Response to Anonymous Referee #1

Thank you very much for your excellent comments on our manuscript. We have carefully considered the comments and modified the manuscript accordingly. The comments and detailed responses are summarized as follows:

Comment 1: The authors used their framework to analyze the VWC of rice in China and compared it with the other three frameworks. However, its innovation was not clarified enough. This work would be of sufficient general interest if it clarified its major difficulties and challenges, and the original achievements to overcome them in a clearer way in abstract and introduction.

Response: We fully agree with the reviewer's opinion that innovation was not clearly clarified.

We added the following sentences in the revised version.

The total VWC is the total volume of freshwater both consumed and affected by pollution during the crop production process including direct and indirect water use. Prior calculation frameworks of VWC of crops do not contain all contents of virtual water content of crops.

However, prior calculation frameworks of VWC of crops have some defects. Some use the water requirement of crops instead of the actual water use, and others ignore the freshwater affected by pollution during the crop production. Besides, in all calculation frameworks the indirect water use of crops was also ignored.

Comment 2: Page 3, lines 23-25. Most of the background data on water use in China cited by the authors was after 2006, except the per capita water use (in 1997). The data would be more unified if the per capita water use was updated.

Response: The data of per capita water use of China is updated in the revised version.

The sentences were modified as following in the revised version.

"*China is one of the world's 13 most water-poor countries (Yu et al., 2006). In*

2012, per capita use of water resources in China was only 2100 m^3, less than 30% of the world per capita consumption. Agriculture is the largest water user in China, accounting for nearly 70% of total water withdrawals (Ministry of Water Resources, 2012)."

Comment 3**:** The introduction would be stronger if the authors explained the reason of choosing rice as the object of the study. Although rice production took a large part in the agricultural production, the productions of wheat and corn were also large. Moreover, cash crops like cotton are also important and were considered in many previous studies. Thus, the authors should justify for their choice.

Response: Rice as a cereal grain is the most widely consumed food for a large part of the population, especially in Asia. According to data from FAOSTAT, rice is the grain with the second-highest worldwide production, after corn. Since a large portion of corn is not for the human consumption, rice is the main human food crop which provides more than one fifth of the calories consumed by humans. China is the biggest rice-producing country in the world. In 2007, the planting area of rice is the second largest in China. Rice production is the largest grain production that around 186 million tons. Rice is an extremely important grain production in China. Therefore, we chose rice as the object of this study.

We added the sentences to further explain the reason of choosing rice as the object of the study.

Rice as a cereal grain is the most widely consumed staple food for a large part of the population, especially in Asia. According to data from FAOSTAT, rice is the gain with the second-highest worldwide production, after maize. China is the biggest rice-producing country in the world. In 2007, the planting area of rice is the second largest in China (about 29 million hectares) and makes up 34% of the total planting area of grain crops. Rice production is the largest grain production in China (around 186 million tons) and accounted for 41% of the total grain (Ministry of Agriculture of the People's Republic of China, 2008).

Comment 4: In Section 2, the authors introduced 5 kinds of VWCs. However, the readers might be confused with the relationships between these VWCs. More details should be furnished. This section would be of sufficient general interest if it included the detailed introduction of direct and indirect VWC. Did the indirect VWC include green, blue and grey water like the direct VWC?

Response: In Section 2, we introduced 6 kinds of VWCs. The VWC_{total} of a crop is the total volume of freshwater both consumed and affected by pollution during the crop production process. The VWC_{total} of a crop is an indicator of freshwater use that looks at both direct and indirect water use during the crop production process. The VWC_{direct} of a crop refers to the fresh water both consumed and affected by pollution that is associated with the water use during the crop production process. It is distinct from the $VWC_{indirect}$, which refers to the freshwater both consumed and affected by pollution that can be associated with the production of the goods and services or the inputs used during the crop production process. While the VWC_{direct} of a crop can be divided into three components: (1) $VWC_{direct,\ green}$ (the precipitation consumed in crop production); (2) $VWC_{direct,\ blue}$ (the surface water or groundwater consumed in crop production); and (3) $VWC_{direct,\ grey}$ (the fresh water required to assimilate the load of pollutants during the crop production process). Accordingly, the $VWC_{indirect}$ also should be divided into three components: $VWC_{indirect,\ green}$, $VWC_{indirect,\ blue}$ and $VWC_{indirect,\ grey}$. However, we only got the data about the total freshwater use of other economic system sectors. So we can only calculate the $VWC_{indirect}$. $VWC_{indirect,\ green}$ (the precipitation consumed that can be associated with the production of the goods and services or the inputs used during the crop production process), $VWC_{indirect,\ blue}$ (the surface water or groundwater consumed that can be associated with the production of the goods and services or the inputs used during the crop production process) and $VWC_{indirect,\ grey}$ (the freshwater required to assimilate the load of pollutants that can be associated with the production of the goods and services or the inputs used during the crop production process) was not able to calculate. That is the reason why we only introduced 6 kinds of VWCs: VWC_{total}, VWC_{direct}, $VWC_{indirect}$, $VWC_{direct,\ green}$, $VWC_{direct,}$

$_{blue}$ and $VWC_{direct,\ grey}$ in the manuscript.

We added the following sentences to give a more detail description:

For the lack of data, we can't divide the $VWC_{indirect}$ *into* $VWC_{indirect,\ green}$, $VWC_{indirect,\ blue}$ and $VWC_{indirect,\ grey}$.

where VWC_{total} *is the total volume of freshwater both consumed and affected by pollution during the crop production process* ($m^3\ kg^{-1}$) ; $VWC_{indirect}$ *is the freshwater both consumed and affected by pollution that can be associated with the production of the goods and services or the inputs used during the crop production process* ($m^3\ kg^{-1}$); VWC_{direct} *is the freshwater both consumed and affected by pollution that is associated to the direct water use during the crop production process* ($m^3\ kg^{-1}$); $VWC_{direct,\ green}$ *is the precipitation consumed in crop production process* ($m^3\ kg^{-1}$); $VWC_{direct,\ blue}$ *is the surface water or groundwater consumed in crop production process* ($m^3\ kg^{-1}$); *and* $VWC_{direct,\ grey}$ *is the freshwater required to assimilate the load of pollutants during the crop production process*($m^3\ kg^{-1}$).

Comment 5**:** We have broken down Comment 5 into two parts as follows:

Comment 5(1)**:** Since the indirect water in the total VWC of rice is very little, the authors should explain why the assessing on indirect water is necessary.

Response: The total VWC of a crop is an indicator of freshwater use that looks at both direct and indirect water use during the crop production process. Indirect water use is an important component in the total VWC of a crop. Although the indirect water in the total VWC of rice is very little, we cannot ignore it. The indirect VWC is higher in the total VWC of some agricultural products including potatoes, cotton and fruits. For example, the proportion of $VWC_{indirect}$ of strawberry in 27 regions of China ranged from 0.8% to 38.0%, with an average of 10.8%. The proportion of $VWC_{indirect}$ of strawberry is not so unimportant. We cannot ignore the indirect water.

Further, we added the following sentences to explain the importance of $VWC_{indirect}$ in *Discussion*.

For example, the proportion of $VWC_{indirect}$ in the VWC_{total} of strawberry in 27 regions of China in 2007 ranged from 0.8% to 38.0%, with an average of 10.8%. The proportion of $VWC_{indirect}$ of strawberry is higher in the VWC_{total}. Therefore we cannot ignore the $VWC_{indirect}$ in the calculation of VWC_{total} of some crops.

Comment 5(2)**:** The introduction on the methodology for indirect water seems a little longer since the indirect water is not that important. This methodology part (section 2.1.1) could be condensed.

Response: The modified calculation framework of VWC of crops is an innovation in this study. Prior calculation frameworks of VWC of crops only calculate the direct water use, ignoring the indirect water use. While in this study, we innovatively put the calculation of indirect water use into the modified calculation framework of VWC of crops. Therefore, we think the methodology part (section 2.1.1) could not be condensed anymore.

Comment 6**:** In the section 2.1.1, the meanings of "direct consumption matrix", "direct consumption coefficient", "complete consumption coefficient matrix" and "complete consumption coefficient" should be explained since they might be confusing for readers. Their units should also be marked.

Response: We added the explanation of meanings of "direct consumption matrix", "direct consumption coefficient", "complete consumption coefficient matrix" and "complete consumption coefficient" and their units had also been marked.

We added the following sentences to make the readers easier to understand.

A is the direct consumption coefficient matrix ($n \times n$ dimensional matrix) in the IO table; a_{ij} is the direct consumption coefficient, which means the monetary volume of products of sector i directly consumed by sector j when producing one unit product.

B is the complete consumption coefficient matrix ($n \times n$ dimensional matrix) in the IO table; b_{ij} is the complete consumption coefficient, which means the monetary volume of products of sector i direct and indirect consumed by sector j when

producing one unit product.

Comment 7**:** The colored lines and circles in the Figures 1 to 5 might be confusing. Do they mean a kind of isometric lines? The authors should clarify the meaning of the lines and circles.

Response: We are sorry for ignoring the explanation of the meanings of the lines and circles in the Figures 1 to 5. We used lines and circles to describe the distribution characteristic of VWCs of rice. And the regions with the same line or circle had the same distribution characteristic. In order to be easily understood, we changed all the circles into the lines in the Figures 1 to 5.

In addition, we added the following sentence to the revised version.

The regions with the same line had the same distribution characteristic of $VWC_{indirect}$ *of rice in Fig. 1.*

Comment 8**:** Page 12, lines 13-14. The authors noted: "The VWC_{total} values show a three-tiered distribution, decreasing gradually from southeast to northwest of China." However, it did not show a strict "three-tiered" distribution but a staggered distribution in Fig. 5.

Response: There were 29 rice cultivated regions in China in 2007. Excessive irrigation made the VWC_{total} of rice much higher in Beijing and Tianjin. The lowest rice yield made the VWC_{total} of rice much higher in Shanxi. VWC_{total} values of rice in Shandong and Henan did not strictly comply with the distribution characteristic of VWC_{total} of rice of China. Except the five regions, the VWC_{total} values of rice for 82.8% planting regions in China showed a strictly three-tiered distribution characteristic, gradually decreasing from southeast to northwest of China. Therefore, we noted: "The VWC_{total} values show a three-tiered distribution, decreasing gradually from southeast to northwest of China." in the previous manuscript.

In order to make the sentence more accurate, "*The* VWC_{total} *values show a three-tiered distribution, gradually decreasing from southeast to northwest of China.*"

was replaced by the sentence "*The VWC_{total} values showed a roughly three-tiered distribution, gradually decreasing from southeast to northwest of China.*"

Comment 9**:** In the Section 4.2.2, the authors described geographical distribution of the VWC of rice in China. But the root reasons of the distribution were not explained detailed. This section would be stronger if the reasons of the distribution were discussed by some instances, e.g., why Beijing has the highest $VWC_{indirect}$ while Ningxia has the lowest one.

Response: We fully agree with the reviewer's comment. In the Section 4.2.2, the root reasons for the distribution of the VWC of rice in China were not explained detailed. The statement has been refined by the following sentence in the revised version.

Generally speaking, the regions in China mostly had the higher $VWC_{direct,\ green}$ of rice and the lower $VWC_{direct,\ blue}$ of rice. For example, in Chongqing the percentage of $VWC_{direct,\ green}$ was 67.6% and the percentage of $VWC_{direct,\ blue}$ was 6.6%; in Sichuan the percentage of $VWC_{direct,\ green}$ was 53.7% and the percentage of $VWC_{direct,\ blue}$ was 12.4 %. Six regions were the exceptions which had the lower $VWC_{direct,\ green}$ of rice and the higher $VWC_{direct,\ blue}$ of rice. In Beijing the percentage of $VWC_{direct,\ green}$ was 19.8% and the percentage of $VWC_{direct,blue}$ was 63.2%; in Tianjin the percentage of $VWC_{direct,\ green}$ was 14.7% and the percentage of $VWC_{direct,\ blue}$ was 69.1%; in Fujian the percentage of $VWC_{direct,\ green}$ was 29.9% and the percentage of $VWC_{direct,\ blue}$ was 49.7%; in Gansu the percentage of $VWC_{direct,\ green}$ was 33.5% and the percentage of $VWC_{direct,\ blue}$ was 37.9%; in Ningxia the percentage of $VWC_{direct,\ green}$ was 24.9% and the percentage of $VWC_{direct,\ blue}$ was 48.1%, and in Xinjiang the percentage of $VWC_{direct,\ green}$ was 12.1% and the percentage of $VWC_{direct,\ blue}$ was 61.6%. There were two reasons for the different situation of the six regions. Excessive consumption of irrigation water caused the lower percentage of $VWC_{direct,\ green}$ of rice and the higher percentage of $VWC_{direct,\ blue}$ of rice in Beijing, Tianjin and Fujian. Limited precipitation caused the lower percentage of $VWC_{direct,\ green}$ of rice and the higher percentage of $VWC_{direct,\ blue}$ of rice in Xinjiang, Ningxia and Gansu. For the country as a whole, the proportion of $VWC_{direct,\ green}$ of rice (43.8%) was larger than the $VWC_{direct,}$

$_{blue}$ of rice (28.2%). Rice growth mainly depend on the $VWC_{direct,\ green}$ in China.

The values $VWC_{indirect}$ in the VWC_{total} of rice for the 29 regions were comparatively less, ranging from 0.001 to 0.010m^3 kg^{-1}. The average $VWC_{indirect}$ of rice was 0.004 m^3 kg^{-1}. $VWC_{indirect}$ of rice is related to the degree of regional economic development. The region with the highest $VWC_{indirect}$ value was Beijing and the region with the lowest value was Ningxia. Because of the small contribution of $VWC_{indirect}$, $VWC_{indirect}$ may not be considered in future research on the VWC of rice. However the $VWC_{indirect}$ is expected to be higher in some agricultural products including potatoes, cotton and fruits. $VWC_{indirect}$ should be included in the VWC_{total}.

Comment 10**:** In the discussion section, the authors did not give guidance for water management basing on their results. Some opponents of virtual water claimed: it does not provide any indication of whether water resources are being used within sustainable extraction limits; therefore the use of virtual water estimates offer no guidance for policy makers (For instance, please see Frontier Economics. 2008. The concept of 'virtual water' - a critical review [http://www.frontiereconomics. com/australia/au/publications/217/]; Australian National Water Commission. 2008. eNewsletter of Australian National Water Commission, Edition 30 [http://www.nwc.gov.au/__data/assets/pdf_file/0005/11885/DistilledJuly2008.pdf]). It would be better to explain how this virtual water study could help China to solve its water problems.

Response: We fully agree with the reviewer's comment. We should give guidance for water management based on our results. Virtual water estimations are important for policy makers. Research on virtual water content of crops can provide the basis for agricultural water resources management, and help to improve the efficiency of agricultural water use. China is well-known for its massive land and the VWC of rice is largely different between regions. The different crops planting structure between regions of China may cause a largely difference in agriculture water use. The VWC of crops in China should be assessed and the spatial characteristics should be also analyzed.

The following sentences were added in the revised version.

Assessing the VWC of crops is an important way to provide the basis for agricultural water resources management, and help to improve the efficiency of agricultural water use. Overall pressure on water resources might be relieved if we locate water-intensive production processes in regions where water is abundant and where it requires less VWC of product. China is well-known for its massive land. The VWC of rice is largely different between regions. The different rice planting structure between regions of China may cause a largely difference in agriculture water use. The VWC of rice in China should be assessed and the spatial characteristics should be also analyzed.

Comment 11**:** As the authors cited, "The concept of virtual water was defined as the water embodied in the traded products" (page 2, line 23-24). Therefore, the authors should discuss more information on the trade of rice; otherwise the "virtual water" would seem not to be different with "water use".

Response: The virtual water trade of rice is very important. However, we think there was a misleading concept of virtual water in our previous version of manuscript, which may have led the reviewer to focus on the trade of rice. We would like to explain the concept of virtual water.

The idea of virtual water was derived from the concept of 'embedded water' applied to agriculture in Israel by Fishelson et al. (1994). The term 'virtual water' was first proposed in 1994 by Allan (1994). Allan defined virtual water as the water used to produce food crops that are traded internationally and later modified by Hoekstra and Chapagain (2007) to indicate the required water input to generate a product or service. The virtual water content of a product is the freshwater embodied in the product, not in the real sense, but in the virtual sense. It refers to the volume of freshwater both consumed and affected by pollution for producing the product, measured over its full production chain (Hoekstra et al., 2011).

We added the following sentences to the revised version.

Later the concept of virtual water was modified by Hoekstra and Chapagain (2007) to indicate the required water input to generate a product or service. The virtual water content of a product is the freshwater embodied in the product, not in the real sense, but in the virtual sense. It refers to the volume of the freshwater both consumed and affected by pollution for producing the product, measured over its full production chain (Hoekstra et al., 2011).

Comment 12**:** Since the authors made many assumptions and simplification in their computing, the uncertainty of the results might be discussed.

Response: We fully agree with the reviewer's comment. We made some assumptions and simplifications in the calculation of $VWC_{indirect}$, $VWC_{direct,\ blue}$ *and* $VWC_{direct,\ grey}$ of rice. The uncertainty of the results should be discussed.

We used the Input–Output model to calculate the $VWC_{indirect}$ of rice supplied by each economic sector. Due to the data limitation, we made an assumption that the proportion of indirect water supplied between economic sectors is the same to each crops. Hence that made the uncertainty of $VWC_{indirect}$ of rice. If we can get the data that the input of rice from each economic sector, the calculation results of $VWC_{indirect}$ of rice will be more accurate.

We used the Sun's method to calculate the $VWC_{direct,\ blue}$ of rice. The direct blue water is calculated according to the proportion of irrigation water consumption of rice in the total irrigation water consumption of the irrigation district. That means the crop needs more irrigation requirement that the crop would consume more irrigation water. However, in many regions, the irrigation water was met to the need of rice irrigation requirement in the first place. Our calculated results of $VWC_{direct,\ blue}$ of rice maybe smaller than the actual $VWC_{direct,\ blue}$ of rice. If we can get the irrigation water consumption of rice, the results of $VWC_{indirect}$ of rice will be more accurate.

The $VWC_{direct,\ grey}$ is calculated by multiplying the fraction of nitrogen that leaches or runs off by the nitrogen application rate and dividing this by the difference between the maximum acceptable concentrations of nitrogen and the natural

concentration of nitrogen in the receiving water body and by the actual crop yield. For the lack of data, the natural nitrogen concentrations were assumed to be 0. On average, 10% of the applied nitrogen fertilizer is lost through leaching. The simplification of natural nitrogen concentrations made the $VWC_{direct,\ grey}$ of rice smaller. The simplification of applied nitrogen fertilizer lost through leaching made the $VWC_{direct,\ grey}$ of rice uncertainty. The natural nitrogen concentrations and applied nitrogen fertilizer lost through leaching should be studied further to reduce the uncertainty of the results. Because the $VWC_{direct,\ grey}$ of rice estimated only considers chemical fertilizer pollution, and not the effect of pesticides and herbicides on water quality, the result of $VWC_{direct,\ grey}$ of rice is a conservative estimate.

We added the following sentences to discuss the uncertainty of the results.

However, in our calculation framework of VWC of crops, we made some assumptions and simplifications in the calculation of $VWC_{indirect}$, $VWC_{direct,\ blue}$ *and* $VWC_{direct,\ grey}$, *which makes the uncertainty of the results. The uncertainty of the results cannot be completely eliminated. We could only make better assumptions and simplifications and use more accurate data to make our results more accurate.*

Comment 13**:** In the conclusions section, the authors may list too many results. This section would be clearer if these results were condensed.

Response: As suggested, we refined the Conclusion section in the revised version.

1. *Analysis showed that the total VWC of rice in China decreased gradually from southeast to northwest.*
2. *The regions with high indirect water were randomly distributed. The indirect VWC of rice in Northwest China and Southwest China was relatively low.*
3. *The regions with higher direct green water were mainly concentrated in the Southeast China and Southwest China. The direct green water of rice for Northwest China and Inner Mongolia was relatively low. The regions with higher direct blue water of rice were mainly concentrated in the eastern and*

southern coastal regions of China and in Northwest China. The direct blue water of rice of Southwest China was relatively low. In the country as a whole, the percentage of direct green water of rice was far above that of direct blue water. Therefore, rice growth is mainly dependent on direct green water in China.

4. *The direct grey water of rice in Northeast China and Northwest China was relatively low. But in all regions, grey water occupies a very important position in total VWC.*

Response to Anonymous Referee #2

We appreciate your valuable comments on our manuscript; they have been very helpful in revising and improving our paper. We have carefully considered the comments and have revised the manuscript accordingly. The comments and detailed responses can be summarized as follows:

Comment 1**:** The abstract did not well highlight the innovation of this paper. The innovation of this paper should be put forward in the abstract by briefly mentioning the deficiencies of the previous research.

Response: The innovation was not clearly clarified, so we added the following sentences in the revised version.

In this research, the VWC of rice, as a major crop in China, was taken as the research object. China is well-known for its massive land. The VWC of rice is largely different between regions. The VWC of rice of China should be assessed and the spatial characteristics should be also analyzed.

The total virtual water content is the total volume of freshwater both consumed and affected by pollution during the crop production process including direct and

indirect water use. Prior calculation frameworks do not contain all contents of virtual water content of crops.

Comment 2**:** This paper has two main purposes: 1) propose a modified calculation framework of VWC of crops; 2) analyze the spatial characteristics of VWC of rice in China. The Introduction section should focus on the advantages of the modified calculation framework of crop VWC and the significance of the spatial distribution analysis of rice VWC in China.

Response: We fully agree with the reviewer's opinion.

We added the following sentences in the revised version.

There is not any research on the total VWC of rice and spatial distribution characteristics in China at provincial scale by the actual total water use. China is well-known for its massive land. The VWC of rice is largely different between regions. The VWC of rice of China should be assessed and the spatial characteristics should be also analyzed.

However, prior calculation frameworks of VWC of crops have some defects. Some use the water requirement of crops instead of the actual water use, and others ignore the freshwater affected by pollution during the crop production. Besides, in all calculation frameworks the indirect water use of crops was also ignored.

Comment 3**:** In the introduction, authors should briefly introduce the results of distribution characteristics of virtual water content of rice by sun (2013a).

Response: Thanks for the advice. In the revised version, we added the sentences to briefly introduce the results from sun (2013a).

We added the following sentences in the revised version.

Sun et al. (2013a) used the crop water requirement to calculate the China average VWC of wheat, maize and rice, and found the proportions of green and blue water were 50.98% and 49.02%, 76.27% and 23.73%, 61.90% and 38.10%, respectively. The VWC of rice was relatively low in the eastern part of Northeast

China, Middle–Lower Reaches of the Yangtze River and the eastern part of Southwest China. In contrast, the high values of VWC for rice were located in the west of Inner Mongolia and south of Xinjiang Uygur Autonomous Region.

Comment 4**:** Authors divided the VWC into direct water and indirect water, and the direct water was divided into direct green water, direct blue water and direct grey water. Why the indirect water was not divided into indirect green water, indirect blue water and indirect grey water?

Response: The VWC_{total} of a crop is the total volume of freshwater both consumed and affected by pollution during the crop production process. The VWC_{total} of a crop is an indicator of freshwater use that looks at both direct and indirect water use during the crop production process. The VWC_{direct} of a crop refers to the freshwater both consumed and affected by pollution that is associated with the water use during the crop production process. It is distinct from the $VWC_{indirect}$. The $VWC_{indirect}$ of a crop refers to the freshwater both consumed and affected by pollution that can be associated with the production of the goods and services or the inputs used during the crop production process. The VWC_{direct} of a crop is divided into three components: (1) $VWC_{direct,\ green}$ (the precipitation consumed in crop production); (2) $VWC_{direct,\ blue}$ (the surface water or groundwater consumed in crop production); and (3) $VWC_{direct,\ grey}$ (the freshwater required to assimilate the load of pollutants during the crop production process). Accordingly, the $VWC_{indirect}$ also should be divided into three components: $VWC_{indirect,\ green}$, $VWC_{indirect,\ blue}$ and $VWC_{indirect,\ grey}$. However, we only had the data about the total freshwater use of other economic system sectors. Using the data, we can only calculate the $VWC_{indirect}$. $VWC_{indirect,\ green}$ (the precipitation consumed that can be associated with the production of the goods and services or the inputs used during the crop production process), $VWC_{indirect,\ blue}$(the surface water or groundwater consumed that can be associated with the production of the goods and services or the inputs used during the crop production process) and $VWC_{indirect,\ grey}$ (the freshwater required to assimilate the load of pollutants that can be associated with the production of the goods and services or the inputs used during the crop production process) was

not able to calculate. That is the reason why the indirect water was not divided into indirect green water, indirect blue water and indirect grey water.

Comment 5**:** For the sector 2.1.3, the meaning of "actual total irrigation water consumption" should be explained more clearly. Authors should explain the relationship between the irrigation water consumption, irrigation water supply and irrigation coefficient. It will help readers better understand the meaning of "actual total irrigation water consumption".

Response: "Irrigation water supply" is the artificial application of water to the land or soil, which can be groundwater extracted from springs or by using wells, surface water withdrawn from rivers, lakes or reservoirs or non-conventional sources. "Irrigation water consumption" is the net artificial application of water to the land or soil, which not includes the irrigation water losses during the transport process from the water sources to cropland and the return flows of irrigation water. "Irrigation coefficient" refers to ratio of the net water use by crops and the total water withdrawals in water irrigation system. Irrigation coefficient can be considered as the ratio of irrigation water consumption and irrigation water supply. In this study, the "actual total irrigation water consumption" is the same as the "irrigation water consumption". We changed the "actual total irrigation water consumption" into "irrigation water consumption".

The following added sentences in the revised version will help readers better understand the meaning of "actual total irrigation water consumption".

The irrigation water consumption is the net artificial application of water use by crops, which not includes the irrigation water losses during the transport process from the water sources to cropland and the return flows of irrigation water.

Comment 6**:** The data source of rice fertilizer is not clear, and reference should be added.

Response: We have changed the sentence "*The average amount of fertilization of crops per unit area is taken from Li et al. (2010).*"into "*The average amount of*

nitrogen fertilizer of rice per unit area is taken from Li et al. (2010), Zhang et al. (2008) and Zhang et al. (2009)." in the revised version.

The following references have been added.

Zhang, S. D., Zhang W. F., Wang J. Q.: Character of Fertilizer Consumption and Supply- Demand and Strategy for Management in Middle and Lower Reaches of Yangtz River of China, Research of agricultural modernization, 29, 100-103. 2008 (in Chinese).

Zhang, S. D., Zhang W. F., Ma L.: Study on the change of fertilizer consumption structure of main grain crop in Hebei, Jilin and Sichuan of China, Phosphate & Compound Fertilizer, 24, 89-91, 2009 (in Chinese).

Comment 7**:** It needs to explain the difference among 'irrigation water consumption', 'irrigation water supply' and 'actual total irrigation water consumption'. These similar terms were motioned in the method without the difference which could be confusing for readers. Which data are used in the calculation?

Response: We explain the differences between the similar terms. The same as the Comment 5, "Irrigation water supply" is the artificial application of water to the land or soil, which can be groundwater extracted from springs or by using wells, surface water withdrawn from rivers, lakes or reservoirs or non-conventional sources. "Irrigation water consumption" is the net artificial application of water to the land or soil, which not includes the irrigation water losses during the transport process from the water sources to cropland and the return flows of irrigation water. In this study, the "actual total irrigation water consumption" is the same as the "irrigation water consumption". The data used in this study actually is the irrigation water consumption. We deleted the "irrigation water supply" in the data resource and changed the sentence into "*The irrigation water consumption for the 29 regions is taken from the Water Resources Bulletins (2007) of 29 regions.*"

Comment 8**:** We have combined Comment 8 with Comment 9.

Comment 8, 9**:** It is necessary to intensively analyze the results of the spatial characteristics of rice VWC in China, and clarify the reasons for the spatial characteristics. The paper should discuss how the various virtual water is transferring or transporting regionally and why? The spatial characteristics of various components of VWC show obvious regionally distribution characteristics, and there are also differences among individual regions. Please clarify their causes.

Response: We fully agree with the reviewer's comment. In the *Results*, we should analyze more about the regionally distribution characteristics of VWCs and the differences among individual regions.

We added the following sentences in the revised version.

$VWC_{direct,\ green}$ of rice was increased gradually from northern to southern regions (Fig. 2). The regional variability of $VWC_{direct,\ green}$ of rice was in accordance with the distribution of precipitation in China. The regions with abundant precipitation usually have high $VWC_{direct,\ green}$ of rice. Precipitation in southern regions of China is far greater than that in northern regions of China. Consequently, the $VWC_{direct,\ green}$ of rice in southern regions would be higher than that in northern regions.

Jilin, Shandong and Henan were the other three regions with relatively low $VWC_{direct,\ blue}$ of rice. Limited irrigation water consumption in the three regions might only meet less than 25% of the irrigation requirement of rice. Therefore, the $VWC_{direct,\ blue}$ of rice in Jilin, Shandong and Henan was relatively low.

The rice yield of Shandong, Henan and Chongqing was much higher than the national average. That made the $VWC_{direct,grey}$ of rice in the three regions also relatively low.

The VWC_{total} values showed a roughly three-tiered distribution, gradually decreasing from southeast to northwest of China.

Comment 10**:** The results in this paper need be compared with those by Sun (2013a)?

Response: We fully agree with the reviewer's advice. The following sentences added

to compare the results between our research and the research by Sun et al. (2013a).

Our result is large different to the result from Sun et al. (2013a). Follow their calculation the VWC of rice was relatively low in the eastern part of Northeast China, Middle–Lower Reaches of the Yangtze River and the eastern part of Southwest China. In contrast, the high values of VWC for rice were located in the west of Inner Mongolia and south of Xinjiang Uygur Autonomous Region. Their calculation framework only considered the crop water requirement. However, our calculation framework considers the effective precipitation and crop evapotranspiration, irrigation water consumption, freshwater that is required to assimilate the load of pollutants and the indirect water use. The difference of the $VWC_{direct,\ blue}$ *and the added* $VWC_{direct,\ grey}$ *of rice caused the large difference of spatial distribution characteristic between actual* VWC_{total} *of rice and the rice water requirement. Our result can be better to describe the spatial distribution characteristic of actual water use of rice in China.*

Comment 11**:** The discussion section mentioned the indirect water ratio of some crops will be higher. Can some evidences be given rather than just speculation?

Response: We fully agree with the reviewer's advice. We added the following sentences as the evidences.

For example, the proportion of $VWC_{indirect}$ *of strawberry in 27 regions of China in 2007 ranged from 0.8% to 38.0%, with an average of 10.8%. The proportion of* $VWC_{indirect}$ *of strawberry is higher in the* VWC_{total}*. We cannot ignore the* $VWC_{indirect}$ *in the calculation of* VWC_{total} *of some crops.*

Comment12**:** In Table 2, the unit "%" should be marked.

Response: Thank you for the reviewer's detailed comment. We modified the title of Table 2 in the revised version.

Table 2 The volume ($m^3\ kg^{-1}$*) and proportion (%) of VWC of rice in Heilongjiang Province by four different frameworks*

VWC / Method	$VWC_{direct,green}$	$VWC_{direct,blue}$	$VWC_{direct,grey}$	$VWC_{indirect}$	VWC
Our method	*0.45 (46.0)*	*0.29 (30.2)*	*0.22(22.9)*	*0.01 (0.9)*	*0.97*
Sun's method	*0.45 (60.5)*	*0.29 (39.5)*	—	—	*0.74*
GBG method	*0.45 (26.6)*	*1.01 (60.1)*	*0.22 (13.3)*	—	*1.68*
CWR method	*0.45 (30.7)*	*1.01 (69.3)*	—	—	*1.45*

Response to Anonymous Referee #3

Thank you very much for your excellent comments on our manuscript. We have carefully considered the comments and have modified the manuscript accordingly. The comments and detailed responses can be summarized as follows:

Comment 1**:** In the introduction section, the authors should descript the innovation of the VWC in detail of rice in China.

Response: We fully agree with the reviewer's opinion that the Introduction section should descript the innovation of the VWC in detail of rice in China.

We added the following sentences in the revised version.

There is not any research on the total VWC of rice and spatial distribution characteristics in China at provincial scale by the actual total water use. China is well-known for its massive land. The VWC of rice is largely different between regions. The VWC of rice of China should be assessed and the spatial characteristics should be also analyzed.

Comment 2**:** In the section of methodology, the authors should give an explanation of the indirect water even it was small in the total of VWC of rice.

Response: The total VWC of a crop is an indicator of freshwater use that looks at

both direct and indirect water use during the crop production process. Indirect water use is an important component in the total VWC of a crop. Although the indirect water in the total VWC of rice is very less, we cannot ignore it. The indirect VWC is higher in the total VWC of some agricultural products including potatoes, cotton and fruits. For example, the proportion of indirect VWC of strawberry in 27 regions of China ranged from 0.8% to 38.0% with an average of 10.8%. The proportion of indirect VWC of strawberry is not so unimportant. We cannot ignore the indirect water.

Further, we added the following sentences to explain the importance of indirect VWC in *Discussion*.

For example, the proportion of $VWC_{indirect}$ in the VWC_{total} of strawberry in 27 regions of China in 2007 ranged from 0.8% to 38.0%, with an average of 10.8%. The proportion of $VWC_{indirect}$ of strawberry is higher in the VWC_{total}. We cannot ignore the $VWC_{indirect}$ in the calculation of VWC_{total} of some crops.

Comment 3**:** In the paragraph of discussion, the author should give more discussion because the calculation process had more uncertainty.

Response: We fully agree with the reviewer's comment. We made some assumptions and simplifications in the calculation of $VWC_{indirect}$, $VWC_{direct,\ blue}$ *and* $VWC_{direct,\ grey}$ of rice. And the uncertainty of the results should be discussed.

We used the Input–Output model to calculate the $VWC_{indirect}$ of rice supplied by each economic sector. Due to the data limitation, we made an assumption that the proportion of indirect water supplied between economic sectors is the same to each crops. Hence that made the uncertainty of $VWC_{indirect}$ of rice. If we can get the data that the input of rice from each economic sector, the calculation results of $VWC_{indirect}$ of rice will be more accurate.

We used the Sun's method to calculate the $VWC_{direct,\ blue}$ of rice. The direct blue water is calculated according to the proportion of irrigation water consumption of rice in the total irrigation water consumption of the irrigation district. That means the crop

needs more irrigation requirement that the crop would consume more irrigation water. However, in many regions, the irrigation water was met to the need of rice irrigation requirement in the first place. Our calculated results of $VWC_{direct,\ blue}$ of rice maybe smaller than the actual $VWC_{direct,\ blue}$ of rice. If we can get the irrigation water consumption of rice, the results of $VWC_{indirect}$ of rice will be more accurate.

The $VWC_{direct,\ grey}$ is calculated by multiplying the fraction of nitrogen that leaches or runs off by the nitrogen application rate and dividing this by the difference between the maximum acceptable concentrations of nitrogen and the natural concentration of nitrogen in the receiving water body and by the actual crop yield. For the lack of data, the natural nitrogen concentrations were assumed to be zero. On average, 10% of the applied nitrogen fertilizer is lost through leaching. The simplification of natural nitrogen concentrations made the $VWC_{direct,\ grey}$ of rice smaller. The simplification of applied nitrogen fertilizer lost through leaching made the $VWC_{direct,\ grey}$ of rice uncertainty. The natural nitrogen concentrations and applied nitrogen fertilizer lost through leaching should be studied further to reduce the uncertainty of the results. Because the $VWC_{direct,\ grey}$ of rice estimated only considers chemical fertilizer pollution, and not the effect of pesticides and herbicides on water quality, the result of $VWC_{direct,\ grey}$ of rice is a conservative estimate.

We added the following sentences to discuss the uncertainty of the results.

However, in our calculation framework of VWC of crops, we made some assumptions and simplifications in the calculation of $VWC_{indirect}$, $VWC_{direct,\ blue}$ *and* $VWC_{direct,\ grey}$, *which makes the uncertainty of the results. The uncertainty of the results cannot be completely eliminated. We could only make better assumptions and simplifications and use more accurate data to make our results more accurate.*