb, Zn and Cu were observed, which may affect the health of the aquatic ecosystem. The high levels of Al, Cd and Pb may have a detrimental effect on health of the rural community residing in the vicinity of river catchment without treatment [34]. The effect of Cd toxicity in human includes kidney damage, mutagenic, carcinogenic and terotogenic effects [12, 13]. It was indicated that, in acidic sandy soils especially metal leaching is substantial and the flux from soils to groundwater is high enough to eventually contribute to the Cd load in nearby surface waters [25].

Water samples were analyzed for heavy metals in Punnakayal estuary, Tuticorin, Tamilnadu, India, at two stations for one year. Heavy metal concentration varied slightly in water samples of both the stations. The metal concentration of the samples was high during monsoon [37]. Organic matter normally present in sediment of water is favorable binding site for heavy metals and humic substance. The organic matter plays a vital role in the sorption of metal on marine sediments due to the presence of charge surfaces [24].

The water samples collected from canal and Bara river (irrigation source) of Akbarpura area of District Nowshera, Pakistan was analyzed for selected heavy metal contents (Cu, Zn, Fe, Mn, Cd, Ni and Cr) using Atomic absorption spectrophotometer. It was found that, the heavy metal contents in Irrigation canal water was much less for Cu, Pb, Fe, Cd, Ni and Cr compared to Bara river water. While Zn and Mn were found in deficient concentration [1]. It was reported that canal sediment could act as sink for a wide range of contaminants including heavy metals from various sources (Agricultural and wastewater discharge). No external addition of heavy metal occurs in case of irrigation canal [23].

A study on impact of heavy metal contamination of Bellandur Lake, Bangalore, India on soil and cultivated vegetation describes that Fe, Cr and Pb showed 50% higher concentration during rainy season, while Cd showed higher concentration during dry season. A marginal difference in concentration is found for Cu and Ni between wet and dry seasons. Zn showed less seasonal variation. Higher concentration of Fe, Cr and Pb during the rainy season is probably due to rainfall and run-off which cause erosion, thereby introducing into the lake soil, silt and even discarded iron waste besides wastewater from drains nearby, the high level of Cd during dry season might be due to concentration effects [26].

2.2 Contamination through fertilizers/pesticides

Excess use of fertilizers and pesticides in agricultural activities to enhance productivity due to rapid population increase and development of technology threaten the groundwater and surface water on a large scale. In most of the countries, soils and waters have been polluted by fertilizers and pesticides used during agricultural activities. These waters and soils continue to be polluted, as the necessary precautions have not been taken. This shows there is an obvious risk for human in the future [18].

Nitrate and heavy metal pollution resulting from agricultural activity was examined to know the risk in Eskipazar, Turkey and the surrounding area. Water discharged from agricultural activities is used as drinking water and for domestic purposes. In particular, periodically varying levels of pollutants, such as Pb and Hg were detected in wells featuring a high NO_3 pollution, high levels of Ca and SO_4 pollution was observed at a well drilled in alluvium. The study area had no sources of pollution, such as mineralization, industrial center, waste disposal area, etc. Thus, it is believed that the main causes of NO_3 and trace element pollution are fertilizers and pesticides used in agricultural activities [18].

Increased use of fertilizers to improve agricultural productivity has also affected the quality of groundwater, including nitrate pollution [21]. Nitrate in waters is an indicator that the water is at a risk of pollution [19]. The usage of water with a high nitrate level for drinking purpose reduces the oxygen carrying capacity of the blood and can lead to methemoglobinaemia in babies. Organic materials, such as farm manures, bio-solids or composts contain higher concentration of trace elements than most agricultural soils. The use of bio-solids and composts increases total amount of Cu, Zn, Pb, Cd, Fe and Mn in soils [20].

The use of phosphate fertilizers in agricultural field has shown to enhance leaching of Cd from soil, which reaches the lake water. It undergoes physical and chemical changes depending on the pH and quality of water and sediment. The available metals in the water phase cause risk to human beings and biota [6]. Carbon and Nitrogen concentration increase in response to irrigation, but it is not clear whether this is due to decreased decomposition rate of crop residues in response to pollution in the irrigation water or to increased amounts of crop residue in the irrigated soils [30].

Intake of vegetables is an important path of heavy metal toxicity to human beings. Crops and vegetables grown in soils contaminated with heavy metals have greater accumulation of heavy metals, it depends upon the nature of vegetables and some of them have a greater potential to accumulate higher concentration of heavy metals than others. Dietary intake of heavy metals through contaminated vegetables may lead to various chronic diseases. Levels of Cd, Cu, Mn, Ni, Pb and Zn were determined in irrigation water, vegetables and soils of Makurdi irrigated farmland along river Benue, Nigeria. The water used for irrigation had the concentration 0.00013±0.0004, 0.0022±0.0010, 0.0024±0.009 µg/g for Cu, Mn and Zn respectively. While Cd, Ni and Pb was not detected in irrigation water. The concentration of all the heavy metals studied was detected in soil and plant samples. Heavy metal concentration varied among different vegetable and fruit studied. Among the vegetables and fruits examined Zn and Mn had the highest concentrations, but were below the recommended safe limits of heavy metals by WHO, FAO, EU Standards [5]. The sources of heavy metals to vegetable crops are growth media (soil, air, nutrient solutions) from which they are taken up by the roots or foliage [9].

Surface water and groundwater samples of certain locations viz., Bugudanahalli, Kallambella, Honnudike, Hebbur, Kadaba, Maidala, and Kunigal situated around Tumkur, Karnataka, India were assessed for selected heavy metals (Cd, Cu, Fe, Hg, Mn, Zn and Ni). All surface waters except Honnudike and Hebbur samples contained low concentration of these metals and are ideal for irrigation. The samples from Honnudike, Kadaba and Hebbur had high iron concentration, only Honnudike and Hebbur samples exceeded 5mg/L (required for irrigation). In groundwater, the concentration of all these heavy metals except Cu were also well in permissible limits and found suitable for drinking. The elements Cd, Hg and Mn were absent in all the samples [2].

The trace metals Cd, Hg and Zn, which may affect human health and aquatic ecosystem, were determined in Umtata, Buffalo, Keiskamma and Tyume rivers and Umtata dam, South Africa. Normal level of the metals were detected in water samples from the Umtata river and the Umtata dam but samples from Buffalo, Keiskamma and Tyume rivers contained elevated level of Cd. The levels of Hg and Zn were normal in samples from all the surface waters. The probable sources of the trace metal in the rivers are due to rural, urban and from agricultural runoff in the catchments although there could be contribution from natural and point sources [39].

The sources, distribution and mobility of heavy metals in Zhuzhou city, Hunan province, China were systematically studied based on environmental monitoring data and random sampling. There was no significant difference in total Pb and Zn in topsoil, which showed the balance between input and output. Heavy metals in the vegetable and rice were higher than the edible standards and background value to some degree with minor exceptions. The maximum concentration level of heavy metals observed were in the order of Cd, Pb, Cu and Zn. Significant positive correlations were found only between cabbage uptake and total soil content for Hg, Pb and Cd, with no significant correlation for the other elements [22].

Heavy metal content in plants depends on its bioavailability in the soil and on the atmospheric deposition, with the media affected by wastewater irrigation and fertilization, and the latter either directly entering the plants through stomata or taken up by plant roots after its deposition on the soil surface [27].

2.3 Contamination through Industrial effluent

With the establishment of industries in suburban area, the domestic wastewater is mixed with industrial effluents and is coming out through culverts from the cities. These culverts and drains not only contain heavily polluted water but also give noxious and off smell gases. The polluted water even then is still used for growing vegetables in the nearby areas of the cities without knowing its adverse impact on the life of consumers. Wastewater mixed with industrial effluent used for irrigation in the vegetable growing area of Korangi, Karachi, Pakistan was tested for its heavy metal contents. Twenty four samples from different drains and four tube well water samples were collected and analyzed. Soil and plant samples were taken from the same area and analyzed to assess its heavy metal contamination. It was noted that 4% samples contained Zn, Cu, Fe and Cr above the critical values; while 7, 21, 14 and 36% samples were higher than the required values in Mn, Cd, Ni and Pb respectively. Soil analysis showed higher values of Zn, Fe, Mn, Cd, Ni and Pb at some places. Plant sample (Spinach) had greater concentration of many heavy metals than the recommended values. The area irrigated with tube well water was safe and heavy metal quantities were within the limits in soil and plants [16].

Industrial effluent is used by local farmers to irrigate agricultural land in Bursa province, N. W. Turkey. Water from seven irrigation points was sampled over four weeks in the summer and analyzed for pH, conductivity, and Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn. Adjacent soil samples were also collected at 0-20 and 20-40 cm depths; from ten irrigated and ten non-irrigated fields. The water was heavily polluted with heavy metal, and its diethylenetriamine pentaacetic acid (DTPA)-extractable concentration was significantly higher in the irrigated soils. Even relatively immobile heavy metals such as Pb had accumulated at both sampling depths at high level. Irrigation significantly increased the soil organic C and N contents and reduced the pH and calcium carbonate content. The year-upon-year accumulation of heavy metals will eventually cause phytotoxic thresholds to be exceeded, especially once the residual carbonate in the soil has been dissolved and soil pH starts to fall [30].

A study on metal pollution assessment of sediment and water in river Hindon, India, describes the longitudinal variations of dissolved, suspended and total metal concentration of Cd, Cr, Cu, Fe, Mn, Ni, Pb, and Zn. The higher concentration of Fe, Cu and Zn occurred in particulates, where as Mn, Cr, Ni, Pb and Cd were observed in higher concentration in dissolved form in the river water. Higher concentration of total Fe and Mn in the upper stretch of the river is due to effluent of the co-operative distillery and runoff from agricultural fields respectively. In the downstream section, however the concentration of Fe and Mn decreased substantially due to dilution effect. In general, the concentration of all dissolved metals was lowest in winter months and highest during summer months. The concentration of dissolved metals decreased in the monsoon months due to dilution during higher flow. Higher percentages of almost all metals in particulate form occurred during the post-monsoon months due to suspended load carried by surface runoff during monsoon season. Any deviations from these trends may be attributed to the site-specific activities, which are likely to increase suspended solid concentration in the water column and thereby decreasing the dissolved metal [35].

Nigeria's industrial cities are resulting in an increased quantity of discharge and a wide range of pollutants reaching water bodies. Urbanization and industrialization have contributed to the large scale of pollution currently observed in most Nigerian cities notably those swarming with industries viz., Lagos, Kano and Kaduna states. There are no incentives for implementing pollution reduction measures. Wastes are disposed indiscriminately especially from small and medium scale industries. The lack of information on pollution is a serious hindrance to pollution management directly or remotely. Thus, in addition to treatment of wastewater before disposal, appraisal of water resources would offer proficient information to indicate areas of main concern. This would prove useful in detection of threats to human and environmental health [32].

Apart from natural sources, other probable sources of heavy metals in surface water included leaching from Ni–Cd based batteries [7]. Possible sources of Ni in surface water include anthropogenic sources, combustion of fossil fuels, old battery waste, components of automobiles, old coins and many other items including stainless steels and other Ni alloys. Among the known health related effects of Ni are skin allergies, lung fibrosis, variable degrees of kidney and cardiovascular system poisoning.

Ag, Cd and Fe in sediment were studied from Bahia Todos Santos, Baja California, Mexico during 2004. Spatial distributions of Ag, Cd and Fe were very similar to that of organic carbon and fine grain size, with values increasing from the inner to the outer parts of the bay. High concentration and enrichment of Ag (0.051-0.071 µg/g dry weight) and Cd (1.9 µg/g dry weight) in Bahia Todos Santos were associated to harbor dredging activities and to coastal upwelling, respectively. However, the distribution of Ag and Cd in most of the study area is controlled by grain size and organic carbon content [8].

Heavy metal contaminants Cd, Pb and Zn in water, sediments and fish of the Mae Kuang river, Northern Thailand was investigated by [33] during (July 2008-June 2009). It was found that the worst water qualities in dry seasons were caused by low water flow, municipal effluents and industrial discharges. Pb and Cd in water were below detection limits, while Zn concentration in water ranged 0.01-0.11 mg/L. The Pb, Cd and Zn concentration in sediment were 3.13-27.56, 0.02-0.43 and 3.42-10.32 mg/kg, respectively. Cd and Pb residues were found in Henicorhynchus siamensis and Puntioplites proctozysron flesh, while the concentration of Zn in these fish was 4.57-6.58 mg/kg. Pb and Cd residues in snake head (Channa striata) were 0.05-2.13 and 0.02-0.24 mg/kg wet weight.

Heavy metal concentration of Zn, Pb, Fe, Mn, Cu, Ni and other physico-chemical parameters were studied in Karanja reservoir, Bidar district, Karnataka, India. Water samples were collected monthly and were analyzed by Atomic adsorption spectrometer. Heavy metals were within the permissible limits, except Fe and Ni which were recorded higher in southwest monsoon, where as Mn has showed higher concentration in northeast monsoon and in summer. All other physico-chemical parameters were within the permissible limit [40].

The water samples collected at regular intervals from five selected sites of river Gomti of Lucknow city, India was analyzed to know the seasonal variation in the concentration of heavy metal Cr, Pb and Hg by using spectrophotometric methods in the pre-monsoon period and the post-monsoon period. The concentration of Cr (VI) and Hg (II) were determined by using UV-VIS Spectrophotometer while Pb (II) concentration was determined using Atomic absorption spectrophotometer. The concentrations of all the three metals were found to be higher in the pre-monsoon period than in the post-monsoon period [29]. The spatial distribution of trace elements in sediments in the estuarine environment were influenced by so many factors including geochemical and biogeochemical processes like sedimentation, precipitation and flocculation of particulate substances and hence was difficult to find the principle. In addition, the spatial distribution of the sediment accumulation rates, which is most likely associated with the basin's hydrological conditions, seem to play a crucial factor for the observed changes [36]. Spatial distributions of different metals show that the industrial zone is the most polluted zone where there is highest average of total metals content. Globally, the sum of these concentrations decreased gradually with increasing distance from the industrial area [38].

The quality of Axios/Vardar River, Southeastern Europe was affected by heavy metal pollution from smelter and fertilizer plants in Veles, ferro-alloys plant in Jegunovee, the disposal of its solid waste near the river bed and also by the untreated industrial wastewater discharge deriving from the industries located in the watershed. The agricultural runoff from cultivated areas of Tetovo, Veles and Koufalia is a significant source of nutrient pollution. The study was based on long-term data (1979-2003) of nitrate, nitrite, ammonium, total phosphorous, BOD_5, Cd, Cr, Zn, Pb and water discharge from twenty two sampling stations along the river collected on a monthly basis. This river was a polluted river presenting high value of heavy metals and nutrients resulting from human activities. There was a need for monitoring program that will provide a representative and reliable estimate of the quality of water resources [28].

Anthropogenic pollution from urban wastewater, industrial effluent and agricultural runoff may be clearly seen in irrigating water. Seasonal variations and flooding water subsequently lead to pollutant dilution. Even though heavy metal contents in water and sediments are below the acceptable levels, a hazardous possibility may generate depending on rapid expansion of urban and industrial development in near future [33].

III. Conclusion

Heavy metals in irrigation water changes the soil properties, there by affecting the growth of crops. The crops uptake these heavy metals and thereby get transferred to animals and humans through food chain causing severe health problems. The agricultural runoff containing heavy metals reaches natural water bodies affecting aquatic species and in turn ecosystem. In many of the countries, people have a misconception that using large amount of fertilizers would yield good amount of crops either, food or commercial crops. In country like India, people are nowadays more aware of ill effects of using fertilizers and pesticides beyond the required limit. Government of India has taken many initiatives in spreading awareness among farmers through electronic media, radio and various other programs, in the usage of fertilizers and pesticides. To overcome this problem, the pollutants have to be controlled at the source itself. Soil has to be tested for nutrient value before deciding the dosage of fertilizers. The rotation of crops has to be adopted with the use of organic manure which is free from heavy metals.

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AUTHORS

First Author – Hariprasad N. V, Research scholar (Corresponding author), Department of Environmental Engineering, Vidyavardhaka college of Engineering, Mysore, Karnataka, India, Email id: hariprasad.nv@gmail.com

Second Author – Professor, Department of Environmental Engineering, Vidyavardhaka college of Engineering, Mysore, Karnataka, India, Email id: nanda_hsd@yahoo.com