Chapter 7
Egg as a Biomonitor of Heavy Metals in Soil

Muhammad Zaffar Hashmi, Naeem Akhtar Abbasi, Xianjin Tang, and Riffat Naseem Malik

7.1 Introduction

The use of avian tissues for biomonitoring of contaminants has widely been used. Avian tissues are usefully used indicator because the concentration level of heavy metals in their tissues reflects their exposure and may also be indicative for trend of the past exposure. Initially, internal organs were collected after sacrificing a live bird, but more recently the demand of noninvasive technique leads to the use of feathers, eggs, and feces for biomonitoring of heavy metals (Burger 1993). Feathers and eggs are very special for metal accumulation studies not only because they can be collected without affecting the life of a bird but also for they have certain important information which is not possible to acquire otherwise (Dauwe et al. 1999). The use of feathers and eggs for heavy metal monitoring in soil has their own respective limitations, but eggs have certain several advantages over the other noninvasive biomonitoring matrices because they are easier to collect and can be preserved for a long time. In addition, eggs are relevant to a specific portion of the population, called as egg-laying female birds; they are formed during a specific duration of the life of a female and hence proven as a very good indicator for local exposure. Prior to egg laying, females of all the bird species from temperate and

---

M.Z. Hashmi
Department of Environmental Engineering, College of Environmental and Resource Sciences, Zhejiang University, Hangzhou 310058, People's Republic of China

N.A. Abbasi • R.N. Malik (✉)
Environmental Biology and Ecotoxicology Laboratory, Department of Environmental Sciences, Faculty of Biological Sciences, Quaid-i-Azam University, Islamabad PO 45320, Pakistan
e-mail: r_n_malik2000@yahoo.co.uk

X. Tang
Institute of Soil and Water Resources and Environmental Sciences, Zhejiang University, 866 Yuhangtang Road Hangzhou 310058, P.R. China

I. Sherameti, A. Varma (eds.), *Heavy Metal Contamination of Soils*, Soil Biology 44, DOI 10.1007/978-3-319-14526-6_7

tropical zones spend a lot of time in their breeding grounds feeding on local resources for egg production (Dauwe et al. 2005). Unlike feathers, the composition of an egg is advantageous because its composition is highly consistent which does not change with size, age, or the position of the body. Eggs have been widely used for many of the recent biomonitoring studies, and it has been a proven fact that collecting a single egg in favorable circumstance has produced negligible effects on population parameters of the species (Furness 1993).

Soil is an important medium to support the life on earth. It is an essential part of biosphere which provides space for animal and plant anchorage and growth and regulates the cycles of nutrients and water. Since the advent of industrial revolution, the concentration of heavy metals increases alarmingly in the soil. As a result of rampant discharge of agricultural and industrial waste, the concentration level of heavy metals like most of the pollutants suddenly touched to the threatening threshold. Municipal waste, ore smelting, and the use of pesticide and fertilizers are the major anthropogenic sources through which toxic heavy metals are introduced in the soil (Meli et al. 2013). Heavy metals are carried from the source to the distant areas through water currents or land/soil movement. Soil is the ultimate medium which receives heavy metals from different sources and deposits them for a long time. Being the largest supporting medium for heavy metal deposition, soil and sediments serve as an archive and reservoir for metal deposition and their subsequent dissemination in plants and animal body parts through their feed. Most of the heavy metals particularly mercury, cadmium, and lead readily adsorbed on dead organic matter, waxy plant material, animal’s membranes, fats, and oppositely charged soil particles. After adsorption, the bioavailability of these toxic heavy metals for an organism will either depend on the properties of the metals and/or the physical, chemical, and biological properties of the medium into which it is released (Gamberg et al. 2005). Elevated concentration of heavy metals in soil greatly affects the capability of the soil to sustain its biological productivity, regulate the local environment, and provide the best condition for the growth of animals and plants and betterment of human health.

Heavy metals present in soil are taken by plants and animals through absorption and ingestion, respectively. Birds being the agile group of vertebrates receive metals during their lifetime exposure to soil. The concentration level in eggs of a species is a very good indicator for local exposure to soil. This is because of the reason that an egg is the only development in birds which is produced during a particular period of time by an egg-laying female fraction of a population. For breeding, birds are either sedentary (remain in their same habitat) or migratory (migrate toward their breeding grounds for breeding). Before egg laying, females build an actively defended breeding/nesting territory and exploit the local resources to the balance of nutrients during egg-laying season. Burger and Gochfeld (1995) reported that the concentration of metals in eggs represents the circulation level of respective metals in the blood which in turn reflects the recent exposure. Metals usually accumulate in the eggshell and/or egg contents during metal sequestration by the female (Mora 2003). Similarly, Burger (1993) said that eggs are the most vulnerable part to be affected with heavy metals and it exhibits the local exposure of the adult female which has laid them. Different studies reported the direct relation between the heavy metal concentration in soil and the level recorded in eggs of different bird species. The concentration of metals such as Pb and Cd concentration was found to be correlated in the soil and egg which suggests that soil is an important source for these elements (Waegeneers et al. 2009a, b). Similarly, the concentrations of Pb, Cd, and Cu in the eggs of gray heron (*Ardea cinerea*) and black-crowned night heron (*Nycticorax nycticorax*) were found indicative for their respective concentration in sediments of Nallihan Bird Paradise, Turkey (Ayaş 2007). In this way, an egg has been proven as a very useful biomonitoring tool for heavy metal contamination in soil.

The concentration of heavy metals in eggs in relation to soil may be affected by several factors. As this relation is much dependent on food of the organism, difference in the food chain may exist. It also depends on the dietary preferences of the species during breeding period. Interspecies differences and spatiotemporal differences were recorded in several studies (Akearok et al. 2010; Burger 2002; Dauwe et al. 2004). The difference between the eggshell and egg contents also gives useful information. Usually, for toxic trace metals such as Pb, Cd, Se, and Hg, the eggshell has been suggested to be a better indicator, while egg contents could be used as a best indicator for essential elements such as Fe, Mn, Zn, etc. (Dauwe et al. 1999). Moreover, it is suggested that data for egg metals for the same species should be collected for a period of consecutive years to identify the addition or deletion of any point or nonpoint pollution source and also to record the past trends of exposure (Burger and Gochfeld 1993). This chapter relates the metal concentration in eggs which is indicating the pollution level at different habitats, factors which affect the soil to egg metal ratio and the inexplicability of egg to soil metal relation. Further, this chapter also discusses the pros and cons for an egg as a biomonitoring tool for metal contamination and its scope for future biomonitoring research.

7.2 Soil Characteristics and Metal Bioavailability for Birds

Depending on the ecosystem, either terrestrial or aquatic, pollutant dynamics are rather different. In terrestrial ecosystems, the ambient environment is usually soil (Burger et al. 2004; Lam et al. 2005; Shahbaz et al. 2013), while in an aquatic one, it is usually the water or the sediment (Boncompagni et al. 2003; Mora 2003; Mora et al. 2007). Once metals get into soil or sediment, they have long residence times before they are eluted to other compartments. Acidity has a marked effect on the solubility of metals in soils and water. The mobility of metals in soils is dictated largely by the clay contents, amount of organic matter, and pH. In general, the higher the clay and/or organic content and pH are, the more firmly bound the metals are and the longer their residence time is in soil. In water, the solubility of metals is strongly pH dependent. In aquatic systems, metals may become “blocked up” in bottom sediments, where they may remain for many years. However, if the pH falls, metal solubility increases, and they become more mobile and hence more bioavailable (Cotín Martínez 2012). As the acidity changes, the oxidation state changes accordingly, and as a result, heavy metals can generate or break bounds with organic compounds generating specific compounds such as methylmercury. Methylated compounds are taken up more readily than the unmethylated form, due to its high lipoaffinity (Cotín Martínez 2012).

Unlike organochlorides (another known family of pollutants), which are distributed widely among body tissues, largely in relation to their lipid contents, heavy metals tend to be held in one particular tissue at much higher levels than the others. The site specificity of metals has an important influence on the choice of tissue for monitoring studies. For example, although females can excrete mercury into eggs, the amount they shed in this way is usually small compared to the amount put into feathers during molting (Honda et al. 1986). There are several different approaches for measuring bioavailability. In vivo tests use an animal to measure absolute bioavailability and toxicity. In vitro tests are performed outside the organism (Furman et al. 2006).

7.3 Egg as a Biomonitor for Soil Heavy Metals from Different Ecosystems

Governmental agencies, tribal nations, policy makers, managers, and the general public are concerned about the health of different ecosystems of the environment and require bioindicators that assess the levels of contaminants in individual organisms, populations, and communities. Chemical use is increasing in our environment and may pose a threat to some species and populations. The levels of many chemicals have been elevated in aquatic ecosystems (wetland, islands, marine land, and coastal areas) and terrestrial ecosystems (agriculture, forest, rural and urban) by using eggs (Table 7.1) as a biomonitor (Burger et al. 2009; Hashmi et al. 2013; Lam et al. 2005; Mora et al. 2011; Shahbaz et al. 2013), because of the influx from rivers, as well as runoff and direct pollution (Furness and Rainbow 1990), and from atmospheric transport and deposition.

7.3.1 Terrestrial Ecosystem

Terrestrial ecosystem exists only on landforms which may cover agricultural areas, forest areas, urban areas, and rural areas. Hence, terrestrial ecosystems are major hotspot for the chemical deposition from anthropogenic activities (agriculture and industrial) and natural processes. These anthropogenic activities and natural processes have not only affected terrestrial ecosystem services but also other living things (human, animals, etc.). Biomonitoring approaches using bird's eggs as a bioindicator tool to probe out the integrity of different areas of terrestrial ecosystem have been used a few decades ago. Several research articles reported eggs as a suitable bioindicator of agricultural areas (Hashmi et al. 2013; Shahbaz et al. 2013),

Table 7.1 Biomonitoring of heavy metals using eggs from different areas and bird species

Authors	Study area	Species
Shahbaz et al. (2013)	Islam Headworks, Pakistan	Little egret
		Cattle egret
	Trimmu Headworks, Pakistan	Little egret
		Cattle egret
Ruuskanen et al. (2014)	Eurasia	*Ficedula hypoleuca*
Jackson et al. (2011)	Virginia	Carolina wren
Beltrame et al. (2010)	Argentina	Burrowing crab
Páez-Osuna et al. (2010)	Mexico	Sea turtle (albumen)
		(yolk)
Burger et al. (2009)	Aleutian Islands, Alaska	Glaucous-winged Gull
Burger and Gochfeld (2009)	New York, USA	Common tern
Custer et al. (2008)	Lostwood, North Dakota	Tree swallows
Tsipoura et al. (2008)	New Jersey, USA	Red-winged blackbird
		Marsh wren
Roodbergen et al. (2008)	Netherlands	Black-tailed godwit
Custer et al. (2007a)	Agassiz National Wildlife Refuge, Minnesota	Franklin's gull
		Black-crowned night heron
		Eared grebe
		Pied-billed grebe
Bostan et al. (2007)	Gujranwala, Pakistan	Cattle egret
Burger and Gochfeld (2007)	Aleutians Islands, Alaska	Common eider
		Glaucous-winged Gull
Custer et al. (2007b)	Mississippi, USA	Tree swallows
	Mexico	Mourning dove
		Burrowing owl
		Marsh wren
Swaileh and Sansur (2006)	Birzeit, Palestine	House sparrows
Ikemoto et al. (2005)	Torishima Island, Japan	Short-tailed albatross
		Black-footed albatross
Dauwe et al. (2005)	Antwerp, Belgium	Great tits
		Great tits
		Great tits
Lam et al. (2005)	Hong Kong	Black-crowned night heron
		Little egret
		Bridled tern
Burger et al. (2004)	Florida	Scrub jay

(continued)

Table 7.1 (continued)

Authors	Study area	Species
Mora (2003)	Arizona, USA	Yellow-breasted chat
		Yellow-breasted chat
		Yellow-breasted chat
		Bell's vireo
		Lesser goldfinch
Boncompagni et al. (2003)	Haleji Lake, Pakistan	Little egret
		Intermediate egret
	Karachi, Pakistan	Little egret
	Taunsa, Pakistan	Little egret
		Cattle egret
Hui (2002)	USA	Rock dove
Burger (2002)	New Jersey, USA	Herring gull
		Great black-backed gull
		Common tern
		Forster's tern
		Skimmer

urban areas (Burger et al. 2004; Burger and Gochfeld 1995, 2004; Dev and Bhattacharjee 2010; Ek et al. 2004; Evers et al. 2003; Fu et al. 2014; Gochfeld 1997; Hui 2002; Lam et al. 2005; Mora 2003; Mora et al. 2007, 2011; Orłowski et al. 2010; Sekeroglu et al. 2013; Swaileh and Sansur 2006), rural areas (Kitowski et al. 2013; Orłowski et al. 2010), and industrial areas (Burger et al. 2004; Burger and Gochfeld 2004; Dauwe et al. 1999, 2005; Gochfeld 1997; Mora et al. 2011; Orłowski et al. 2010; Scheuhammer et al. 2001).

7.3.2 Aquatic Ecosystem

Aquatic ecosystems or environments are particularly sensitive to heavy metal contamination because aquatic physicochemical conditions can facilitate the conversion of unavailable forms of heavy metals into more bioavailable forms, which accumulate very efficiently in top predators. The life histories and ecological niches occupied by many aquatic birds predispose them to accumulating heavy metals, and the toxicology and merits/limitations of using eggs for monitoring heavy metals have been studied extensively. Aquatic ecosystems such as wetlands, islands, marine lands, and coastal areas provide breeding habitats for egrets, herons, and waterfowls and receive untreated effluents from agriculture and industries and cities from point and nonpoint sources of pollution. Hence, wetlands, islands, marine lands, and coastal areas act as a depository reservoir of organic as well as inorganic pollutants. Species that forage in aquatic environments are particularly vulnerable because of the potential for the rapid movement of contaminants in water, compared to the movement in terrestrial environments, and because chemicals can be stored in sediments in intertidal environments, providing a pool for years to come.

A variety of toxic substances enter the water from surface runoff, industrial effluent, air pollution, wave action, the movement of organisms, and the high traffic of marine shipping entering these ports. Organisms that live in these estuarine systems can bioaccumulate organic and certain inorganic substances over time and are at risk from both lethal and sublethal effects, as their body burdens increase. Several studies used eggs as a biomonitor of heavy metal contamination in the soil and sediments of wetland ecosystems (Shahbaz et al. 2013; Hashmi et al. 2013; Jackson et al. 2011; Ayaş 2007; Kertész and Fáncsi 2003; Burger and Gochfeld 2004; Mora 2003; Mora et al. 2007 Boncompagni et al. 2003; Bischoff et al. 2002; Goutner et al. 2001), island ecosystems (Xu et al. 2011; Burger et al. 2009; Pereira et al. 2009; Burger et al. 2008; Ayaş et al. 2008; Agusa et al. 2005; Burger 2002; Gochfeld 1997; Sanpera et al. 2000, 1997; Burger and Gochfeld 1995), marine ecosystems (Akearok et al. 2010; Day et al. 2006), and coastal ecosystems (Pereira et al. 2009; Burger and Gochfeld 2003; Mateo et al. 2003). However, most of the published literature focused on the island and wetland ecosystems to monitor the heavy metal contamination by using eggs than the other ecosystems.

7.4 Factors Influencing Accumulation of Soil Heavy Metals in Eggs

7.4.1 Interspecific Variations

Metal accumulation in eggs is different for different species of birds. Several factors such as age and health of the female, diet preferences during breeding season, taxonomic affiliation, and the trophic level of the species and metal concentration level in the surrounding environment either singly or synergistically influence the overall metal burden in egg of different bird species. Heavy metal accumulation in eggs of different species largely depends upon the metal availability, metal intake, and physiological mechanisms for metal circulation, accumulation in the parts of the body, regulation, and subsequent excretion. All of these factors vary for different species and/or within the species and hence cause intra- and interspecific variation for metal accumulation in eggs. Differences of heavy metal concentrations in the eggs of different species have been reported in several studies (Akearok et al. 2010; Boncompagni et al. 2003; Burger 2002). There are several possible reasons for interspecific metal variation in eggs. One of the most important is the difference of the habitats/locations which different species prefer for foraging during breeding season. As the choice and requirement of nutrients differ for species, they accumulate metals in different quantities in their eggs (Ayaş 2007). A study reported by Boncompagni et al. (2003) concluded that the dissimilar concentration level of heavy metals in the eggs of three egret species foraging in the same area was because the female may have to visit different habitats for foraging prior to or during breeding and egg formation. So the phenomenon of visiting different locations for the sake of fulfilling its nutrient requirement has proved to be the basic factor influencing the ratio of soil and egg concentration level of heavy metals for different species. The next question in this regard may be that why eggs of different species exhibit different concentrations of metals inhabiting the same location? There is no straightforward answer yet being provided through research. But it is described by the physiological mechanism differences for the circulation, regulation, excretion, and replenishment of metals for different species. In general, one can say that both of the abovementioned factors, i.e., the difference of location and difference of the regulation of body metal burden, markedly influence the metal concentration level in eggs.

7.4.2 Influence of the Trophic Levels

Concentrations of metals in eggs are mainly attributed to the diet of the organism. Shahbaz et al. (2013) reported that elevated concentrations of toxic metals such as Cd, Cr, and Pb and some essential elements, viz, Mn, Fe, and Zn, in the egg contents of cattle egret are directly related to the higher concentrations of these metals in prey and soil of their foraging sites. They also deduced that unlike feathers, the concentration of heavy metals in eggs is more influenced by the environmental condition and food items. Similarly, elevated concentrations of Pb and Cd in the diet and sediments were found to be directly associated with the higher concentration of these metals in herons of Korea (Kim et al. 2010). The higher concentration of strontium in the eggshell of passerine birds from Arizona was probably associated with the higher deposition of Sr in the surrounding of the nesting sites of these birds. These passerine birds feed on certain invertebrates and insects which were associated with the recycling of Sr in the soil (Mora 2003). While studying the accumulation of Hg in different species, Burger (2002) found that larger fish-eating birds tend to accumulate more metals in their eggs when compared to small fish eaters. Similarly, in comparison with carnivores, omnivores and invertebrate-eating species accumulate lower metal accumulation in their eggs and showed that for birds, certain metal concentration increases with the increase in the trophic position. But this is not true for all the metals nor for all species. Being higher on the food web, the concentration of Hg in the eggs of common tern (*Sterna hirundo*) was found twice than those of duck species (Akearok et al. 2010). Boncompagni et al. (2003) reported that the concentration level of different heavy metals in the eggs and different other tissues of egret species was indicative of the concentration of the respective metals in sediments and prey items. So the birds which feed on the prey which largely relies on metal-rich soil for their food should have more metal concentration in their eggs. In general, one can say that the concentration level of heavy metals increases with the increase in the trophic position of the species, but one has to keep in mind the respective food chain and food web to get a meaningful result.

7.4.3 Temporal Variations (Inter-clutch and Intra-clutch Differences)

Temporal variation in egg metal content describes the time-based changes in the level of metal concentration and hence the difference in the local exposure. Temporal variation in the egg metal level provides information that can be useful for understanding the sudden shift of metals which in turn can be used to find any new addition in the metal pollution source (Burger and Gochfeld 2003). It is usually recommended to collect year-wise data for the same species for consecutive years to get a better understanding about the trends of metal accumulation. Significant differences in the concentration of heavy metals such as Pb, Cd, Se, and Hg were recorded in eggs of herring gulls (*Larus argentatus*) between the years 1998 and 1994. But the concentration level of metals in eggs rarely remains consistent for any metals between the years because of the changing metal pollution level for the location which the female is visiting for foraging prior to egg laying (Burger 1994). Furthermore, seasonal variation in the availability of heavy metals is obvious, so the exposure varies between different species and seasons. This is because the onset of breeding period is not the same for all the species, so the female of the different species may be exposed to the varying levels of heavy metals and hence accumulate different levels of metals in their egg. Seasonal bioavailability of heavy metals in soil is largely based on soil characteristics and local environmental condition and weather attributes. Besides inter-clutch variation in metal concentration, intra-clutch variation has also been observed for several metals. Custer et al. reported that sometimes systematic trends of metal concentration could be observed with egg-laying order, but it is not consistent for all the species nor for all the metals. Usually, the early laid egg has higher concentration of metals than later ones. Dauwe et al. (2004) reported that the time difference for laying eggs in any one breeding season has no significant effect on the metal accumulation in the female egg and hence on the number of sperm stored in perivitelline layer of the egg. Conversely, the concentration of several trace metals varied significantly between the home-produced chicken eggs in autumn and spring, but this temporal discrepancy of metals has not solely depended upon the concentration of these metals in soil (Waegeneers et al. 2009a). Similarly, temporal trends were recorded as spatial and temporal variations of Hg in the egg contents of gannet (*Morus bassanus*) between the years 1974 and 2004 from Bass Rock (North Sea) and Ailsa Craig (eastern Atlantic) (Pereira et al. 2009). Intra- and inter-clutch variations in the Hg level in the eggs of marine birds were reported and attributed to the diet switching of these marine species during their clutch periods. It is also proposed that an early clutch could be a better representative of the environmental state because it exhibits maximum metal load in females, metal burden which may be transferred to the offspring, and metals available for the predator (Akearok et al. 2010). The selenium level increases more than twofolds in the eggs of Florida scrub jays (*Aphelocoma coerulescens*) from 1996 to 2001 (Burger et al. 2004). No intra-clutch variation in the egg Hg level was reported in some piscivore and insectivore birds. The reason for this could be the body replenishment of Hg during egg-laying season mainly through ingestion and/or partly from the stored methylmercury in tissues and muscles (Brasso et al. 2010). Burger et al. (2008) reported that the clutches with more number of eggs exhibit variation than those with less number of eggs. In other words, the metal concentration varies within and among clutches, but no consistent trend has yet been observed. The lack of inconsistency among clutches of consecutive years is primarily attributed to the difference in the metal pollution level at the site where females visit during breeding season and partly may be due to species-specific responses toward metal burden in the consecutive years. Females may replenish the metal deficiency after laying the first egg and make up the metal deficiency effectively from the surrounding environment after each egg laid.

7.4.4 Geographical Difference

Metal contamination in egg is also influenced by the metal distribution level in the surrounding environment. Although not true for all the cases, the metal concentration level in egg is greatly influenced by the overall metal pollution burden of the surrounding environment and produces certain impairments in the egg. Differential exposure of species to soil heavy metals affects the total metal burden of the eggs and may produce certain abnormalities in the egg which in turn may affect reproduction. The exposure to the extreme level of heavy metals did not affect the egg of blue tit (*Parus caeruleus*) (Dauwe et al. 2002), while substantial impairments were observed in the eggs of pied flycatcher (*Ficedula hypoleuca*) and great tit (*Parus major*). It was also concluded that poor forest soil with less nutrient in combination with acidification affects the metal accumulation in egg and hence effects on egg quality (Eeva and Lehikoinen 1996). The soils with greater heavy metal pollution have been reported with lower sperm quality in males, poor mobility, and subsequent trapping in the perivitelline layer of the egg (Dauwe et al. 2002). Roodbergen et al. (2008) noted that the concentration of heavy metals such as Hg, Pb, and Cd was greater in soil, in earthworms, and subsequently in the egg of black-tailed godwit (*Limosa limosa*) at a polluted site which is contrasting to the reference site and suggested a direct transport of metals from the soil to the eggs through earthworm which is the primary prey of black-tailed godwit. Sekeroglu et al. (2013) reported that the metal concentration in eggs from the village chicken of Turkey is directly proportional to the distance from the roadside. Similarly, the concentration of toxic metals such as Pb, Cu, and Zn increases in the eggs of black kite (*Milvus migrans*) and decreases in distance from the solid waste incinerator (Blanco et al. 2003). Concentrations of heavy metals in the eggs of egret species were found higher in cosmopolitan areas where the metal pollution level was quite higher than relatively pristine areas (Boncompagni et al. 2003). Locational differences of Hg and Cd and Pb, As, Se, and Mn contamination in common tern (*Sterna hirundo*) eggs were recorded from five different locations of Barnegat Bay, New

Jersey (Burger and Gochfeld 2003). It is evident from the above discussion that soil from different locations has the varying capacities of heavy metals which it can offer to plants, small invertebrates, and higher organisms. The greater the metal pollution sources, the higher the concentration in soil, and consequently more metals reached to the avian tissues and sequestered in egg which truly represents the local environmental state.

7.4.5 Eggshell or Egg Content Differences

Eggshell is thought to be associated with the sequestration of most of inorganic elements (Dauwe et al. 1999) and usually exhibits greater metal concentration of most of the inorganic elements when compared with egg contents. Mora (2003) reported that the concentration of most of the studied metals including Ba, Ni, Sr, Zn, Mn, and V was 2–35 times higher in eggshells of yellow-breasted chats (*Icteria virens*) and willow flycatchers (*Empidonax traillii extimus*) when compared with egg contents. Similar results for higher eggshell/egg content ratio were recorded in black-tailed gulls (*Larus crassirostris*) in Japan (Agusa et al. 2005) and for little egret (*Egretta garzetta*) and black-crowned night heron (*Nycticorax nycticorax*) in Hong Kong (Lam et al. 2004). Metals sequestered through eggs depend upon the requirement of the respective metals for embryonic development and need for metal regulation and excretion. Ayaş (2007) reported that the metal concentration in the eggshell itself is a very good indicator for the metal concentration level in egg content. The level of metal contents in the eggshell and egg content is different for different metals. Dauwe et al. (1999) draw an important conclusion that there is a discrepancy for metal sequestration between the egg contents and eggshell. They reported that essential metals such as Zn and Cu were greater in egg contents of great tit (*Parus major)* and blue tit (*Parus caeruleus*), whereas the nonessential metals such as Cd, Pb, and As were higher in the eggshell. No significant difference between the polluted and reference site was recorded. Further, they deduced that the eggshell being highly associated with sequestered nonessential metals is a good indicator as compared to egg content. Similarly, the concentration of Zn, Cu, Hg, and Mn was found 80–99 % lower in the eggshell of Audouin's gulls (*Ichthyaetus audouinii*) than in egg contents (Morera et al. 1997). It is reported that eggshells are important for the excretion of heavy metals in birds (Burger 1994; Hashmi et al. 2013). The greater concentration level of essential nutrients in egg content is evidently associated with the regulation mechanism of these metals in the egg contents, whereas nonessential metals are sequestered in the eggshell for excretion. But the elevated concentration of these nonessential metals in the respective soil would tend to accumulate more metals in different bird tissues and subsequently sequester in the eggshell at a higher rate and affect egg quality and hence reproduction.

7.5 Heavy Metals in Soil and Eggs: An Equivocal Relation

Egg laying may be an additional excretory pathway for heavy metals available to laying female birds. Contaminant levels in eggs are useful bioindicators of exposure because they potentially represent different periods of exposure. The concentrations of metals in eggs are derived from females and represent the recent exposure in waters close to the breeding grounds, as well as mobilization of stored metals from the past intake (Burger 1994; Burger and Gochfeld 1996). However, the contaminant concentration in the eggs is also influenced by the presence of contaminants in nonbreeding areas (Burger 2002). Eggshell formation and egg laying are recognized as a means of excreting environmental contaminants (e.g., metals) by oviparous females (Burger and Gochfeld 1995; Gochfeld and Burger 1998; Lam et al. 2004, 2005), and thus contaminant concentrations in eggs can potentially be used as a surrogate for contaminant monitoring in egg-laying wildlife. Besides metals, bird eggs are also useful for evaluating lipophilic persistent organic pollutants (Connell et al. 2003). However, the contaminant concentrations in the eggs can also be influenced by contaminants present in areas utilized by these birds outside the breeding seasons (Burger 2002). Further, heavy metal content in the bird's egg reflects local pollution levels (Burger 2002); because hens live in close contact with the outside environment, they are exposed to contaminants (Furness et al. 1993). Also, numerous studies have related the heavy metal contents of bird's eggs and internal organs come from environmental pollution (Burger 2002; Burger et al. 2004; Hui 2002; Mora 2003; Sekeroglu et al. 2013). Hence, eggs are not influenced directly by soil heavy metal contamination, and there are no reports which suggest a direct relationship between soil heavy metal contamination and eggs (Day et al. 2006). However, several reports suggested eggs as bioindicator of soil heavy metal contamination by food chain (Boncompagni et al. 2003; Ikemoto et al. 2005; Mora et al. 2011; Shahbaz et al. 2013) or by intake of heavy metals from air into birds. The literature published so far on eggs as indicator of soil heavy metal contamination considered the food chain. Then, the birds after the regulation of heavy metals in the internal body excrete or maternally transfer heavy metals in the eggs or eggshell. Scheuhammer (1987) suggests that the transfer to the eggs only takes place if the concentration in the tissues of the female is high. Egg heavy metal contamination suggested that maternal transfer, food chain, and inhalation of metals could be responsible. However, some reports suggested that eggshells (Burger 1994) and egg contents (Lewis et al. 1993; Monteiro and Furness 1995; Monteiro et al. 1995) are important for the excretion of some trace elements in birds. Hence, eggshells and egg contents may be suitable to assess burdens of trace elements in mother birds during the period of egg development (Fossi et al. 1994). Hence, the published literature discussed here indicated that heavy metals in soil and eggs exhibited an equivocal relation.

7.6 Scope of Egg as a Biomonitor of Soil Heavy Metals

The egg in birds is a self-sustained life support system which comprised of the egg contents and eggshell. The bird's egg virtually serves as a good indicator for heavy metal pollution in the environment. Heavy metals are sequestered by the females during egg production (Burger 2002). But the sequestration of heavy metals is not consistent; cadmium, for example, is reported to be transmitted to the egg in a very limited quantity (Burger 1993). So, the use of egg for biomonitoring of those metals which are not sequestered properly by females will be limited. Scheuhammer (1987) suggested that the transfer of heavy metals to eggs takes place only if the concentration of the respective metals is very high in body tissues. In this way, females predominately sequester only those elements which are present in higher concentration in their body tissues, and the information about the other elements would be masked. So far, very limited information on the maternal transfer rate of heavy metals is available which means that the percentage of heavy metals in the egg to the whole body burden of metals has rarely been studied. To fill this gap of knowledge, extensive research on the maternal transfer rate of heavy metals to the eggs should be studied which will not only enhance the pool of existing knowledge on metal soil to egg metal ratio but will also provide the information about the extent to which eggs could be useful for biomonitoring of heavy metals in soil. Moreover, the concentration level of most of the essential metals such as Cu, Zn, and Fe in the eggs could partly be explained by the internal regulatory mechanism of the body. Some metals may be mobilized by the female body during the egg production from the stored metals in different tissues in the body which the organism has ingested elsewhere not from the local soil. For example, Pb sequestered in egg may reflect the mobilization of lead from accumulated mass during the previous breeding season from the same area. Therefore, concentrations of certain metals are not necessarily linked to the soil metal level. For a meaningful interpretation of the results, one has to take care about all these possible discrepancies. As the egg provides information only about the concentration in the soil of breeding grounds, the information about the metal addition at wintering grounds would be missing. Before using egg as a biomonitoring tool for heavy metal accumulation through soil, one must know the characteristics and history of the local soil, especially the turnover rate of sediments. By using these information and egg-related discrepancies, one could give the evocative description on soil to egg metal transfer.

References

Agusa T et al (2005) Body distribution of trace elements in black-tailed gulls from Rishiri Island, Japan: age-dependent accumulation and transfer to feathers and eggs. Environ Toxicol Chem 24:2107–2120

Akearok JA et al (2010) Inter-and intraclutch variation in egg mercury levels in marine bird species from the Canadian Arctic. Sci Total Environ 408:836–840

Ayaş Z (2007) Trace element residues in eggshells of grey heron (*Ardea cinerea*) and black-crowned night heron (*Nycticorax nycticorax*) from Nallihan Bird Paradise, Ankara-Turkey. Ecotoxicology 16:347–352

Ayaş Z, Celikkan H, Aksu ML (2008) Lead (Pb) and copper (Cu) concentration in the eggshells of Audouin's gulls (Larus audouinii) in Turkey. Turk J Zool 32:379–384

Beltrame MO, De Marco SG, Marcovecchio JE (2010) Influences of sex, habitat, and seasonality on heavy-metal concentrations in the burrowing crab (Neohelice granulata) from a coastal lagoon in Argentina. Arch Environ Contam Toxicol 58:746–756

Bischoff K, Pichner J, Braselton W, Counard C, Evers D, Edwards W (2002) Mercury and selenium concentrations in livers and eggs of common loons (Gavia immer) from Minnesota. Arch Environ Contam Toxicol 42:71–76

Blanco G, Frías O, Jiménez B, Gómez G (2003) Factors influencing variability and potential uptake routes of heavy metals in black kites exposed to emissions from a solid-waste incinerator. Environ Toxicol Chem 22:2711–2718

Boncompagni E et al (2003) Egrets as monitors of trace-metal contamination in wetlands of Pakistan. Arch Environ Contam Toxicol 45:399–406

Bostan N, Ashraf M, Mumtaz AS, Ahmad I (2007) Diagnosis of heavy metal contamination in agro-ecology of Gujranwala, Pakistan using cattle egret (Bubulcus Ibis) as bioindicator. Ecotoxicology 16:247–251

Brasso RL, Abdel Latif MK, Cristol DA (2010) Relationship between laying sequence and mercury concentration in tree swallow eggs. Environ Toxicol Chem 29:1155–1159

Burger J (1993) Metals in avian feathers: bioindicators of environmental pollution. Rev Environ Toxicol 5:203–311

Burger J (1994) Heavy metals in avian eggshells: another excretion method. J Toxicol Environ Health 41:207–220

Burger J (2002) Food chain differences affect heavy metals in bird eggs in Barnegat Bay, New Jersey. Environ Res 90:33–39

Burger J et al (2004) Metal and metalloid concentrations in the eggs of threatened Florida scrub-jays in suburban habitat from south-central Florida. Sci Total Environ 328:185–193

Burger J, Gochfeld M (1993) Lead and cadmium accumulation in eggs and fledgling seabirds in the New York Bight. Environ Toxicol Chem 12:261–267

Burger J, Gochfeld M (1995) Heavy metal and selenium concentrations in eggs of herring gulls (Larus argentatus): temporal differences from 1989 to 1994. Arch Environ Contam Toxicol 29:192–197

Burger J, Gochfeld M (1996) Heavy metal and selenium levels in Franklin's gull (*Larus pipixcan*) parents and their eggs. Arch Environ Contam Toxicol 30:487–491

Burger J, Gochfeld M (2003) Spatial and temporal patterns in metal levels in eggs of common terns (*Sterna hirundo*) in New Jersey. Sci Total Environ 311:91–100

Burger J, Gochfeld M (2004) Metal levels in eggs of common terns (*Sterna hirundo*) in New Jersey: temporal trends from 1971 to 2002. Environ Res 94:336–343

Burger J, Gochfeld M (2007) Metals and radionuclides in birds and eggs from Amchitka and Kiska Islands in the Bering Sea/Pacific Ocean ecosystem. Environ Monit Assess 127:105–117

Burger J, Gochfeld M (2009) Comparison of arsenic, cadmium, chromium, lead, manganese, mercury and selenium in feathers in bald eagle (Haliaeetus leucocephalus), and comparison with common eider (Somateria mollissima), glaucous-winged gull (Larus glaucescens), pigeon guillemot (Cepphus columba), and tufted puffin (Fratercula cirrhata) from the Aleutian Chain of Alaska. Environ Monit Assess 152:357–367

Burger J, Gochfeld M, Jeitner C, Snigaroff D, Snigaroff R, Stamm T, Volz C (2008) Assessment of metals in down feathers of female common eiders and their eggs from the Aleutians: arsenic, cadmium, chromium, lead, manganese, mercury, and selenium. Environ Monit Assess 143:247–256

Burger J et al (2009) Mercury and other metals in eggs and feathers of glaucous-winged gulls (Larus glaucescens) in the Aleutians. Environ Monit Assess 152:179–194

Connell D et al (2003) Risk to breeding success of fish-eating Ardeids due to persistent organic contaminants in Hong Kong: evidence from organochlorine compounds in eggs. Water Res 37:459–467

Cotín Martínez J (2012) Birds as bioindicators of pollution in aquatic and terrestrial environments. Thesis, Universitat de Barcelona. http://hdl.handle.net/10803/101099

Custer TW, Custer CM, Johnson KM, Hoffman DJ (2008) Mercury and other element exposure to tree swallows (Tachycineta bicolor) nesting on Lostwood National Wildlife Refuge, North Dakota. Environ Pollut 155:217–226

Custer TW, Custer CM, Eichhorst BA, Warburton D (2007a) Selenium and metal concentrations in waterbird eggs and chicks at Agassiz National Wildlife Refuge, Minnesota. Arch Environ Contam Toxicol 53:103–109

Custer TW et al (2007b) Water level management and contaminant exposure to tree swallows nesting on the Upper Mississippi River. Environ Monit Assess 133:335–345

Dauwe T et al (1999) Are eggshells and egg contents of great and blue tits suitable as indicators of heavy metal pollution? Belg J Zool 129:439–447

Dauwe T et al (2005) Heavy-metal concentrations in female laying great tits (*Parus major*) and their clutches. Arch Environ Contam Toxicol 49:249–256

Dauwe T et al (2004) The effect of heavy metal exposure on egg size, eggshell thickness and the number of spermatozoa in blue tit *Parus caeruleus* eggs. Environ Pollut 129:125–129

Dauwe T et al (2002) Great and blue tit feathers as biomonitors for heavy metal pollution. Ecol Indic 1:227–234

Day RD et al (2006) Murre eggs (Uria aalge and Uria lomvia) as indicators of mercury contamination in the Alaskan marine environment. Environ Sci Technol 40:659–665

Dev B, Bhattacharjee P (2010) Heavy metals in egg shells of six species of Ardeidae (Aves) from Barak Valley, Assam. Ass Univ J Sci Technol 5:48–52

Eeva T, Lehikoinen E (1996) Growth and mortality of nestling great tits (*Parus major*) and pied flycatchers (*Ficedula hypoleuca*) in a heavy metal pollution gradient. Oecologia 108:631–639

Ek KH et al (2004) Platinum group elements in raptor eggs, faeces, blood, liver and kidney. Sci Total Environ 334:149–159

Evers D et al (2003) Common loon eggs as indicators of methylmercury availability in North America. Ecotoxicology 12:69–81

Fossi MC et al (1994) Blood esterase inhibition in birds as an index of organophosphorus contamination: field and laboratory studies. Ecotoxicology 3:11–20

Fu J et al (2014) Monitoring of non-destructive sampling strategies to assess the exposure of avian species in Jiangsu Province, China to heavy metals. Environ Sci Pollut Res 21:2898–2906

Furman O et al (2006) Risk assessment test for lead bioaccessibility to waterfowl in mine-impacted soils. J Environ Qual 35:450–458

Furness R (1993) Birds as monitors of pollutants. In: Furness RW, Greenwood JJD (eds) Birds as monitors of environmental change. Springer, New York, NY, pp 86–143

Furness R et al (1993) Can birds be used to monitor the environment? In: Furness RW, Greenwood JJD (eds) Birds as monitors of environmental change. Springer, New York, NY, pp 1–41

Furness RW, Rainbow PS (1990) Heavy metals in the marine environment. CRC Press, Boca Raton, FL

Gamberg M et al (2005) Spatial and temporal trends of contaminants in terrestrial biota from the Canadian Arctic. Sci Total Environ 351:148–164

Gochfeld M (1997) Spatial patterns in a bioindicator: heavy metal and selenium concentration in eggs of Herring gulls (*Larus argentatus*) in the New York Bight. Arch Environ Contam Toxicol 33:63–70

Gochfeld M, Burger J (1998) Temporal trends in metal levels in eggs of the endangered roseate tern (*Sterna dougallii*) in New York. Environ Res 77:36–42

Goutner V, Furness R, Papakostas G (2001) Mercury in feathers of Squacco Heron (Ardeola ralloides) chicks in relation to age, hatching order, growth, and sampling dates. Environ Pollut 111:107–115

Hashmi MZ et al (2013) Heavy metals in eggshells of cattle egret (*Bubulcus ibis*) and little egret (*Egretta garzetta*) from the Punjab province, Pakistan. Ecotoxicol Environ Saf 89:158–165

Honda K et al (1986) Distribution of heavy metals and their age-related changes in the eastern great white egret, Egretta alba modesta, in Korea. Arch Environ Contam Toxicol 15:185–197

Hui CA (2002) Concentrations of chromium, manganese, and lead in air and in avian eggs. Environ Pollut 120:201–206

Ikemoto T, Kunito T, Tanabe S, Tsurumi M, Sato F, Oka N (2005) Non-destructive monitoring of trace element levels in short-tailed albatrosses (Phoebastria albatrus) and black-footed albatrosses (Phoebastria nigripes) from Torishima Island, Japan using eggs and blood. Mar Pollut Bull 51:889–895

Jackson AK et al (2011) Mercury exposure affects the reproductive success of a free-living terrestrial songbird, the Carolina wren (Thryothorus ludovicianus). Auk 128:759–769

Kertész V, Fáncsi T (2003) Adverse effects of (surface water pollutants) Cd, Cr and Pb on the embryogenesis of the mallard. Aquat Toxicol 65:425–433

Kim J et al (2010) Effects of age on heavy metal concentrations of black-crowned night herons Nycticorax nycticorax from Korea. J Environ Monit 12:600–607

Kitowski I et al (2013) Trace elements in eggshells of the Grey Heron (*Ardea cinerea*) from the colony in the Roztocze Hills (South East Poland). Zool Ecol 23:240–244

Lam JC et al (2005) Risk to breeding success of waterbirds by contaminants in Hong Kong: evidence from trace elements in eggs. Environ Pollut 135:481–490

Lam JC et al (2004) Trace element residues in eggs of Little Egret (*Egretta garzetta*) and Black-crowned Night Heron (*Nycticorax nycticorax*) from Hong Kong, China. Mar Pollut Bull 48:390–396

Lewis S et al (1993) Mercury levels in eggs, tissues, and feathers of herring gulls *Larus argentatus* from the German Wadden Sea Coast. Environ Pollut 80:293–299

Mateo R, Beyer WN, Spann J, Hoffman D, Ramis A (2003) Relationship between oxidative stress, pathology, and behavioral signs of lead poisoning in mallards. J Toxic Environ Health A 66:1371–1389

Meli M et al (2013) Population-level consequences of spatially heterogeneous exposure to heavy metals in soil: an individual-based model of springtails. Ecol Model 250:338–351

Monteiro L, Furness R (1995) Seabirds as monitors of mercury in the marine environment. Water Air Soil Pollut 80:851–870

Monteiro L et al (1995) Mercury levels in seabirds from the Azores, mid-north Atlantic Ocean. Arch Environ Contam Toxicol 28:304–309

Mora MA (2003) Heavy metals and metalloids in egg contents and eggshells of passerine birds from Arizona. Environ Pollut 125:393–400

Mora MA et al (2011) Regional and interspecific variation in Sr, Ca, and Sr/Ca ratios in avian eggshells from the USA. Ecotoxicology 20:1467–1475

Mora MA et al (2007) Potential ecotoxicological significance of elevated concentrations of strontium in eggshells of passerine birds. Condor 109:199–205

Morera M, Sanpera C, Crespo S, Jover L, Ruiz X (1997) Inter-and intraclutch variability in heavy metals and selenium levels in Audouin's gull eggs from the Ebro Delta, Spain. Arch Environ Contam Toxicol 33:71–75

Orłowski G et al (2010) Geographical and habitat differences in concentrations of copper, zinc and arsenic in eggshells of the Rook Corvus frugilegus in Poland. J Ornithol 151:279–286

Páez-Osuna F, Calderón-Campuzano M, Soto-Jiménez M, Ruelas-Inzunza J (2010) Lead in blood and eggs of the sea turtle, Lepidochelys olivacea, from the Eastern Pacific: concentration, isotopic composition and maternal transfer. Mar Pollut Bull 60:433–439

Pereira MG, Walker LA, Best J, Shore RF (2009) Long-term trends in mercury and PCB congener concentrations in gannet (Morus bassanus) eggs in Britain. Environ Pollut 157:155–163

Roodbergen M, Klok C, van der Hout A (2008) Transfer of heavy metals in the food chain earthworm Black-tailed godwit (Limosa limosa): comparison of a polluted and a reference site in The Netherlands. Sci Total Environ 406:407–412

Ruuskanen S et al (2014) Large-scale geographical variation in eggshell metal and calcium content in a passerine bird (Ficedula hypoleuca). Environ Sci Pollut Res 21:3304–3317

Sanpera C, Morera M, Crespo S, Ruiz X, Jover L (1997) Trace elements in clutches of yellow-legged gulls, Larus cachinnans, from the Medes Islands, Spain. Bull Environ Contam Toxicol 59:757–762

Sanpera C, Morera M, Ruiz X, Jover L (2000) Variability of mercury and selenium levels in clutches of Audouin's gulls (Larus audouinii) breeding at the Chafarinas Islands, southwest Mediterranean. Arch Environ Contam Toxicol 39:119–123

Scheuhammer A (1987) The chronic toxicity of aluminium, cadmium, mercury, and lead in birds: a review. Environ Pollut 46:263–295

Scheuhammer A et al (2001) Mercury, methylmercury, and selenium concentrations in eggs of common loons (*Gavia immer*) from Canada. Environ Monit Assess 72:79–94

Sekeroglu A et al (2013) Effect of distance from the roadway on heavy metal content and egg quality of village laying hen's egg along roadsides of Tokat-Turhal, Turkey. J Agr Sci 50 (2):299–304

Shahbaz M et al (2013) Relationship between heavy metals concentrations in egret species, their environment and food chain differences from two Headworks of Pakistan. Chemosphere 93:274–282

Swaileh K, Sansur R (2006) Monitoring urban heavy metal pollution using the House Sparrow (Passer domesticus). J Environ Monit 8:209–213

Tsipoura N, Burger J, Feltes R, Yacabucci J, Mizrahi D, Jeitner C, Gochfeld M (2008) Metal concentrations in three species of passerine birds breeding in the Hackensack Meadowlands of New Jersey. Environ Res 107:218–228

Waegeneers N et al (2009a) Transfer of soil contaminants to home-produced eggs and preventive measures to reduce contamination. Sci Total Environ 407:4438–4446

Waegeneers N et al (2009b) Trace elements in home-produced eggs in Belgium: levels and spatiotemporal distribution. Sci Total Environ 407:4397–4402

Xu X, Li Y, Wang Y, Wang Y (2011) Assessment of toxic interactions of heavy metals in multi-component mixtures using sea urchin embryo-larval bioassay. Toxicol in Vitro 25:294–300