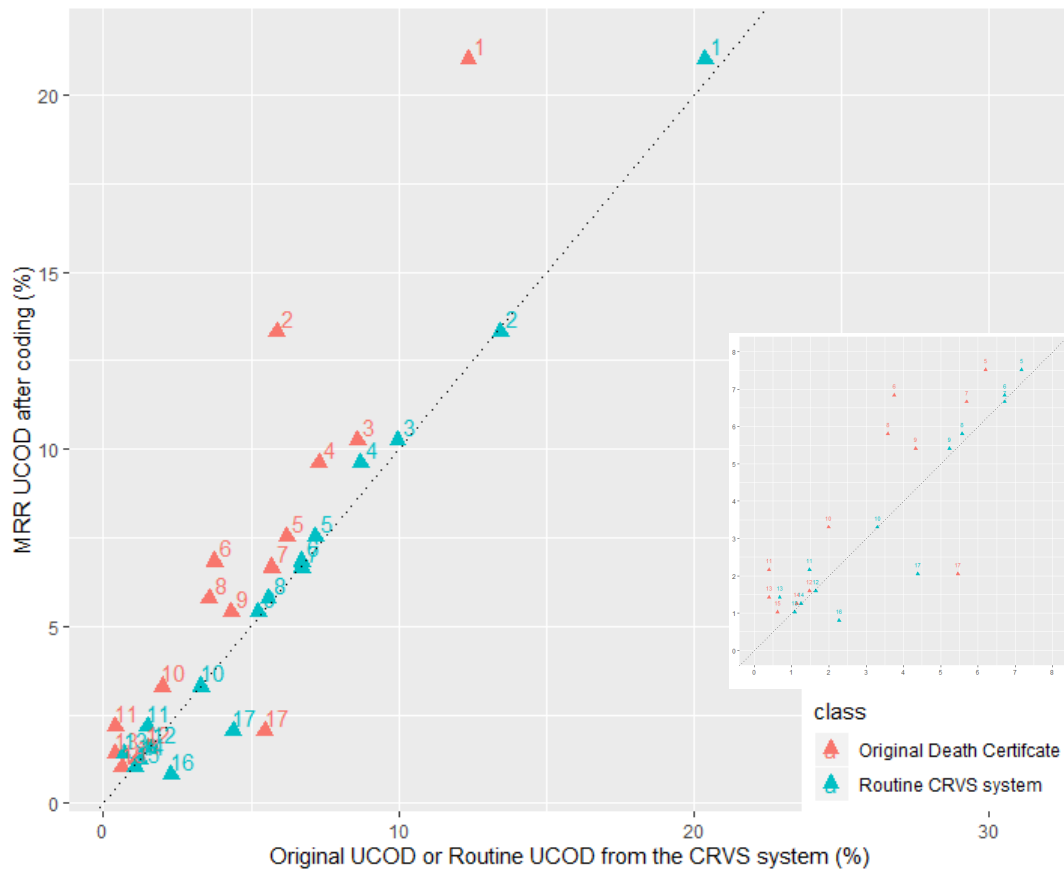


Supplementary Table 1. Leading ICD UCOD of garbage codes in original death certificates (%), all facilities

	ICD name	N	%
1	Essential (primary) hypertension	147	27.7
2	Pneumonia, unspecified organism	107	20.2
3	Ill-defined and unknown cause of mortality	48	9.1
4	Heart failure, unspecified	34	6.4
5	Respiratory failure, unspecified	27	5.1
6	Unspecified kidney failure	10	1.9
7	Other and unspecified disorders of circulatory system	9	1.7
8	Sepsis, unspecified organism	8	1.5
9	Sudden cardiac death, so described	8	1.5
10	Stroke, not specified as haemorrhage or infarction	7	1.3
11	Neoplasm of uncertain behavior, unspecified	6	1.1
12	Gastrointestinal hemorrhage, unspecified	6	1.1
13	Sequelae of other accidents	6	1.1
14	Compression of brain	5	0.9
15	Malignant neoplasm of intestinal tract, part unspecified	4	0.8
	Total	432	

Supplementary Table 2. Top 15 UCODs (%) by source, Shanghai, 2017

	Original UCOD	%	Routine UCOD	%	MRR UCOD (Gold standard)	%
1	Garbage Code	31.0	Ischemic heart disease	20.4	Ischemic heart disease	21.0
2	Ischemic heart disease	12.4	Ischemic stroke	13.4	Ischemic stroke	13.3
3	Tracheal, bronchus, and lung cancer	8.6	Tracheal, bronchus, and lung cancer	10.0	Tracheal, bronchus, and lung cancer	10.2
4	Chronic obstructive pulmonary disease	7.3	Chronic obstructive pulmonary disease	8.7	Chronic obstructive pulmonary disease	9.6
5	Stomach cancer	6.2	Stomach cancer	7.2	Stomach cancer	7.5
6	Ischemic stroke	5.9	Colon and rectum cancer	6.7	Intracerebral hemorrhage	6.8
7	Colon and rectum cancer	5.7	Intracerebral hemorrhage	6.7	Colon and rectum cancer	6.7
8	Pancreatic cancer	4.3	Liver cancer	5.6	Liver cancer	5.8
9	Intracerebral hemorrhage	3.8	Pancreatic cancer	5.2	Pancreatic cancer	5.4
10	Liver cancer	3.6	Diabetes mellitus type 2	3.3	Diabetes mellitus type 2	3.3
11	Diabetes mellitus type 2	2.0	Garbage Code	2.3	Falls	2.2
12	Cirrhosis and other chronic liver diseases	1.5	Breast cancer	1.7	Breast cancer	1.6
13	Breast cancer	1.5	Falls	1.5	Chronic kidney disease due to diabetes mellitus type 2	1.4
14	Esophageal cancer	1.1	Esophageal cancer	1.3	Esophageal cancer	1.3
15	Atrial fibrillation and flutter	0.6	Prostate cancer	1.1	Prostate cancer	1.0



Rank	Disease name	Rank	Disease name
1	Ischemic heart disease	10	Diabetes mellitus type 2
2	Ischemic stroke	11	Falls
3	Tracheal, bronchus, and lung cancer	12	Breast cancer
4	Chronic obstructive pulmonary disease	13	Chronic kidney disease due to diabetes mellitus type 2
5	Stomach cancer	14	Esophageal cancer
6	Intracerebral hemorrhage	15	Prostate cancer
7	Colon and rectum cancer	16	Garbage Code
8	Liver cancer	17	All other diseases
9	Pancreatic cancer		

Supplementary Fig 1. CSMF of original UCOD or routine UCOD versus MRR

UCOD(%)

Supplementary Table 3. The severity classification of original UCODS which were assigned as garbage codes.

Rank	garbage codes of original UCODs	ICD-name	level 1	level 2	level 3	level 4	Total
1	R99	Ill-defined and unknown cause of mortality	48	0	0	0	48
2	I50.9	Heart failure, unspecified	34	0	0	0	34
3	J96.9	Respiratory failure, unspecified	27	0	0	0	27
4	N19	Unspecified kidney failure	10	0	0	0	10
5	A41.9	Sepsis, unspecified organism	8	0	0	0	8
6	I46.1	Sudden cardiac death, so described	8	0	0	0	8
7	K72.9	Hepatic failure, unspecified	8	0	0	0	8
8	J69.0	Pneumonitis due to inhalation of food and vomit	4	0	0	0	4
9	E14.9	Unspec DM without complication	3	0	0	0	3
10	I26.9	Pulmonary embolism without acute cor pulmonale	3	0	0	0	3
11	R57.0	Cardiogenic shock	3	0	0	0	3
12	R57.1	Hypovolemic shock	3	0	0	0	3
13	D64.9	Anemia, unspecified	2	0	0	0	2
14	G91.9	Hydrocephalus, unspecified	2	0	0	0	2
15	I46.9	Cardiac arrest, cause unspecified	2	0	0	0	2
16	R57.8	Other shock	2	0	0	0	2

17	D64	Other anemias	1	0	0	0	1
18	E14.2	Unspecified DM with renal complication	1	0	0	0	1
19	E87.1	Hypo-osmolality and hyponatremia	1	0	0	0	1
20	E87.2	Acidosis	1	0	0	0	1
21	E87.8	Other disorders of electrolyte and fluid balance, not elsewhere classified	1	0	0	0	1
22	I50.1	Left ventricular failure	1	0	0	0	1
23	J86.9	Pyothorax without fistula	1	0	0	0	1
24	J96	Respiratory failure, not elsewhere classified	1	0	0	0	1
25	J98.1	Pulmonary collapse	1	0	0	0	1
26	K65.9	Peritonitis, unspecified	1	0	0	0	1
27	M84.4	Pathological fracture, not elsewhere classified	1	0	0	0	1
28	N17.9	Acute kidney failure, unspecified	1	0	0	0	1
29	R54	Age-related physical debility	1	0	0	0	1
30	R57	Shock, not elsewhere classified	1	0	0	0	1
31	R57.9	Shock, unspecified	1	0	0	0	1
32	R79.8	Other specified abnormal findings of blood chemistry	1	0	0	0	1
33	R91	Abnormal findings on diagnostic imaging of lung	1	0	0	0	1
34	R93.1	Abnormal findings on diagnostic imaging of heart and coronary circulation	1	0	0	0	1
35	R96.0	Instantaneous death	1	0	0	0	1
36	Z99	Dependence on enabling machines and devices, not elsewhere classified	1	0	0	0	1
37	I10	Essential (primary) hypertension	0	147	0	0	147
38	Y86	Sequelae of other accidents	0	6	0	0	6
39	I27.9	Pulmonary heart disease, unspecified	0	4	0	0	4
40	J94.8	Other specified pleural conditions	0	4	0	0	4
41	S72.0	Fracture of neck of femur	0	3	0	0	3

42	S06.5	Traumatic subdural haemorrhage	0	2	0	0	2
43	I74.9	Embolism and thrombosis of unspecified artery	0	1	0	0	1
44	J81	Pulmonary edema	0	1	0	0	1
45	J90	Pleural effusion, not elsewhere classified	0	1	0	0	1
46	J94.1	Fibrothorax	0	1	0	0	1
47	R04.2	Hemoptysis	0	1	0	0	1
48	R09.2	Respiratory arrest	0	1	0	0	1
49	R18	Ascites	0	1	0	0	1
50	S06.3	Focal brain injury	0	1	0	0	1
51	S06.6	Traumatic subarachnoid haemorrhage	0	1	0	0	1
52	S06.7	Intracranial injury with prolonged coma	0	1	0	0	1
53	S06.9	Intracranial injury, unspecified	0	1	0	0	1
54	S22.3	Fracture of one rib	0	1	0	0	1
55	S32.0	Fracture of lumbar vertebra	0	1	0	0	1
56	S72.1	Pertrochanteric fracture	0	1	0	0	1
57	S72.8	Fractures of other parts of femur	0	1	0	0	1
58	S72.9	Fracture of femur, part unspecified	0	1	0	0	1
59	T17.9	Foreign body in respiratory tract, part unspecified	0	1	0	0	1
60	T93.1	Sequelae of fracture of femur	0	1	0	0	1
61	X59.9	Exposure to unspecified factor causing other and unspecified injury	0	1	0	0	1
62	I99	Other and unspecified disorders of circulatory system	0	0	9	0	9
63	D48.9	Neoplasm of uncertain behavior, unspecified	0	0	6	0	6
64	K92.2	Gastrointestinal hemorrhage, unspecified	0	0	6	0	6
65	G93.5	Compression of brain	0	0	5	0	5
66	C26.0	Malignant neoplasm of intestinal tract, part unspecified	0	0	4	0	4

67	I49.9	Cardiac arrhythmia, unspecified	0	0	4	0	4
68	C80	Malignant neoplasm without specification of site	0	0	2	0	2
69	I96.9	-	0	0	2	0	2
70	C76.2	Malignant neoplasm of abdomen	0	0	1	0	1
71	C78.7	Secondary malignant neoplasm of liver and intrahepatic bile duct	0	0	1	0	1
72	C78.8	Secondary malignant neoplasm of other and unspecified digestive organs	0	0	1	0	1
73	C97	Malignant neoplasms of independent (primary) multiple sites	0	0	1	0	1
74	D37.7	Other digestive organs	0	0	1	0	1
75	G93.4	Other and unspecified encephalopathy	0	0	1	0	1
76	G96.8	Other specified disorders of central nervous system	0	0	1	0	1
77	I49.3	Ventricular premature depolarization	0	0	1	0	1
78	I49.5	Sick sinus syndrome	0	0	1	0	1
79	I51.9	Heart disease, unspecified	0	0	1	0	1
80	J98.4	Other disorders of lung	0	0	1	0	1
81	N40	Enlarged prostate	0	0	1	0	1
82	J18.9	Pneumonia, unspecified organism	0	0	0	107	107
83	I64	Stroke, not specified as haemorrhage or infarction	0	0	0	7	7
84	I67.9	Cerebrovascular disease, unspecified	0	0	0	2	2
85	I42.0	Dilated cardiomyopathy	0	0	0	1	1
86	I67.8	Other specified cerebrovascular diseases	0	0	0	1	1
87	J15.9	Unspecified bacterial pneumonia	0	0	0	1	1
88	J18.8	Other pneumonia, unspecified organism	0	0	0	1	1
Total(%)			187(34.50)	185(34.13)	50(9.23)	120(22.14)	542

Supplementary Table 4. Validation metrics comparing original UCOD or routine UCOD with MRR UCOD (top 15 specific UCOD) from tertiary hospitals

	Cause of Death	Original UCOD					CSMF accuracy	Routine UCOD					
		Sensitivity	PPV	Kappa	CCC	CSMF		Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy
1	Breast cancer	0.80	0.89	0.84	0.79	1.2		1.00	0.91	0.95	1.00	1.5	
2	Chronic kidney disease due to diabetes mellitus type 2	0.10	1.00	0.18	0.04	0.1		0.50	0.71	0.58	0.47	0.9	
3	Chronic obstructive pulmonary disease	0.54	0.82	0.63	0.51	4.4		0.74	0.82	0.76	0.72	6.0	
4	Colon and rectum cancer	0.76	0.98	0.85	0.75	6.1		0.90	0.93	0.91	0.89	7.6	
5	Diabetes mellitus type 2	0.25	0.56	0.33	0.20	1.2		0.50	0.43	0.45	0.47	3.1	
6	Esophageal cancer	0.71	1.00	0.83	0.70	0.7		0.86	1.00	0.92	0.85	0.8	
7	Falls	0.00	..	0.00	-0.06	0.0		0.35	0.78	0.47	0.31	1.2	
8	Garbage Code	1.00	0.02	0.02	1.00	34.7		0.25	0.05	0.07	0.20	2.8	
9	Intracerebral hemorrhage	0.54	0.89	0.66	0.51	3.7		0.89	0.85	0.86	0.88	6.4	
10	Ischemic heart disease	0.57	0.92	0.64	0.54	13.7		0.85	0.84	0.80	0.84	22.5	
11	Ischemic stroke	0.38	0.97	0.52	0.34	4.4		0.74	0.89	0.78	0.72	9.3	
12	Liver cancer	0.46	1.00	0.62	0.43	3.3		0.93	0.98	0.95	0.92	6.8	
13	Pancreatic cancer	0.64	0.94	0.75	0.62	4.3		0.89	0.93	0.91	0.89	6.0	
14	Prostate cancer	0.50	1.00	0.66	0.47	0.4		0.67	0.57	0.61	0.65	0.9	
15	Stomach cancer	0.68	1.00	0.79	0.66	5.6		0.90	0.98	0.94	0.90	7.6	
16	Tracheal, bronchus, and lung cancer	0.72	0.98	0.81	0.70	7.8		0.95	0.97	0.96	0.95	10.5	
17	Others	0.32	0.13	0.14	0.28	8.4		0.52	0.28	0.33	0.49	6.3	
	Average				0.48		0.61				0.69		0.94

Supplementary Table 5. Validation metrics comparing original UCOD or routine UCOD with MRR UCOD (top 15 specific UCOD) from secondary hospital

	Cause of Death	Original UCOD					Routine UCOD						
		Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy	Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy
1	Breast cancer	0.90	1.00	0.95	0.89	2.0		1.00	1.00	1.00	1.00	2.3	
2	Chronic kidney disease due to diabetes mellitus type 2	0.09	0.50	0.15	0.03	0.5		0.18	1.00	0.30	0.13	0.5	
3	Chronic obstructive pulmonary disease	0.52	0.93	0.64	0.49	6.6		0.77	0.98	0.84	0.75	9.3	
4	Colon and rectum cancer	0.83	0.94	0.87	0.82	7.0		0.97	0.89	0.93	0.97	8.6	
5	Diabetes mellitus type 2	0.14	0.22	0.15	0.09	2.0		0.43	0.33	0.35	0.39	4.1	
6	Esophageal cancer	1.00	0.80	0.89	1.00	1.1		1.00	0.80	0.89	1.00	1.1	
7	Falls	0.09	1.00	0.16	0.03	0.2		0.73	0.89	0.80	0.71	2.0	
8	Garbage Code	1.00	0.01	0.02	1.00	31.6		0.50	0.13	0.19	0.47	1.8	
9	Intracerebral hemorrhage	0.56	0.96	0.68	0.53	5.7		0.86	0.95	0.89	0.85	8.9	
10	Ischemic heart disease	0.57	0.92	0.65	0.54	11.6		0.88	0.87	0.84	0.87	19.1	
11	Ischemic stroke	0.34	0.91	0.46	0.30	5.2		0.80	0.84	0.80	0.79	13.2	
12	Liver cancer	0.64	1.00	0.77	0.61	3.2		1.00	1.00	1.00	1.00	5.0	
13	Pancreatic cancer	0.92	1.00	0.95	0.91	5.0		1.00	1.00	1.00	1.00	5.5	
14	Prostate cancer	0.43	1.00	0.60	0.39	0.7		1.00	1.00	1.00	1.00	1.6	
15	Stomach cancer	0.88	0.97	0.91	0.87	6.6		0.97	1.00	0.98	0.97	7.0	
16	Tracheal, bronchus, and lung cancer	0.83	1.00	0.90	0.82	4.5		0.96	0.96	0.96	0.96	5.5	
17	Others	0.60	0.11	0.17	0.58	6.4		0.80	0.20	0.31	0.79	4.5	
	Average				0.55		0.63				0.76	0.93	

Supplementary Table 6. Validation metrics comparing original UCOD or routine UCOD with MRR UCOD (top 15 specific UCOD) from CHCs

	Cause of Death	Original UCOD					Routine UCOD						
		Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy	Sensitivity	PPV	Kappa	CCC	CSMF	CSMF accuracy
1	Breast cancer	1.00	1.00	1.00	1.00	1.4		1.00	1.00	1.00	1.00	1.4	
2	Chronic kidney disease due to diabetes mellitus type 2	0.75	0.75	0.75	0.73	0.7		0.75	1.00	0.86	0.73	0.5	
3	Chronic obstructive pulmonary disease	0.88	0.89	0.87	0.87	11.7		0.94	0.94	0.93	0.94	11.9	
4	Colon and rectum cancer	0.96	0.96	0.95	0.95	4.1		0.96	0.96	0.95	0.95	4.1	
5	Diabetes mellitus type 2	0.58	0.82	0.67	0.56	3.0		0.67	0.94	0.77	0.65	3.0	
6	Esophageal cancer	0.91	1.00	0.95	0.90	1.8		1.00	1.00	1.00	1.00	1.9	
7	Falls	0.86	1.00	0.92	0.85	1.1		1.00	0.88	0.93	1.00	1.4	
8	Garbage Code	1.00	0.06	0.08	1.00	25.1		0.63	0.45	0.52	0.60	1.9	
9	Intracerebral hemorrhage	0.39	0.92	0.53	0.35	2.3		0.97	0.97	0.97	0.97	5.5	
10	Ischemic heart disease	0.48	0.90	0.56	0.45	11.2		0.83	0.94	0.86	0.82	18.6	
11	Ischemic stroke	0.42	0.79	0.49	0.38	8.3		0.96	0.79	0.83	0.95	19.1	
12	Liver cancer	0.88	0.96	0.92	0.88	4.2		0.96	1.00	0.98	0.96	4.4	
13	Pancreatic cancer	0.92	1.00	0.95	0.91	3.9		0.96	1.00	0.98	0.96	4.1	
14	Prostate cancer	1.00	1.00	1.00	1.00	0.9		1.00	1.00	1.00	1.00	0.9	
15	Stomach cancer	0.97	0.97	0.97	0.97	6.7		0.97	0.97	0.97	0.97	6.7	
16	Tracheal, bronchus, and lung cancer	0.95	0.99	0.96	0.94	12.7		0.95	0.99	0.96	0.94	12.7	
17	Others	0.17	0.20	0.17	0.11	0.9		0.83	0.50	0.62	0.82	1.8	
	Average				0.75		0.76				0.85		0.95