

EFFECT OF HEAT EXPOSURE ON DEHYDRATION AND KIDNEY FUNCTION AMONG SEA SALT WORKERS IN THAILAND

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ABSTRACT

Background. Excessive heat exposure and dehydration among agricultural workers have been reported to reduce kidney function and lead to chronic kidney disease of unknown etiology (CKDu).

Objective. This cross-sectional study aimed to assess heat exposure, factors related to dehydration and the relationship between dehydration and biomarkers of kidney function among sea salt workers in Thailand.

Material and methods. Wet bulb globe temperature (WBGT) was used at the time workers started work outdoors on salt farms. Urine-specific gravity, urine osmolality, and serum creatinine were collected from 50 workers after work.

Results. The results showed that more than 50% of the participants were dehydrated after work. The maximum hours spent working per day was 10. The average water intake was 1.51 L. Urine specific gravity was highly significant correlated with urine osmolality ($r_s = 0.400$, $p < 0.01$), and urine osmolality was significantly correlated with the estimated glomerular filtration rate (eGFR) ($r_s = 0.349$, $p < 0.05$). In bivariate analysis adjusted for age, sex, and current alcohol consumption, we found that a $WBGT_{TWA} \geq 30^\circ C$ (OR = 0.08, 95% CI = 0.01-0.44, $p = 0.003$) and hours spent working (OR=2.22, 95% CI = 1.42-3.47, $p < 0.001$) were independently associated with dehydration. This suggests that workers should increase their time spent on breaks and increase water consumption.

Conclusions. Educational program on heat exposure and heat-related illness prevention strategies should be provided.

Keywords: *heat exposure, dehydration, kidney function, agricultural work*

INTRODUCTION

From 2000 to 2016, approximately 125 million people were exposed to and impacted by heat waves, which represents an increase in exposure from previous periods [1, 2]. Recent studies have examined the effects of increased heat exposure on health and have found it to be linked with heart disease, respiratory disease, and nephropathy [3, 4]. Several studies in high-heat countries, such as Nicaragua, El Salvador, and Guatemala, found that chronic kidney diseases occurs in groups of agricultural workers who engage in primarily outdoor activities and experience extreme heat exposure, such as sugarcane workers and rice farmers, without finding a common cause, such as hypertension or diabetes. Therefore, these people are classified as having chronic kidney disease of unknown etiology (CKDu). Past studies have identified possible causes of CKDu among agricultural workers, including heat exposure and dehydration [5, 6]. CKDu

is therefore another health concern for people who work outdoors in hot areas.

Normally, the core human body temperature is maintained below $38^\circ C$ or $38.5^\circ C$ in unacclimatized and acclimatized workers, respectively [7]. When the body temperature increases, sweat is produced to cool the body through evaporation. However, if the loss of heat through the evaporation of sweat cannot balance the exposure to heat, heat stress can occur [8]. Heat stress often occurs in conjunction with dehydration and other heat-related symptoms, such as headache, muscle cramps, and fatigue. Previous studies have not yet clarified how dehydration causes CKD, but many researchers believe that occupational heat stress and dehydration are some of the factors affecting kidney health [9].

Thailand is a country located in the tropical zone, and its inhabitants regularly engage in agriculture. Sea salt farming has been an occupation since ancient times and is still practiced today. Salt is harvested between January and May every year during periods

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of hot weather. During the harvest, human laborers using ancient techniques are the main form of labor. It is difficult work, even though there are tools that can reduce the workload to a certain degree. Salt farm workers work 4-10 consecutive hours a day and are inevitably exposed to heat because salt farms are in open areas with no available shade, even during breaks. Previous studies of the health effects of this type of work on salt farm workers found signs and symptoms associated with heat exposure. However, studies assessing biomarkers have been lacking.

The objectives of this study were to assess heat exposure, possible factors related to dehydration and the relationship between dehydration and biomarkers of kidney function in salt farm workers.

MATERIAL AND METHODS

Study site and population

As salt farming is a seasonal production, the land will be prepared before the rainy season starts. The harvest season will start around January or February and end before the rainy season (May-June). This cross-sectional study was conducted on the first week of February 2020 when the first round of salt was ready to be harvested. Samut Sakhon Province, an area approximately 45 km south of Bangkok, is one of three largest areas for sea salt farming and has established a sea salt learning center to share relevant knowledge with local farmers and anyone else who is interested. In this study, the sea salt workers were from the Khok Kham subdistrict, the largest area in Samut Sakhon Province. The protocol of this study was presented to the chairman of the sea salt learning center by our research team, and the chairman provided a list of workers in this area (approximately 80 workers). We randomly selected males and females who had worked on salt farms for at least 1 harvest season, were aged between 18-60 years, and did not report having a history of hypertension, diabetes or kidney disease. After excluding those workers who did not meet the eligible criteria, 50 workers met the eligibility criteria, were willing to participate in this study, and signed informed consent forms. The workers on the sea salt farm were separated into five categories: farm owners, deliverers, extractors, pilers, and scoopers. The deliverers are men, who scoop the salt from the pile into the cart and push the cart to the storeroom. The extractors are both male and female workers, and they extract the salt from the ground using a wooden tool. The pilers form the salt into triangular piles. Farm owners usually drive a compactor, check the sea water level in each pond, and test the salinity. Lastly, scoopers help the deliverers scoop the salt into carts. They work as a team and do not switch roles.

With regard to the workload [10], deliverers and extractors perform “heavy work (>350 kcal/hr)”, pilers and scoopers perform “moderate work (200-350 kcal/hr)”, and farm owners perform “light work (<200 kcal/hr)”. Agrochemicals are not used in any step in the process of salt farming. Sea salt workers normally wear long pants and short-sleeved or long-sleeved shirts. Most wear sandals or socks; a few wear boots while working. Some workers use hats or fabric to cover their faces or sunglasses. Workers bring their own water and beverages from home. They can refill their bottles with water provided by the owner of the salt farm. All participants received a marked bottle to measure their water intake while working. This study was approved by the Ethics Review Committee for Research Involving Human Research Subjects, Health Science Group, Chulalongkorn University, Thailand (COA No. 035/2020)

Data collection

Data were collected on sea salt farms during the harvest season. Heat exposure data were collected on two days in the same week in the study area. Subjects worked on sea salt farms in the area for at least 2 weeks. The participants were assumed to be acclimatized to heat. A standardized wet bulb globe temperature (WBGT) monitor, model ISO 7243 (3M QUEST temp 32°), was used to measure ambient conditions 1.25 m above the ground. WBGT data collection started when the workers began to work outdoors on the salt farms. The monitor was set up as close to the workers as possible and calibrated before use. Digital data were recorded every hour, and six parameters were measured: natural wet bulb temperature (Twb), dry bulb temperature (Tdb), globe bulb temperature (Tg), WBGT, relative humidity (%RH), and heat index (HI). The average WBGT was calculated, using the hour individuals worked, as the time-weighted average WBGT ($WBGT_{TWA}$) for all individuals to determine their heat exposure. Individual skin temperatures were measured with a forehead infrared thermometer while the workers were working on the sea salt farm.

After-shift data were collected at the sea salt learning center, which is located in the middle of the sea salt area; the learning center was spacious and clean, and a toilet was available. Medical examinations and blood collection were performed by medical technicians from hospitals in the area interested in health-promoting activities. First, urine samples were collected in standard polypropylene specimen containers, and each participant provided 20-50 ml of mid-stream urine. For the urinalysis, the urine specific gravity, urine osmolarity, urine creatinine, pH and color were recorded. Next, medical examinations, including measurements of blood pressure, pulse rate, weight, and height, were performed. Then, 2-3

ml of blood was drawn and used to test the levels of kidney biomarkers, namely, serum creatinine, blood urea nitrogen [11] and uric acid. Finally, validated questionnaires were used to ask participants about their characteristics and exposure factors, including age, alcohol consumption and smoking, medical and herbal supplement intake, water and other beverage intake, frequency of urination, work experience on salt farms, hours spent working, and heat-related symptoms. Blood and urine samples were packed on ice and immediately sent to a certified laboratory. The methods of analysis were the following; reflectance photometry was used for urine specific gravity, freezing point depression method for urine osmolality and *Jaffe's* kinetic method was used for serum creatinine.

Statistical analysis

Data analyses were performed using SPSS version 22 for Windows. Descriptive statistics, including frequencies, percentages and medians (IQRs), were used to describe the characteristics and heat exposure factors. Nonnormally distributed variables were tested with the *Kolmogorov-Smirnov* test. For primary outcome, associations between dehydration and exposure factors, including age, sex, use of herbal supplements, smoking and alcohol consumption, workload, WBGT, water intake, other beverage intake, hours spent working and work experience, were tested with binary logistic regression. Significant predictors of CKD identified in previous studies, including age, sex and current alcohol consumption, were used as covariates [12]. For secondary outcomes, associations between dehydration, based on the urinalysis, and kidney biomarkers, as measured in the blood samples, were tested with Spearman's correlation analysis.

RESULTS

The sea salt workers were 58% male, with an average age of 47.16 years. More than half of the participants did not drink alcohol (60%) and were nonsmokers (68%). The average water intake on the study day was 1.53 liters (approximately 70% was accounted for by other beverages). Approximately half of the participants had worked at sea salt farms for more than 15 years. Fifty-six percent of participants worked more than 4 hours, 70% took fewer than two rest breaks, and 50% wore long-sleeved shirts with long pants. In total, 48% engaged in heavy work, 36% in moderate work, and 16% in light work. Most workers did not feel hotter than normal on the study day (90%); however, 44% of the workers had heat-related symptoms (Table 1).

As presented in Figure 1, heat exposure measurements at the sea salt farms started at 6:00 AM

Table 1. Sea salt worker characteristics and exposure factors in Thailand (n=50)

Characteristics and exposure factors	n (%), mean, median (IQR)
Sex	
Male	29 (58.0)
Female	21 (42.0)
Age (years)	47.16, 51.0 (41.75, 56.0)
<29	6 (12.0)
30-39	5 (10.0)
40-49	12 (24.0)
>50	27 (54.0)
Alcohol consumption status	
No	30 (60.0)
Yes	20 (40.0)
Smoking status	
No	34 (68.0)
Yes	16 (32.0)
Water intake, L	1.53, 1.50 (1.0, 2.0)
≤ 1	21 (42.0)
> 1	29 (58.0)
Other beverage intake	
No	15 (30.0)
Yes	35 (70.0)
Working experience	16.24, 12.50 (5.0, 25.0)
< 15 yrs	26 (52.0)
≥ 15 yrs	48 (48.0)
Hours spent working	
≤ 4 hours	22 (44.0)
> 4 hours	28 (56.0)
Number of breaks	
≤ 2	35 (70.0)
> 2	15 (30.0)
Clothing	
Short-sleeved/long-sleeved shirt + shorts/long pants	25 (50.0)
Long-sleeved shirt+ long pants	25 (50.0)
Workload	
Light work	8 (16.0)
Moderate work	18 (36.0)
Heavy work	24 (48.0)
Felt hotter than normal	
No	45 (90.0)
Yes	5 (10.0)
Heat-related symptoms on the study day	
No	28 (56.0)
Yes	22 (44.0)

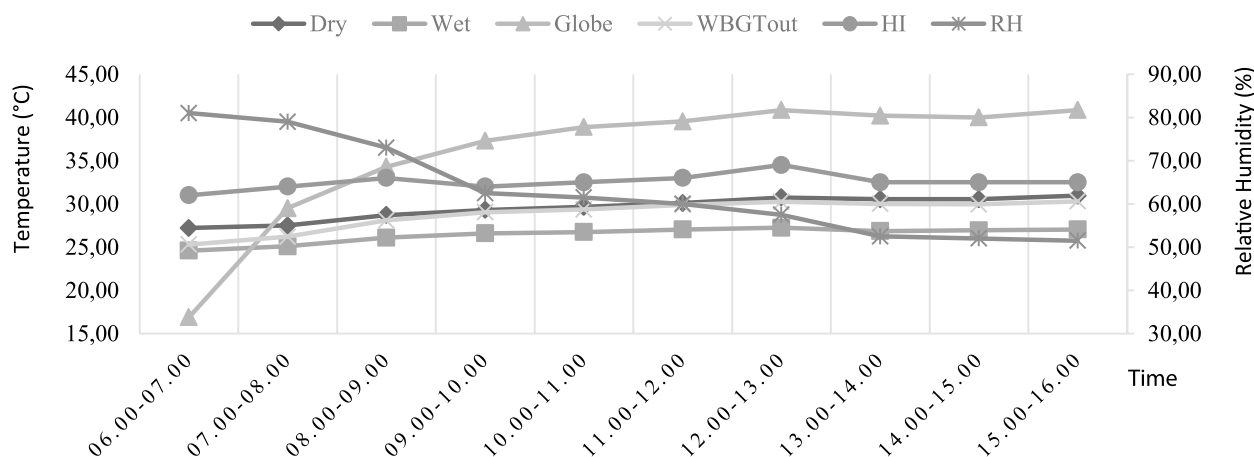


Figure 1. Heat exposure monitored by wet bulb globe temperature measurements on a sea salt farm (Dry=Dry Bulb Temperature; Wet=Wet Bulb Temperature; Globe=Globe Bulb Temperature; WBGTout=Wet Bulb Globe Temperature Outdoor; HI=Heat Index; RH=Relative Humidity)

and continued until 4:00 PM. The WBGT over the 2 days varied from 25.30°C to 30.30°C, and the average was 28.84°C. The dry bulb temperature varied from 27.20°C to 30.95°C, and the average was 29.53°C. The wet bulb temperature varied from 24.60°C to 27.25°C, and the average was 26.43°C. The globe bulb temperature varied from 16.90°C to 40.85°C, and the average was 35.84°C. The RH ranged from 51.50 to 81.00%, with an average of 63.05%. The mean HI was 32.55°C. The WBGT_{TWA} calculated to determine individual heat exposure on each working day was 29.83°C.

Most of the participants had urine that was yellow (72%) and not cloudy (82%). The median urine pH was 5.26, the urine specific gravity was 1.025, the urine creatinine level was 189.05 g/L, and the urine osmolality was 863 mOsm/L. The median levels of the serum biomarkers were as follows: serum creatinine, 0.9 mg/dL; blood urea nitrogen, 13.0 mg/dL; and uric acid, 6.85 mg/dL. In total, 58% of the workers were not dehydrated, while 42% were dehydrated. The eGFR, calculated with the CKD-EPI equation, showed that 52% of the workers were defined as having stage 1 CKD, and three out of 50 (6%) workers had low eGFR (< 60 ml/min/1.73 m²) (Table 2).

Based on results from binary logistic regression, WBGT_{TWA} ≥ 30°C (*p* = 0.003) was significantly associated with dehydration. Those workers that were exposed to high heat, based on a WBGT_{TWA} ≥ 30°C, were 0.11 times more likely to be dehydrated than with a WBGT_{TWA} < 30°C. Moreover, the number of hours spent working was significantly associated with dehydration (*p* < 0.001), and each unit increase in the number of hours spent working increased the odds of dehydration 2 times (OR = 2.0, 95% CI 1.37-2.91). Then, after adjusting for age, sex, and current alcohol consumption, we found that a WBGT_{TWA} ≥ 30°C (OR = 0.08, 95% CI = 0.01-0.44, *p* = 0.003) and the number

Table 2. Biomarkers in Sea Salt Workers in Thailand (n=50)

Biomarkers	n %, median (IQR)
Urine biomarkers	
Color	
Pale yellow	5 (10.0)
Yellow	36 (72.0)
Deep yellow	4 (8.0)
Orange	2 (4.0)
Brown	3 (6.0)
Appearance	
Clear	41 (82.0)
Turbid	9 (18.0)
pH	5.26 ± 0.52
Urine specific gravity	1.025 (1.02,1.03)
Urine creatinine (g/L)	189.05 (140.0,247.825)
Urine osmolality (mOsm/L)	863.0 (675.25,953.0)
Serum biomarkers	
Serum creatinine (mg/dL)	0.9 (0.8,1.1)
Blood urea nitrogen (mg/dL)	13.0 (11.0,16.0)
Uric acid (mg/dL)	6.85 (5.70,7.85)
Hydration status based on urine specific gravity	
Euhydration (≤ 1.025)	29 (58.0)
Dehydration (> 1.025)	21 (42.0)
Kidney function	
Estimated glomerular filtration rate, eGFR-EPI, ml/min/1.73 m ²	90.60 (72.08,99.43)
Reduced kidney function stage, n (%) – eGFR-EPI	
Stage 1, eGFR > 90	26 (52.0)
Stage 2, eGFR 60-90	21 (42.0)
Stage 3a, eGFR 45-59	3 (6.0)

of hours spent working (OR=2.22, 95% CI = 1.42-3.47, $p < 0.001$) were independently associated with dehydration, as shown in Table 3.

The correlation between hydration status and kidney function showed that the urine specific gravity was correlated with urine osmolality ($r_s = 0.400$, $p < 0.01$), and urine osmolality was correlated with the eGFR ($r_s = 0.349$, $p < 0.05$), as shown in Table 4.

DISCUSSION

The sea salt workers in this study were local Thai people living in Samut Sakhon Province. More workers were male, and their ages ranged from 18 to 60 years old. They had an average of 12.5 years of experience working on salt farms. The number of hours spent working each day ranged from 2 to 10, depending on how many salt ponds were ready to be harvested. Each salt pond takes approximately 2-3 hours to harvest, and workers harvested between 1 and 3 pounds per day. Many jobs on agricultural

farms involve heavy workloads, including sugarcane cutting, corn farming and rice farming. In this study, many workers had heavy workloads. Sea salt farm activities involve intense manual labor, repetitive movements, whole-body movements, few breaks, and long periods spent working in the heat. The delivery task was the most labor intensive job on these salt farms, and only men performed this task. Other jobs, including extracting the salt, piling the salt, scooping the salt and managerial tasks, were performed by both male and female workers. A previous study on sea salt workers in Thailand involved a population that was 75% male, with an average age of 36.6 years [13].

Heat exposure was measured by the WBGT, a gold standard for studies investigating occupational heat stress. The recorded WBGT varied from 25.30°C to 30.30°C, with an average of 28.84°C. Overall, the average level of heat exposure was not greater than that stipulated in the regulations for those working in hot conditions (heavy work should not be performed when the temperature is over 30°C, moderate work

Table 3. Binary logistic regression predicting dehydration based on urine-specific gravity^a in sea salt farm workers in Thailand (n=50)

Variables	Univariate		p-value	Adjusted**		p-value
	OR	95% CI		OR	95%CI	
Age ≥40 years	2.28	0.52-9.92	0.270	2.28	0.51-10.15	0.276
Male sex	0.94	0.30-2.93	0.917	0.90	0.28-4.20	0.903
Use of herbal supplement	0.65	0.05-7.97	0.755	0.54	0.04-7.21	0.642
Current smoking	1.61	0.48-5.36	0.433	1.81	0.39-8.32	0.441
Current alcohol consumption	0.87	0.27-2.75	0.872	0.92	0.23-3.63	0.910
Medium-heavy workload	0.36	0.07-1.75	0.211	0.34	0.06-1.68	0.188
WBGT _{TWA} ≥ 30°C	0.11	0.02-0.49	0.003*	0.08	0.01-0.44	0.003*
Water intake ≤ 1 L	0.53	0.16-1.71	0.293	0.52	0.16-1.74	0.295
No intake of other beverages	0.59	0.16-2.09	0.418	0.56	0.14-2.10	0.392
Hours spent working ^b	2.00	1.37-2.91	<0.001*	2.22	1.42-3.47	<0.001*
Work experience	1.05	1.00-1.11	0.023	1.05	1.00-1.11	0.044

* Association significant at $p < 0.05$, **Adjusted for age, sex, current alcohol consumption

^aUrine specific gravity ($0 \leq 1.025$ and $1 > 1.025$), ^bContinuous data

Table 4. Spearman’s correlation analyses of the associations between hydration and kidney function (n=50) in sea salt workers in Thailand

Predictor	Spearman’s correlation coefficient (r_s) (p-value)		
	Hydration status		Kidney function
	urine specific gravity	urine osmolality	eGFR
Hydration status			
Urine specific gravity	1.00		
Urine osmolality	0.400** (0.004)	1.00	
Kidney function			
eGFR	0.089 (0.540)	0.349* (0.013)	1.00

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

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

should not be performed when the temperature is over 32°C, light work should not be performed when the temperature is over 34°C [14]. Samut Sakhon Province is approximately 1-2 meters above sea level (masl). In general, regions at relatively low altitudes and coastal areas (<500 meters above sea level; masl) have higher temperatures than regions at relatively high altitudes (≥ 500 masl), and the difference is approximately 4°C [15]. The mean WBGT increased over the course of the morning and was the highest at noon. Sea salt workers continue to work at noon because their tasks have to be finished, and only 30% of the workers took more than 2 breaks. The Occupational Safety and Health Administration [16] has recommended maintaining an appropriate WBGT in the work environment to avoid excessive increases in body temperature. Workers should rest 75% of the time when WBGT exceeds 30°C (OSHA1999). Field workers are more frequently exposed to heat than workers in other areas [12]. A study of the health impact of climate change in Thailand included 5 types of worksites: sites in the pottery industry, power plants, sites in the knife industry, construction sites and agricultural sites. The outdoor WBGT ranged from 25.2°C-34.6°C, and the highest was 34.6°C at the agricultural sites [17]. Moreover, this study reported that most workers did not feel hotter than normal on the study day, although 44% of the workers had heat-related symptoms, which was similar to the findings of a previous study on a salt farm that reported an average WBGT of 33.83°C and heat-related symptoms in 50.88% of the workers, despite the fact that they did not feel hotter than normal (53.22%). This study found a moderate positive correlation between heat-related symptoms and the WBGT [13]. The WBGT in our study did not exceed the recommendation in the regulations, but nearly half of the workers had heat-related symptoms.

Hydration was assessed with urine biomarkers, which is a convenient method for a field study. The urine biomarkers included urine specific gravity and urine osmolarity. Urine specific gravity is the most popular biomarker of hydration, while urine osmolarity is considered a good marker, with a sensitivity of 91% and an adequate specificity for dehydration [18, 19]. We collected urine samples from each worker immediately after work. The criteria for dehydration were a urine specific gravity >1.025 g/ml [20] and a urine osmolarity >700 mOsm/L [21]. The median urine specific gravity and median urine osmolarity were at the upper limits of euhydration. Twenty-one sea salt workers had urine specific gravity that indicated that they were dehydrated. This is similar to the findings in a study involving miners, in which 42% of the population was dehydrated after work [22]. Several studies on dehydration in agricultural workers

have noted that working in hot temperatures, the loss of water and electrolytes, an imbalance in the core body temperature, high humidity and a heavy workload can lead to dehydration [23].

The intake of water and the intake of other beverages were not associated with dehydration. Workers in this study had an insufficient intake of liquids. This may be due to their jobs, which required them to work in long stretches without stopping (2-3 hours). Participants consumed beverages other than water, such as energy drinks, electrolyte drinks, sugary drinks and coffee. The average amount of water consumed on a work day was 1.5 L, which is less than the recommended amount. To prevent heat-related illness, the American Conference of Governmental Industrial Hygienists recommended threshold limit value [7] is approximately 235 ml of water every 20 minutes when working in a hot environment. Thus, to prevent dehydration, sea salt workers should increase their water intake and number of breaks while working.

Kidney function was monitored by the eGFR. The CKD-EPI formula was used to calculate the eGFR in this study [24]. The average post-shift serum creatinine level in these sea salt workers was higher than that in a previous study among sugarcane workers in Nicaragua [25] but lower than that in another study in sugarcane workers in El Salvador [26]. Moreover, the average post-shift eGFR in sea salt workers was lower than that in previous studies in sugarcane workers in several countries, such as Nicaragua, El Salvador and Guatemala [25-27]. Sugarcane workers work in hot conditions, with a WBGT ranging from 30.9°C-35.5°C, which is similar to the work environment experienced by sea salt workers; however the tasks and other aspects of the work environment are different. Salt farms are open, and there are no shady spots or tents in which to rest. The wage is earned by the entire team, unlike sugarcane workers, who are paid individually. This encourages sea salt workers to continue their work until they are finished, without taking a break; they try to hurry to finish and start another round of harvesting.

Many studies have concluded that the decreased kidney function indicated by the eGFR value after work was due to several occupational factors that led to heat stress and dehydration. Urine specific gravity and urine osmolarity increase with dehydration [20]. We found that dehydration, as indicated by urine specific gravity, was significantly related to urine osmolarity ($r=0.400$). Two cross-sectional studies on heat exposure and dehydration were conducted in Sri Lanka [20] and Japan [21]. The study in Sri Lanka showed that approximately 40% of the paddy farmers were dehydrated after work and that there was a significant correlation between urine specific gravity and urine osmolarity ($r=0.917$) [20], while the study

of 23 construction workers in Japan found that 21% of the workers were dehydrated and that there was a strong correlation between urine specific gravity and urine osmolarity ($r=0.87$) [21]. Moreover, our study showed that urine osmolarity was significantly related to the eGFR ($r=0.349$). Workers at lower altitudes are more likely to be exposed to heat than those at higher altitudes; heat exposure can cause dehydration and is related to the development of CKD [26]. The loss of water from the body stimulates the release of the hormone vasopressin, causing the urine to become more concentrated and also causes renal vasoconstriction, which is associated with the GFR. If the water loss is severe or prolonged, it can impair the GFR or cause ischemia, leading to acute kidney injury (AKI) [1]. There is evidence that if AKI is sustained and prolonged, it can progress to CKD [8].

This study has several limitations. First, the sea salt workers were randomly selected from only one area of the salt farm, and the sample size was limited. Second, we only obtained one set of urine and blood samples after work. Third, we measured only the volume of water intake. We did not measure the volume of other beverages consumed, which could be linked to dehydration. However, we found that many of the workers were dehydrated and that there were relationships between heat exposure and dehydration and between dehydration and kidney biomarkers.

CONCLUSIONS

This study provides new evidence that sea salt workers are at a relatively higher risk of CKDu in countries affected by climate change. The findings showed that these workers have a heavy physical workload in a hot environment, and sea salt workers were found to be dehydrated after work, which could lead to a decrease in kidney function. We suggest that workers should increase their number of breaks and their intake of liquids. Education on hazardous heat exposure and heat-related illness prevention strategies should be provided.

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Conflict of interest

The authors declare no conflict of interest.

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