An Integrated GIS and Satellite Image-based Model using a Reduced Simple Ratio Index for Evaluating the Efficacy of the Hammer Marsh Restoration Plan

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Abstract: Iraqi Marshes in Mesopotamia are considered one of the major wetland ecosystems in the world. These marshes were subjected to a deliberate drought several times. This paper aims to conduct a spatiotemporal assessment for the reality and compliance of the land cover in the Western part of the Hammer Marsh versus the inundation processes. The OLI Landsat satellite images and GIS were integrally used to implement a land cover wetness evaluation model using the reduced simple ratio index (RSR). This model was applied to assess the marsh land cover wetness level and to study the impact of inundation processes in the marsh for the period from 2013 to 2020. The results indicated a positive relationship between the RSR index values and inflow discharges, where the RSR index classes (1.5-3), which represent the moderate wetness class, increased to 23.69% and 23.21% of the marsh area in 2019 and 2020 while decreased to 19.13% and 16.23% in 2015 and 2018 in conjunction with the increase and decrease in the inflow discharge. In general, there is no noticeable improvement in the inundation of the study area, except a slight and temporary improvement in 2019 and 2020 based on the increase and continuity of inflow discharges. Fluctuation of the inflow discharges reduces the efficacy of the restoration process. However, to achieve the aim of the restoration plan, a continuous and stable supply of the specified discharges in the restoration plan must be maintained without a considerable fluctuation. The developed RSR model with the aid of integral use of GIS and satellite images can be sufficiently applied to monitor and evaluate the spatiotemporal change of the wetness level of the marsh land cover.

Keywords: RSR, Hammer Marsh, GIS, Satellite-based Model.

1 Introduction

Wetlands are among the most productive ecosystems on Earth [1]. Wetlands play critical roles in providing habitats, improving water quality, reducing erosion, and mitigating flood severity [2]. Even with their significance in preserving biodiversity and providing ecosystem requirements, wetland loss has been widespread worldwide [3]. Salinization, pesticide and heavy metal pollution, loss of fringing vegetation, and altered hydrological regimes caused by urbanization and agricultural practices are all obvious and direct causes of wetland degradation [4]. Drought is regarded as one of the most serious effects of climate change, affecting the worldwide ecosystem, particularly in Africa and Asia. Drought caused deterioration of nature and life, as well as depleted vital water resources. Therefore, protecting ecological systems and confronting threats resulting from drought and desertification has become a very serious and vital issue. The Iraqi marshes have been suffered from intentional drying and drought in several periods. After the year 2003, the Iraqi Ministry of Water Resources (IMoWR) seriously attempted to restore these marshlands. However, these marshes have markedly been affected by Overexploitation of water from upstream countries that caused high shortage in water supply and the extensive intentional drying activities over the 1980s to 1990s. However, the Integrating Remotely Sensed (RS) data with Geographical Information System (GIS) techniques by building a model based on satellite images is a unique opportunity to conduct the spatiotemporal assessment of the wetlands. In monitoring and assessment of the wetlands ecology, the spectral vegetation indices (SVIs) are commonly used efficient tools for evaluating the land cover of these wetlands. In [5], the leaf area index (LAI), the normalized difference vegetation index (NDVI), the simple ratio (SR), and the

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reduced simple ratio (RSR) were computed from Landsat ETM for two sites in Finland. For all the computed SVIs, a fair positive correlation is indicated with LAI. However, a more dynamic response is indicated for the RSR to LAI than these of SR or NDVI. Using the RSR, the maps of computed LAI are highly agreed with these of measured LAI [5]. Results from [6], regarding a study about relationships among LAI, SR, and RSR by relationships between LAI comprising data from the major boreal tree species in Canada, showed that, for both coniferous and deciduous stands, RSR correlated better with LAI compared to SR. This paper aims to detect and assess the response and compliance of the land cover in the Western part of the Hammer Marsh to the inundation plan and applied processes. To this end, the GIS and satellite images were integrally used to implement a satellite image-based model using the RSR.

2 Materials and Methods

The method used to achieve the research objective relied on using a model based on Landsat 8 satellite imagery using the RED and SWIR bands to apply the Low Simple Ratio Index (RSR). After downloading the images that cover the study area and implementing the necessary pre-processing such as radiometric calibration, layer stack, mosaicked, and image subset, the result of RSR was categorized into four categories by the soil moisture level and vegetation cover to describe the soil class and vegetation cover within the marsh. Then, the area of each class is calculated and compared to the inflow discharge of the same period to obtain the required evaluation.

2.1 RSR

The Reduced Simple Ratio Index (RSR) is sensitive to soil and vegetation wetness and can skyrocket immediately after rainfall or irrigation, making it only appropriate for forests in LAI retrieval algorithms. The RSR Index is defined as bellow:

$$RSR = \frac{NIR}{RED}\left[1 - \frac{SWIR - SWIR_{min}}{SWIR_{max} - SWIR_{min}}\right] \quad (1)$$

Where NIR is the near-infrared, RED is the visible wavelength and SWIR is the shortwave-infrared [6]. RSR is more significantly correlated with the Leaf Area Index (LAI) for different jungle lands because it is very sensitive to the variation in LAI. Therefore, RSR is particularly useful for mixed cover types; The middle-infrared (MIR) reflectance is very sensitive to the land cover greenness because of the high absorption of MIR by understorey moss, and grass. Therefore, the impact of the background optical properties is very small on RSR. [5] [6].

2.2 Study Area

Hammer Marsh is the largest water body in the southern part of Iraq. It is located to the right side of the Euphrates River between latitudes ($30^{\circ}\ 33' - 30^{\circ}\ 58'N$) and longitudes ($46^{\circ}\ 24' - 47^{\circ}39'E$). It extends from near Al-Nasiriyah City to the suburbs of Basra City in the east. To the south, it is adjacent to the southern desert and saline lakes. Historically, this marsh has an area of around 2800 km^2, expanding to approximately 4500 km^2 during the flood years. The marsh length and width were approximately 120 km and 25 km, respectively with a maximum water depth of 3 m [7].

Hammer Marsh is separated into two parts by the Hammer dike. The western part of the Hammer Marsh, which is in Thi-Qar province with an area of 1326 km^2 shown in Fig 1, extends from near Al-Nasiriyah to the northwest of Al-Basra Province in southern Iraq and it is fed by many rivers, while the east part within Al-Basra City which is fed by the tidal phenomenon through the Shatt Al-Arab River. Euphrates River and Main Outfall Drain (MOD) are the main water sources of the western part of the Hammer Marsh. The marsh is fed by the AlKurmashia, UmNakhal, and Al-Hamedy rivers. Moreover, the marsh is fed by sub-rivers, which are the BC3, BC3 opining, BC4, BC4 opining, Central opening, which sometimes work as feeders and other times as outlets, conveying the water from Euphrates River to the marsh body and sometimes from the marsh to Euphrates River depending about water levels in the marsh and these rivers. Al-Khamissiya works as a feeder to convey the water from the MOD to the marsh. However, the west part of the marsh is reconnected with the MOD at the southern east by several pipes to be the main outlet, as shown in Fig 1.

2.3 Western Part of the Hammer Marsh Inflow Discharge

The average annual discharges inflow into the Western part of the Hammer Marsh from Euphrates River and Main Outfall Drain (MOD) were as shown in Fig 2. (CRIMW, 2020 unpublished data). These discharges were ranged between 0 to 143 m^3/sec.

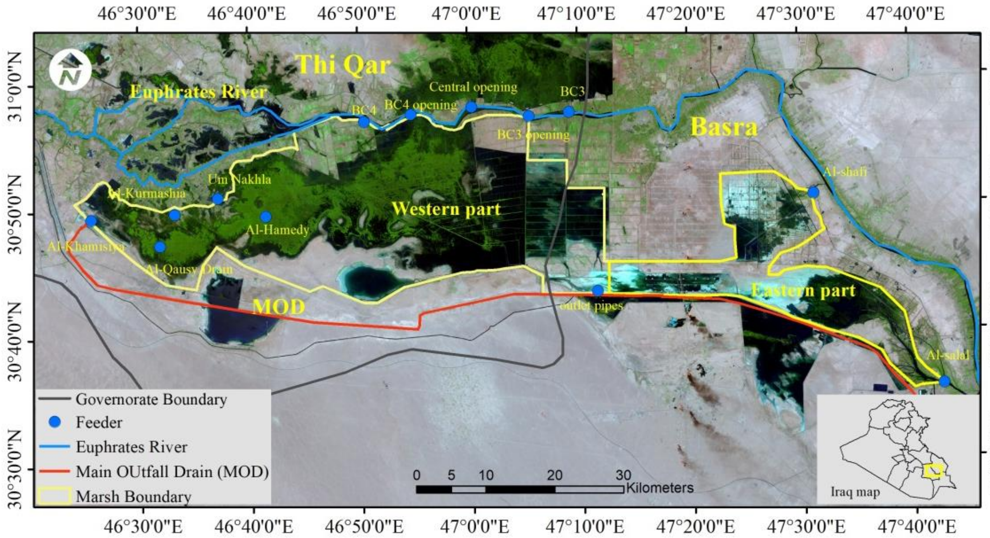

Fig. 1. Location of the study area with feeders and outlets.

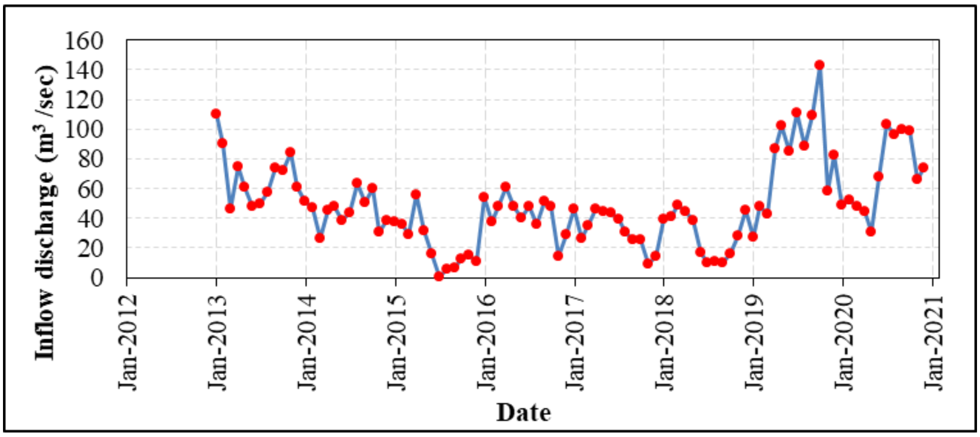

Fig. 2. Monthly inflow discharge into the western part of the Hammer Marsh in m^3 /sec recorded by (Based on CRIMW, 2020 unpublished data).

2.4 Remote Sensing Data

Landsat data are widely used for land cover classifications due to the reliability of their spatial resolution (30 m), revisit period (16 days), and spatial coverage (185×185 km). A series of Landsat 8 satellite images for the summer season was chosen to cover the study area from 2013 to 2020, as listed in Table 1. These images were downloaded from the United States Geological Survey (USGS) with a free cloud cover. During this time of the year, there is no rainfall, and the water sources are completely dependent on the water inflow that is provided to the marshes from the main outlets listed in the study area description.

The Landsat 8 images were successfully mosaicked after converting them to top-of-atmosphere spectral reflectance values to account for the radiometric contrast using ENVI 5.3.

Table 1. The available Landsat data for the Western part of Al-Hammer Marsh.

Satellite	Date of acquisition	Path/Row	Date of acquisition	Path/Row
Landsat 8	12/07/2013	166/39	03/07/2013	167/39
	15/07/2014	166/39	06/07/2014	167/39
	18/07/2015	166/39	09/07/2015	167/39
	05/08/2016	166/39	27/07/2016	167/39
	23/07/2017	166/39	30/07/2017	167/39
	27/08/2018	166/39	17/07/2018	167/39
	27/06/2019	166/39	04/07/2019	167/39
	29/06/2020	166/39	06/07/2020	167/39

3 Results

3.1 RSR Computation Model

The GIS model builder was used to implement a satellite based RSR index computation model by adopting Eq. (1), where the spectral bands 4, 5, and 6 of the Landsat 8 represent RED, NIR, and SWIR, respectively. The max is the maximum reflectance of SWIR and, the min is the minimum reflectance of SWIR in Landsat 8. The developed model is shown in Figs 3 and 4.

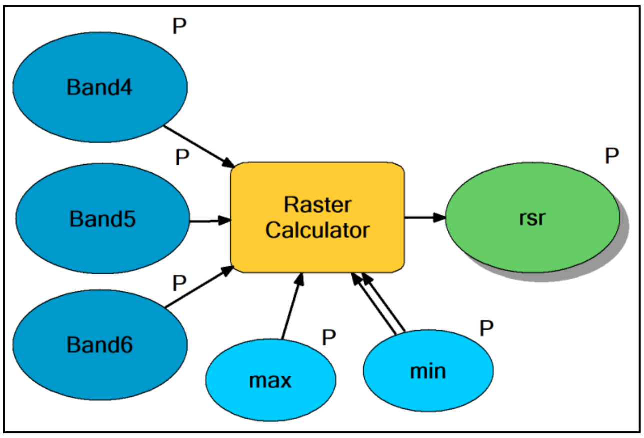

Fig. 3. Prepared RSR model in the environment of Arc GIS model builder.

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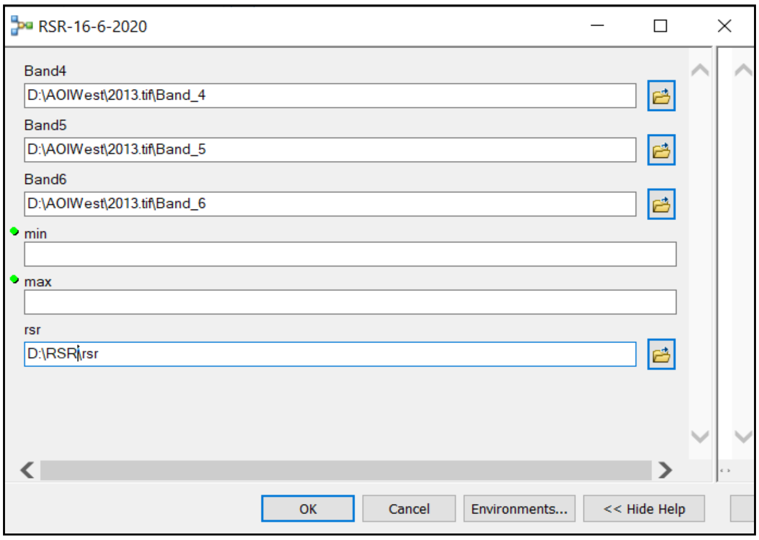

Fig. 4. Input and output menu for the RSR model.

3.2 Spatiotemporal Distribution of the RSR Index

The spatial distribution of the RSR index is shown in Fig 5. The values of the RSR index were classified into four classes according to the wetness level of the soil and vegetation. The (0.0-1.5), (1.5-3.0), (3.0-4.5), and (4.5-6.0) classes of RSR index represent the Low, Moderate, High, and Very high wetness levels, respectively of the soil and vegetation cover within the marsh.

The considerable moderate to high values of the RSR index is concentrated in the middle zone of the marsh and near the main feeders, where it represented the wetting area and vegetation cover. While the low values of the RSR index, which represented the dry areas, were distributed within the near-border areas of the marshes. These results are consistent with the topography of the region, where the near-border areas have high levels, while the levels are low in the middle, and the distribution of inundation areas and the vegetation cover are mainly distributed within these low-level zones and along with the marsh's feeders and outlets.

As shown in Fig 6, the low wetness class of the RSR (0.0-1.5) was the dominant class within the marsh with 71% and 73 % from the total marsh area in 2013 and 2014, respectively, then it increased in 2015 and 2018 to be 81% and 83%, respectively. While it decreased in 2016 and 2017 to 70% and 66%, respectively. Then, it decreased in 2019 and 2020 to 72% and 66%, respectively. It clearly shows an increase in the percentage of low-wetness lands during the considered period, especially in the years 2015 and 2018, which was accompanied by severe outflow decreases.

However, the moderate wetness class, RSR (1.5-3.0), was 29% and 27% in 2013 and 2014, respectively. Then, it decreased to 19% in 2015. While it increased in 2016 and 2017 to 27% and 34%, respectively. In 2018, it decreased to 16% and increased again to 24% and 23% in 2019 and 2020, respectively. This indicates an increase in the moderate wetness class with the increase in inflow discharges in 2017, 2019, and 2020.

The high wetness class of RSR (3.0-4.5) was the lowest and the less apparent class during the studied period with 3%, 4%, and 0.1% in 2016, 2019, and 2020, respectively, while it was closer to zero percent in the remaining study periods. Moreover, the very high wetness class of RSR index (4.5-6.0) rarely appears during the study period with a very small area, and it only appeared within a very small area (around zero percent) in 2019 and 2020 while it did not exist in other years.

In general, the relationship is positive between the results of the RSR index and the inflow discharge, where the RSR value increased in conjunction with an increase in the inflow discharge. The fluctuation in the quantities and times of water releases makes the inundation process useful and there is no noticeable improvement in the inundated areas, as the results showed fluctuation in the areas of inundation between an increase and decrease in conjunction with inflow discharges.

4 Conclusions

Implementation of plans to restore the Iraqi marshes after subjecting these marshes to deliberate drought several times in conjunction with the shortage in water sources necessitates the development of methods and techniques for monitoring the spatiotemporal change of the land cover response and assessing the restoration plans. The integration between remote sensing techniques and GIS is an efficient tool in monitoring the enhancement and/or deterioration of marsh's land cover, which gives more effective results, continuous, spatiotemporal, and low-cost monitoring of the large wetland area, especially when using a time series of appropriate periods that allows continuous monitoring of the changes that occur in the study area. It also assists in studying the changes, which gives clear results about the reality of the marsh and the response to the implemented inundation plans. From the results of the RSR index, there is no noticeable improvement in the inundation areas, as the results showed fluctuation in the inundation areas between an increase and decrease in a way that coincides with the increase and decrease of inflow discharge, as the areas of dry land increased in the category (0-1.5) of the RSR index for the years 2015 and 2018 with a severe decrease in the amount of water entering the marsh. The fluctuation in the inundation areas in conjunction with the fluctuation with the inflow discharge between an increase and a decrease shows that the conducted inundation does not serve the restoration plants in the region, as the inundation areas recede due to the lack of water releases and the water does not remain for a period to restore life to the plants. The relationship is positive between the inflow discharge and the improvement of the vegetation cover, but the improvement in a temporary manner depends on the increase and continuity of inflow discharge, and since the inflow discharges are irregular and there is considerable fluctuation in the quantities and timings of inflow discharge, the restoration process became insufficient and useless.

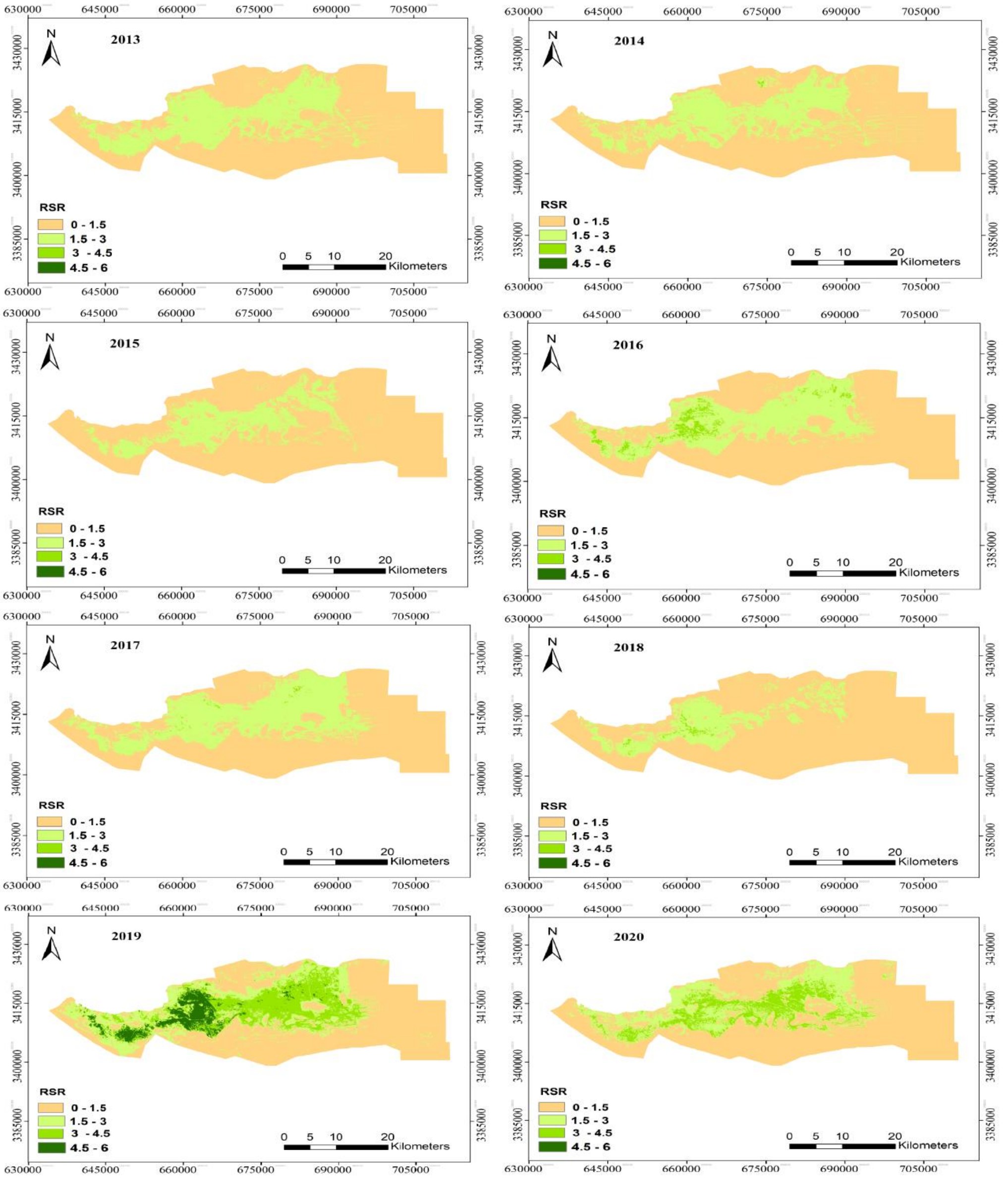

Fig. 5. Spatial distribution of RSR index.

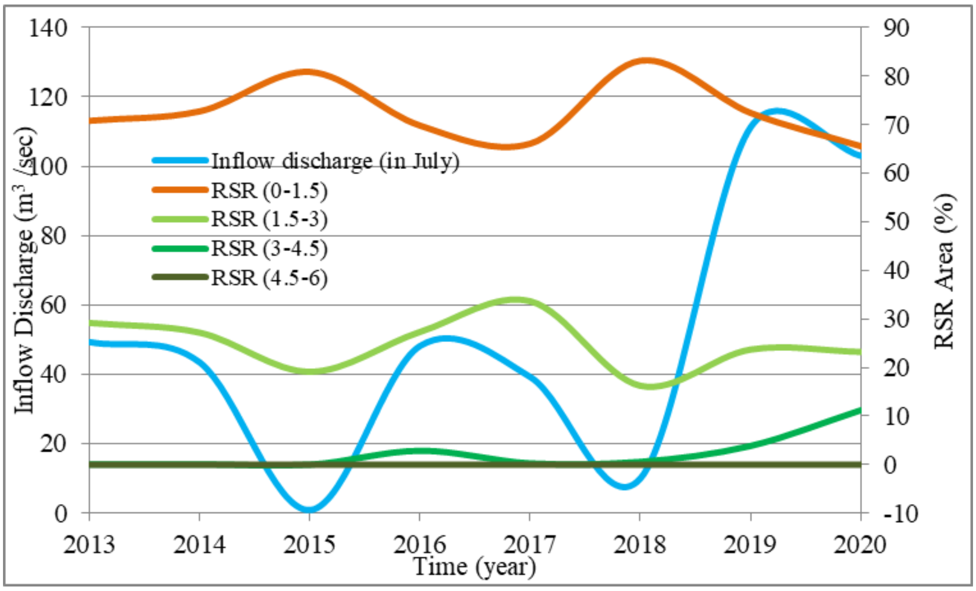

Fig. 6. Variation of RSR class area.

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