Comparative Study on the Irrigation Water Quality Standards in China and Australia

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Abstract. Water quality standards for irrigation are crucial to ensure the safety of cultivated land, groundwater and agricultural products. The comparative study in Sino-Australia was conducted based on the specific requirements of Standards for Irrigation Water Quality (GB 5084-2021) and Guidelines for Irrigation Water Quality (1992) in terms of general indicators, inorganic toxic pollutants, organic toxic contaminations and radioactivity indexes, following the review of irrigation water quality standards development history. On the basis of the results, it was found that more attention has been paid to the biological and organic parameters in China, and control levels varying with the crop classifications as well; in contrast, Australia has set more stringent limits on heavy metals and radionuclide indices. In addition, the reasons for discrepancies in both countries have been further discussed. Consequently, the mutual improvement and reference related to the revision of irrigation water quality standards or guidelines can be provided in China and Australia.

Keywords: water quality standards · irrigation water · China · Australia

1 Introduction

With the rapid development of China's national economy, environmental protection and ecological civilization construction have entered a prosperous development period, posing irrigation water quality standard was closely related to the agricultural sustainable development, food safety, and the soil and groundwater quality. As a member of developed countries, Australia has been facing the fact that water scarcity which hac been taken into account in China [1, 2]. In light of the significantly increased wastewater discharge amount and the increasingly stringent irrigation water quality requirements, China has established relatively integrated system from the perspectives of water saving and quality, playing a positive role in irrigation water environmental protection. However, water quality indicators diversity has more different impacts on agricultural environment. Therefore, it is necessary to carry out a study on the current irrigation water

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quality standard in compared with Australia's, a developed country with the similar situation in China, to obtain more comprehensive enlightenment and reference.

This paper is aimed to provide scientific basis and theoretical foundation for the future improvement of irrigation water quality standards and the guarantee of food safety through exploring the potential reasons why existing similarities and differences following comparing the development history in both countries.

2 Development Characteristics of Irrigation Water Standards in China and Australia

2.1 Development History of Irrigation Water Quality Standards in China

Since the 21st century, one of the most serious challenges in China was to provide adequate food for its growing population while maintaining the deteriorating environment [3]. Recently, the uncertainty of food production has been influenced by risk factors related to the climate change and water resources availability would be one of the factors limiting crop production and food safety. To cope with the urgent problem, the state issued a series of standards in response to the water sustainability, especially in the agricultural field [4].

As shown in Table 1, the irrigation water quality standards and norms have experienced four stages. From only referring to Soviet standards in the early phase to preliminarily exploring and formulating 8 industrial and national standards, China has changed the situation of passive dependence for a long period. With the continuous outcomes of scientific research and innovation achievements and the driver of water resources safety management, 34 standards and specifications covering irrigation engineering, technology, materials and other fields have been established, indicating that China has entered the stage of comprehensive development. After 2000, more attention has been paid to the concept of water-saving irrigation. A variety of irrigation technologies, such as sprinkler irrigation and micro-irrigation, have emerged as the times requirements and a total of 27 standards have been revised and integrated [5]. Most likely, the economic, social and environmental benefits with the cost reduction, optimization of agricultural product planting structure, realization of water-saving irrigation and improvement of ecological environment, can open up new paths for future research direction.

In 1985, the Standard for Irrigation Water Quality was issued firstly and revised in 1992, 2005 and 2021 respectively. The first edition was divided into two types of limited values in accordance with the different sources of irrigation water, primarily including 22 indexes such as heavy metals, common pesticides and chemical materials. The second edition was classified as paddy field crops, dry land crops and vegetables, meanwhile, the standard values of Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Suspended Solids (SS), Kjeldahl nitrogen, total phosphorus, anionic surfactant and the ascaris eggs number were added, as 7 elements of total 29. The third edition divided all water quality standards into two categories including basic and selected control items. Different regions can choose independently according to the local economic development level and actual water environmental conditions. This version contained 27 indicators on account of the uncontrolled Kjeldahl nitrogen and total phosphorus. Additionally, the limits of BOD, COD, SS, chloride, cadmium, lead, copper, faecal coliforms and ascaris eggs number have been revised. Since the implementation of the edition in 2005, it has played an important role in standardizing the irrigation water quality, ensuring the soil environment and the safety of agricultural products. As the social and economic development of agriculture and rural areas in China and the in-depth implementation of the Law on Pollution Prevention and Control of Soil Pollution, Law on Prevention and Control of Water Pollution and Soil Pollution Prevention and Control Action Plan, new requirements have been put forward for the irrigation water

Table 1. Development history of water quality standards for irrigation in China

Stages	Time	Number	Characteristics	Milestone
Initial introduction	1950s-1980s	0	The poor infrastructure and referred to Soviet standards	Design Specifications for Irrigation System Channel in Soviet was translated in 1956
Exploration	1980s-1990s	8	Multi-department cooperation to formulate standards, to change the situation of passive dependence on external	Design Specifications for Irrigation System Channel (SDJ217–1984) and Technical Specifications for Sprinkler Irrigation Engineering (GBJ85–1985) were established in 1985
Comprehensive development	1990s	34	A serious of standards for irrigation have been issued based the national conditions and scientific research	Standard for Irrigation Water Quality (GB 5084–1992); Technical Specifications for Micro-irrigation Engineering (SL103–1995); Technical Specifications for Water-saving Irrigation (SL207–1998); Technical Specifications for Irrigation and Drainage Design Engineering (GB50288–1999)

(*continued*)

Table 1. (*continued*)

Stages	Time	Number	Characteristics	Milestone
Improvement and perfection	21st century	27	Water-saving irrigation and higher project quality with balanced development	Standard for Irrigation Water Quality (GB 5084–2005); Technical Specifications for Water-saving Irrigation Engineering (GB/T50363–2006); Technical Specifications for Sprinkler Irrigation Engineering 9GB/T50085–2007); Technical Specifications for Micro-irrigation Engineering (GB/T50485–2009); Standard for Irrigation Water Quality (GB 5084–2021)

quality management, and the standard has been updated and revised again in 2021. The latest version added total nickel index as one of the selected control items and the whole number has been changed from 27 to 36. As such, irrigation water quality standard is one of the basic cornerstones of soil and water pollution prevention and control. It has been revised and improved constantly for many years to ensure the soil environmental quality of agricultural land and product safety.

2.2 Development History of Irrigation Water Quality Standards in Australia

In view of the geographic conditions, two-thirds of Australia is located in the arid or semi-arid region due to the lower latitude. Research has shown that water shortages in Australia have led to a decline trend in irrigation levels around rural areas [6]. The utility of surface water and groundwater accounted for 70% of Australia's water has a unique function on ensuring the agricultural production. However, it could introduce inevitably pollutants including salt and other chemicals, as well as microorganisms, into soil and crops, resulting in the changes in soil properties, the health of livestock, the spread of disease and food contamination. From a long-term perspective, the crop yields cannot be maintained if the irrigation water has unexpected effects on the soil properties with physical and chemical elements.

Agricultural water supply is a decisive factor in agricultural productivity and indirectly affects export output. At present, Australian agricultural production is facing

Table 2. Development history of water quality standards for irrigation in Australia

Year	Territory	Guideline
1992	Australia	Australian water quality guidelines for fresh and marine waters
1999	Australia Capital Territory	ACT-wastewater reuse for irrigation
2000	Australia	Australian and New Zealand water quality guidelines for fresh and marine water quality
2002	Tasmania	Environmental guidelines for the use of recycled water in Tasmania
2003	New South Wales	The guidelines for sewage systems: use of reclaimed water (ARMCANZ-ANZECC-NHMRC 2000)
2003	Victoria	The guidelines for environmental management: use of reclaimed water, guidelines for environmental management: dual pipe water recycling schemes-health and environmental risk management
2008	Queensland	The water quality guidelines for recycled water schemes
2009	Western Australia	Guidelines for the use of recycled water in Western Australia
2014	Northern Australia	Guidelines for wastewater works design approval of recycled water systems

serious water shortage crisis. Progressively worse, the problem has become more complicated as water quality was increasingly threatened by the pressures of urbanization, industrialization and agricultural practices in this country. The typical guidelines and standards related to the irrigation water quality between 1992 and 2014 can be obtained from Table 2 [7].

In 1992, Agriculture and Resource Management Council of Australia and New Zealand (ARMCANZ) and Australian and New Zealand Environment and Conservation Council (ANZECC) were cooperated to develop and implement the National Water Quality Management Strategy (NWQMS). In the same year, ANZECC formulated the Australian Water Quality Guidelines for Fresh and Marine Waters. With the increasing demand of agricultural water environmental protection and human health risk awareness, ARMCANZ and ANZECC revised the original standard and termed as Australian and New Zealand Water Quality Guidelines for Fresh and Marine Water Quality after eight years. Since the millennium drought, the states and territories have paid more attention to the irrigation water safety and management, gradually strengthening the formulation of corresponding irrigation water quality guidelines and promoting the perfect implementation. The Guidelines for Irrigation Water Quality listed in the Australian Water Quality Guidelines for Fresh and Marine Waters have summarized the number of biological parameters, major ions, total dissolved solids, heavy meatal and trace ions and radioactivity indicators were one, three, one, twenty-one and two items, respectively.

The updated revision, a new guideline implemented in 2000, mainly focused on the inorganic contaminants with stricter threshold.

2.3 Comprehensive Comparison of Current Editions in China and Australia

According to the review of irrigation water quality standards development history in China and Australia, various water sources for crop irrigation have been developed in Australia since the 1990s, including seawater and reclaimed water from treated sewage/wastewater to alleviate water scarcity. In contrast, China preferred to improving the utilization rate of irrigation water considering about the water-saving performance of advanced irrigation facilities. Currently, the reclamation rate was 20% lower than 30–40% in the developed countries [8]. In order to make high-quality resource utilization, it is worth learning to apply reclaimed water to agricultural irrigation following the example of using alternative water resources in water-deficient countries. On the one hand, there is a rigid demand for 1.8 billion of farmland in China, and agricultural water consumption is large. The large-scale implementation of water reuse for irrigation can greatly alleviate the water resource shortage. On the other hand, reuse water for irrigation can loose the standard of nitrogen and phosphorus removal and reduce the amount of fertilizer application. Thus, the expansion of different schemes for irrigation, especially recycling water, can be regarded as effective measures in China.

The data collected from Standards for Irrigation Water Quality (GB 5084–2021) and Guidelines for Irrigation Water Quality (1992) can be visualized as demonstrated in Fig. 1. It can be observed that there were significant differences in index number and types. In comparison, China attached importance to the limitation of general indicators such as BOD, COD and SS, while the priority considerations in Australia contained the inorganic toxic pollutants with the number of 20, significantly higher than China. Furthermore, there existing voids in the China's radionuclides and Australia's organic pollutants respectively.

2.4 General Index

For pH values, China (5.5–8.5) has a stricter range than Australia (4.5–9.0) as summarized in Table 3. Australia has not set limits for BOD, COD, SS and other indicators, whereas China set limits for the above indicators according to three crop types (paddy field crops, dry land crops and vegetables). Moreover, the concentration of chloride was more stringent in Australia, ranging from 30 mg/L to 700mg/L depending on the crop classifications, however, the limit was no higher than 350mg/L In China. In terms of microbiological parameters, the faecal coliforms and ascaris eggs number were both set in China, while only the number of faecal coliforms was limited in Australia.

The mentioned analysis showed that the limit values of pH, COD, BOD, SS and microorganisms were stricter in China, except for chloride, indicating that the higher attention in this country. Notably, the accurate concentrations of several biological indicators in Australia, such as BOD, have not been identified due to the insufficient available data or controversial arguments among stakeholders, leading to there were no recommended values [9]. Additionally, there was no limits on COD in Australia, but a relatively

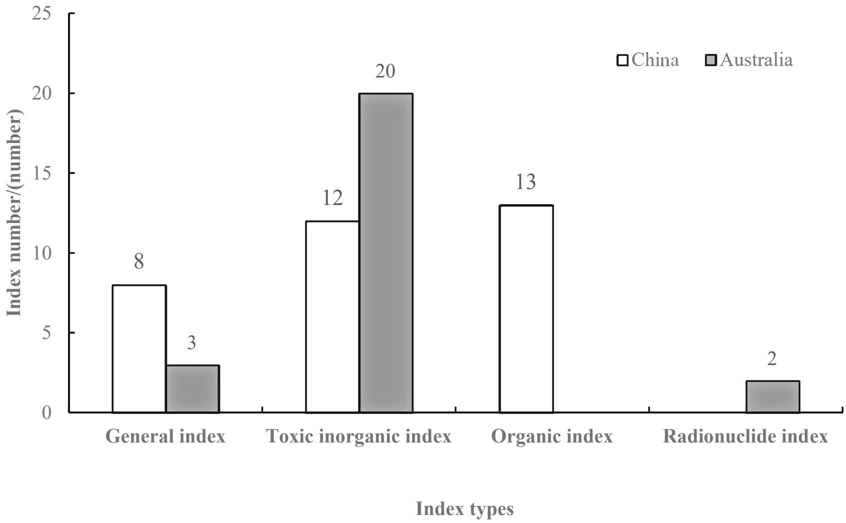

Fig. 1. Comparison of irrigation water quality index types and numbers in China and Australia

high concentration of COD might pose risks to the public and environmental health considering the presence of unbiodegradable organic compounds and other substances in recycled water used for irrigation. Apparently. it cannot be ignored that Australia is located in a unique geographical position. The land area mainly distributed in the southeast coastal zone which is suitable for livestock and farming is extremely limited with the higher requirements for agricultural water quality. As a consequence, the suggestions that appropriate limits on organic matter should be carried out in the future can be recommended to ensure the irrigation water quality comply with the targeted demand.

2.5 Toxic Inorganic Index

There were no corresponding limit values for heavy metal indexes including aluminum (Al), beryllium (Be), cobalt (Co), iron (Fe), lithium (Li), manganese (Mn), molybdenum (Mo), uranium (U) and vanadium (V) in China, while strict standards have been set in Australia. Basically, the recommended concentrations of total cadmium (Cd), hexavalent chromium (Cr), total lead (Pb), total nickel (Ni) and total selenium (Si) in China and Australia were as the same level. In certain scenarios, for instance, the limit of fluoride (F) was relatively strict in Australia without more than 1mg/L, whereas, the threshold varied with regional characteristics (2 mg/L in general area, 3 mg/L in high fluorine area) in China. Another example was that the recommended value of copper (Cu) in Australia was 0.2mg/L, however, it was limited separately taking account crop species (0.5 mg/L for paddy field crops, 1 mg/L for dry land crops and vegetables) in China. As a whole, it was reflected that the limited values of these two items were more stringent in Australia although they were classified as different categories in China with a loose range. Interestingly, China's requirement for total mercury (Hg) was twice as strict as Australia's (0.001 mg/L in China and 0.002 mg/L in Australia).

According to the Australian national data in 2021 [10], the country has abundant mineral resources, as many as 70 kinds, among which the reserves rank first in the world including lead, nickel, silver, uranium, zinc and tantalum. As the world's largest producer of lithium zirconium and the largest exporter of bituminous coal, bauxite, diamond and zinc concentrate, the output of gold, iron, coal and manganese ore also ranks first in the globe. The previously certificated reserves of bauxite, iron ore, lead, nickel and zinc with economic exploitation value were about 5.3 billion tons, 14.6 billion tons, 22.9 million tons, 22.6 million tons and 41 million tons respectively. It can be concluded that the sewage discharged containing large mineral resources in the process of mining and smelting has a potential negative impact on public health. The study has shown that exposure to heavy metals from diet may cause health risks [11]. The contents of heavy metals in Australian food were characterized as white rice and rice were lower than organic brown rice and vegetables, indicating the latter were potential sources of heavy metal pollution. Some heavy metals (such as manganese and zinc) are essential to human beings although the concentration of these metals in food is too high. The higher concentration can cause harm to health, requiring Australia especially pay attention to the cadmium (Cd), cobalt (Co), chromium (Cr), copper (Cu), manganese (Mn), nickel (Ni), lead (Pb), zinc (Zn) and other heavy metal pollutants and take actions on developing strategies to limit them strictly. In the future, the standards of international organizations, such as World Health Organization (WHO), could be further referenced. Appropriate Tolerable Dietary Intake (TDI) limits for these metals based on the weight and age of consumers could be established to assess the actual level of health hazards.

2.6 Organic Index

The possible reasons that the limits of 13 organic pollutants such as benzene and xylene in China's irrigation water quality standards have been recommended while Australia has not made specific regulations on such pollutants, could be ascribed to China was the only one country with all industrial sectors and has become the ambitious manufacturing power. By 2019, China's industry accounted for 32% of GDP, and the added value had a proportion of 24.9% as a share of the world's industrial value-added, implying the trend of industrialization was steady and active [12]. However, the organic pollutants produced in the industrial production process are likely to remain in the soil and water environment along with wastewater discharge, thereby endangering the crop safety, resulting in lower yields, and even threatening public health. The study has verified that aniline widely used in chemical industry has significant toxic effects on rice, which can inhibit yields and quality and cause acute toxic reaction when entering human bodies [13]. In 2015, China required to actively practice the new development concepts of innovation, balanced, green, open and shared development, advocate green and low-carbon industrial development, and basically realize the new-type industrialization goal by 2035 while minimizing environmental pollution, accelerating the speed of adopting stricter standards for organic pollutant indicators.

In fact, Australia was a lag convert from agricultural to industrial economy [14], signifying it can be regarded as one country with a relatively single industrial category compared with China [15]. The limited level of man-made organic pollutants has not been as a measure of environmental contamination on account of observing the unharmful impacts on the surroundings. The actual practice has shown that the concentration of residual pesticides in surface water was generally less than 1 μg/L. The lower concentrations were unlikely to accumulate from plants to reach the critical concentrations which were dangerous for humans and livestock. Moreover, no negative effects of pesticides on crops have been observed in Australia, and hence, there were no guidelines for use have been recommended [16].

2.7 Radionuclide Index

Gross Alpha and Gross Beta activity less than 0.1Bq /L can be acceptable in Australia, while China only set the limit standard of radionuclides for food [17]. In general, plants can be contaminated through radionuclides in two ways, including the direct adsorption on the plant surface by sprinkler irrigation, and the root uptake and translocation within the plant system. The absorption of the radionuclides cesium and cobalt presented in irrigation water via root system was much lower than the absorption on the plant surface. The important radionuclides that can be absorbed and concentrated are strontium, cesium, barium, iodine, calcium, chromium, potassium, ruthenium, zirconium and zinc. Relatively abundant radionuclide with long half-lives, such as ^{90}strontium and ^{137}cesium, may be highly concentrated in the soil and the plant-animal food chain, increasing the possibility of contamination risks. Advice on considering radionuclide index establishment according to the different regions can be further deliberated.

3 Conclusions

Overall, there existing significant differences between the standards for irrigation water quality in China and Australia, implying imperious needs on the appropriate improvement and adjustment are required to be further considered arising from the technology development and public engagement, so as to ensure the crop yields and quality. At present, Australia has taken actions on irrigation using alternative water resources, such as desalination and wastewater reclamation, with typical standards on specific water sources, which can be used as one important reference for the standard formulation in China. Undoubtedly, China attached great importance to the biological indexes and the organic contaminations derived from industrial processing, whereas, heavy metal pollution and radioactivity indicators with strict limits have been obtained attractions in Australia. To summarize, these two countries have set corresponding standards to mitigate the adverse impacts on agricultural environment and achieve the minimum risks on public health and ecological surroundings. The several key findings based on the results and discussions can be identified as follows:

1) China set limit values on biological indicators including BOD, COD, faecal coliforms and ascaris egg number, however, Australia only focused on the faecal coliforms, indicating microbiological risks were more fragile in China.

Table 3. Comparison of water quality standards for irrigation in China and Australia

Parameters	China			Australia
	Paddy field crops	Dry land crops	Vegetables	
General index				
pH	5.5–8.5			4.5–9.0
BOD_5 (mg/L)	≤60	≤100	≤ (vegetables with cooking and processing), ≤ 5(raw vegetables, melons and herbaceous fruits)	-
COD_{Cr} (mg/L)	≤150	≤200	≤ 0(vegetables with cooking and processing), ≤ 0(raw vegetables, melons and herbaceous fruits)	-
Faecal coliforms (MPN/L)	40000	40000	20000(vegetables with cooking and processing), 10000(raw vegetables, melons and herbaceous fruits)	10000
ascaris eggs number (number/10 L)	20	≤20(vegetables with cooking and processing), ≤ 0(raw vegetables, melons and herbaceous fruits)		-
Suspended solids (mg/L)	≤80	≤100	≤60(vegetables with cooking and processing), ≤15(raw vegetables, melons and herbaceous fruits)	-
Sulfide (mg/L)	≤1			-
Chloride (mg/L)	≤350			30–700
Toxic inorganic index				
Cyanide (mg/L)	≤0.5			-
Fluoride (mg/L)	2(general area), 3(high fluorine area)			1

(*continued*)

Table 3. (*continued*)

Parameters	**China**			**Australia**
	Paddy field crops	Dry land crops	Vegetables	
Aluminum (mg/L)-	-			5
Arsenic (mg/L)	≤0.05	≤0.1	≤0.05	0.1
Beryllium (mg/L)-	-			0.1
Boron (mg/L)	1(sensitive crops), 2(Moderately tolerant), 3(Very tolerant)			0.5–6.0
Cadmium (mg/L)	≤0.01			0.01
Chromium (mg/L)	≤0.1			0.1
Copper (mg/L)	≤0.5	≤1		0.2
Cobalt (mg/L)	-			0.05
Iron (mg/L)	-			1
Lead (mg/L)	≤0.2			0.2
Lithium (mg/L)	-			2.5(Citrus: 0.075mg/L)
Manganese (mg/L)	-			2
Mercury (mg/L)	≤0.001			0.002
Molybdenum (mg/L)	-			0.01
Nickle (mg/L)	≤0.02			0.02
Selenium (mg/L)	≤0.02			0.02
Uranium (mg/L)	-			0.01
Vanadium (mg/L)	-			0.1
Zinc (mg/L)	≤2			2 (1mg /L for sandy soil below pH 6)

(*continued*)

Table 3. (*continued*)

Parameters	**China**			**Australia**
	Paddy field crops	Dry land crops	Vegetables	
Organic index				
Benzene (mg/L)	≤2.5			-
Methylbenzene (mg/L)	≤0.7			-
Xylene (mg/L)	≤0.5			-
Isopropyl benzene (mg/L)	≤0.25			-
Aniline (mg/L)	≤0.5			-
Acrolein (mg/L)	≤0.5			-
Chlorobenzene (mg/L)	≤0.3			-
1,2- dichlorobenzene (mg/L)	≤1.0			-
1,4- dichlorobenzene (mg/L)	≤0.4			-
Nitrobenzene (mg/L)	≤2.0			-
Chloral (mg/L)	≤1	≤0.5		-
Petroleum (mg/L)	≤5	≤10	≤1	-
Volatile phenol (mg/L)	≤1			-
Radionuclide index				
Gross α (Bq/L)	-			0.1
Gross β (Bq/L)	-			0.1

2) In comparison, China has established organic pollutants indices due to the developed industrial system, but the livestock industry and minerals mining predominately comprised of Australia's economy, and thus, the organic pollutants were excluded according to the current edition.
3) In light of the mineral resource richness, Australia has higher requirements for inorganic pollutants such as heavy metals and radionuclides, most of which are stricter than China's standards.
4) China has set limits based on the crop classifications in terms of paddy field crops, dry land crops and vegetables to meet the targeted objectives.

In conclusion, the types and limit values for irrigation water quality standards need to be reviewed regularly as required based on the real-time monitoring data in recent years, given that the irrigation water quality is associated with the soil environmental quality and agricultural products safety. Therefore, there existing necessity that learning from each other and improving the standards at regular time, in order to accomplish the adaptive development and comply with the quality requirements of crop irrigation, as well as further ensure the food safety and human health using the state-of-the-art technologies.

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